C64DX SYSTEM SPECIFICATION

- ☐ **Design Concepts**
- ☐ **Hardware Specifications**
- ☐ **Software Specifications**

Requires ROM Version 0.9A.910228 or later.

PRELIMINARY

March, 1991

Commodore®

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APPLICATION		REVISIONS			
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C64DX SYSTEM SPECIFICATION

A.K.A. C65

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COMMODORE PART	STATUS				
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SIGN-OFF		DATE	TITLE
DRWN	FRED BOWEN	06/13/89	C64DX SYSTEM SPECIFICATION REVISION A (PILOT PRODUCTION)
SYS	FRED BOWEN	06/13/89	
TEST			
COMP			SIZE A

SHEET 1 OF MANY

```
 CCCC       666     555555
C    C     6        5
C         6         5
C         6         55555
C         66666     5    5
C         6    6         5
C         6    6         5
C    C    6    6    5    5
 CCCC      6666      5555
```

This system specification reflects the latest information available at this time. Updates will occur as the system evolves. Commodore Business Machines, Inc. makes no warranties, expressed or implied, with regard to the information contained herein including the quality, performance, merchantability, or fitness of this information or the system as described.

This system specification contains the contributions of several people including: Fred Bowen, Paul Lassa, Bill Gardei, and Victor Andrade.

```
PPPPP   RRRRR   EEEEE  L      III  M     M  III  N    N   AAAA   RRRRR   Y     Y
P    P  R    R  E      L       I   MM   MM   I   NN   N  A    A  R    R   Y   Y
P    P  R    R  E      L       I   M M M M   I   N N  N  A    A  R    R    Y Y
P    P  R    R  E      L       I   M  M  M   I   N  N N  A    A  R    R     Y
PPPPP   RRRRR   EEEE   L       I   M     M   I   N   NN  AAAAAA  RRRRR      Y
P       R R     E      L       I   M     M   I   N    N  A    A  R R        Y
P       R  R    E      L       I   M     M   I   N    N  A    A  R  R       Y
P       R   R   E      L       I   M     M   I   N    N  A    A  R   R      Y
P       R    R  EEEEE  LLLLLL III  M     M  III  N    N  A    A  R    R     Y
```

Revision 0.2 (pilot release) January 31, 1991

At this time, Pilot Production, the C65 system consists of either revision 2A or 2B PCB, 4510R3, 4567R5 (PAL only), F011B/C FDC, and 018 DMAgic chips. There will be changes to all these chips before Production Release.

This work is by:

Fred Bowen	System Software-	C65
Paul Lassa	Hardware engineer-	C65, DMAgic
Bill Gardei	LSI engineer-	4567, FDC
Victor Andrade	LSI engineer-	4510

Included are contributions by contractors hired by Commodore for the C65 project. These contributions include the DOS, Graphics, Audio, and Memory management areas.

Several 4502 assembler systems are available:

VAX, Amiga, and PC based BSO-compatible cross assemblers.

PC based custom cross assembler by Memocom, compatible with Memocom 4502 emulator and Mem-ulator systems.

C128-based BSO compatible cross assembler by Commodore.

Custom software support is available for the following logic analyzers:

Hewlett Packard HP655x A and B logic analyzers.

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1.0 Introduction

This specification describes the requirements for a low-cost 8-bit microcomputer system with excellent graphic capabilities.

1.1 System Concept

The C65 microcomputer is a low-cost, versatile, competitive product designed for the international home computer and game market.

The C65 is well suited for first time computer buyers, and provides an excellent upgrade path for owners of the commercially successful C64. The C65 is composed of concepts inherent in the C64 and C128.

The purpose of the C65 is to modernize and revitalize the 10 year old C64 market while still taking advantage of the developed base of C64 software. To accomplish this, the C65 will provide a C64 mode of operation, offering a reasonable degree of C64 software compatibility and a moderate degree of add-on hardware and peripheral compatibility. Compatibility can be sacrificed when it impedes enhanced functionality and expandability, much as the C64 sacrificed VIC-20 compatibility.

It is anticipated that the many features and capabilities of the new C65 mode will quickly attract the attention of developers and consumers alike, thereby revitalizing the low-end home computer market. The C65 incorporates features that are normally found on today's more expensive machines, continuing the Commodore tradition of maximizing performance for the price. The C65 will provide many new opportunities for third party software and hardware developers, including telecommunications, video, instrument control (including MIDI), and productivity as well as entertainment software.

1.2 System Overview

- **CPU** -- Commodore CSG4510 running at 1.02 or 3.5 Mhz
  - New instructions, including Rockwell and GTE extensions
  - Memory Mapper supporting up to 1 Megabyte address space
  - R6511-type UART (3-wire RS-232) device, programmable baud rate (50-56K baud, MIDI-capable), parity, word size, sync and async. modes. XD/RD wire ORed/ANDed with user port.
  - Two CSG6526-type CIA devices, each with 2 I/O ports, programmable TOD clocks, interval timers, interrupt contro

- **Memory**
  - RAM-- 128K bytes (DRAM)
    Externally expandable from additional 512K bytes to 4MB using dedicated RAM expansion port.
  - ROM -- 128K bytes
    C64 Kernel and BASIC 2.2
    C65 Kernel, Editor, BASIC 10.0, ML Monitor (like C128)
    DOS v10- (1581 subset)
    Multiple character sets: 40 and 80 column versions
    National keyboards/charsets for foreign language systems
    Externally expandable by conventional C64 ROM cartridges via cartridge/expansion port using C64 decodes.
    Externally expandable by additional 128K bytes or more via cartridge/expansion port using new system decodes.
  - DMA -- Custom DMAgic controller chip built-in
    Absolute address access to entire 8MB system map, including I/O devices, both ROM & RAM expansion ports.
    List-based DMA structures, can be chained together
    Copy (up,down,invert), Fill, Swap, Mix(boolean Minterms)
    Hold, Modulus (window), Interrupt, and Resume modes
    Block operations from 1 byte to 64K bytes
    DRQ handshaking for I/O devices
    Built-in support for (optional) expansion RAM controller

1.2 System Overview (continued)

- **Video** -- Commodore CSG 4567 enhanced VIC chip
  - RGBA with sync on all colors or digital sync
  - Composite NTSC or PAL video, separate chroma/luma
  - Composite NTSC or PAL digital monochrome
  - RF TV output via NTSC or PAL modulator
  - Digital foreground/background control (genlock)
  - All original C64 video modes:
    - 40x25 standard character mode
    - Extended background color mode
    - 320x200 bitmap mode
    - Multi-color mode
    - 16 colors
    - 8 sprites, 24x21
  - 40 and 80 character columns by 25 rows:
    - Color, blink, bold, inverse video, underline attributes
  - True bitplane graphics:

320 x 200 x 256	(8-bitplane)	non-interlaced
640 x 200 x 16*	(4-bitplane)	non-interlaced
1280 x 200 x 4*	(2-bitplane)	non-interlaced
320 x 400 x 256	(8-bitplane)	interlaced
640 x 400 x 16*	(4-bitplane)	interlaced
1280 x 400 x 4*	(2-bitplane)	interlaced

*plus sprite and border colors

-
  - Color palettes:
    - Standard 16-color C64 ROM palette
    - Programmable 256-color RAM palette, with 16 intensity levels per primary color (yeilding 4096 colors)
  - Horizontal and vertical screen positioning verniers
  - Display Address Translator (DAT) allows programmer to access bitplanes easily and directly.
  - Access to optional expansion RAM
  - Operates at either clock speed without blanking

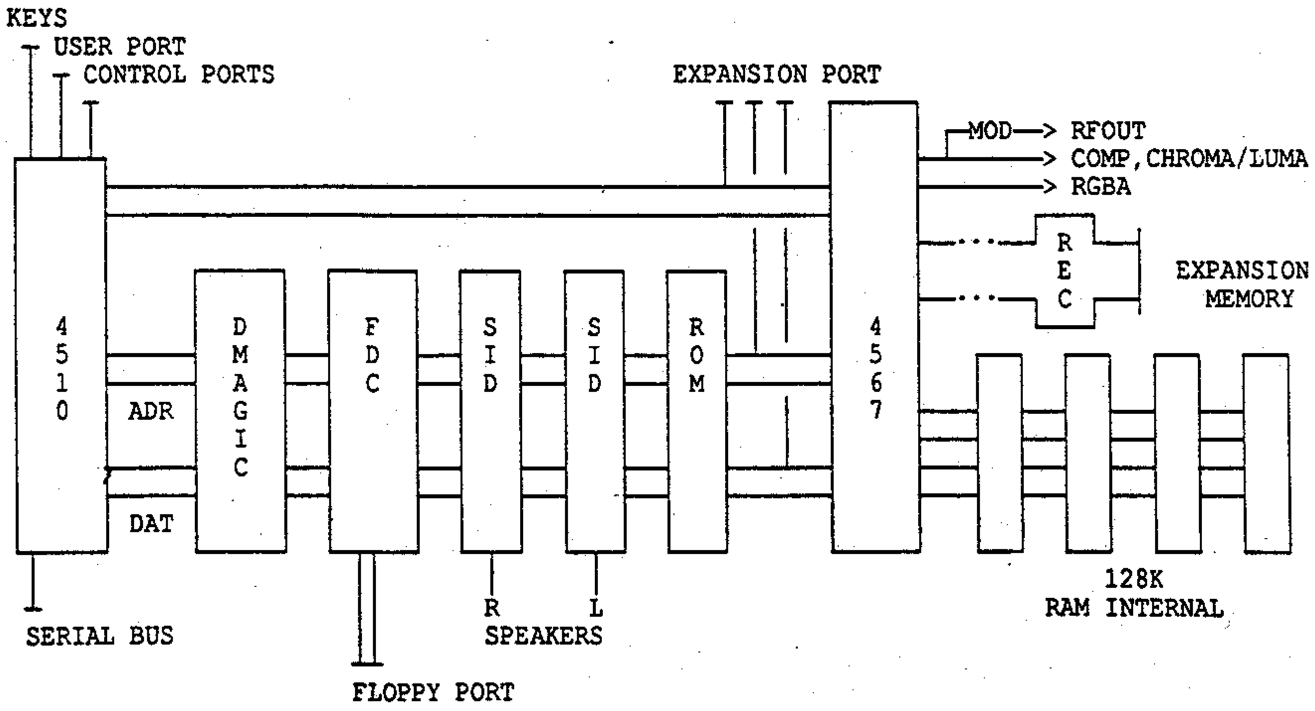
- **Audio** -- Commodore CSG8580 SID chips
  - Stereo SID chips:
    - Total of 6 voices, 3 per channel
    - Programmable ADSR envelope for each voice
    - Filter, modulation, audio inputs, potentiometer
    - Separate left/right volume, filter, modulation control

1.2 System Overview (continued)

- **Disk, Printer support --**
  - FDC custom MFM controller chip built in, with 512-byte buffer, sector or full track read/write/format, LED and motor control, copy protection.
  - Built-in 3.5" double sided, 1MB MFM capacity drive
  - Media & file system compatible with 1581 disk drive
  - Supports one additional "dumb" drive externally.
  - Standard CBM bus serial (all modes, about 4800 baud)
  - Fast serial bus (C65 mode only, about 20K baud)
  - Burst serial (C65 mode only, about 50K baud)
- **External ports --**
  - 50-pin Cartridge/expansion port (ROM cartridges, etc.)
  - 24-pin User/parallel port (modem (1670), RS-232 serial)
  - Composite video/audio port (8-pin DIN)
  - Analog RGB video port (DB-9)
  - RF video output jack
  - Serial bus port (disks (1541/1571/1581), printers, etc.)
  - External floppy drive port (mini DIN8)
  - 2 DB9 control ports (joystick, mouse, tablets, lightpen)
  - Left and right stereo audio output jacks
  - RAM expansion port, built-in support for RAM controller
- **Keyboard --** 77 keys, including standard C64 keyboard plus:
  - Total of 8 function keys, F1-F16, shifted and nonshifted
  - TAB, escape, ALT, CAPS lock, no scroll, help (F15/16)
  - Power, disk activity LEDs
  - Reset button
- **Power supply --** external, brick type
  - +5VDC at 2.2A and +12VDC at .85A

1.3 System Components

Microcontroller:	4510	(65CE02, 2x6526, 6511 UART, Mapper, Fast serial)
Memory:	4464 271001	DRAM (128K bytes) ROM (128K bytes)
Video controller:	4567	(extended VIC, DAT, PLA)
Audio controllers:	6581	(SID)
Memory control:	41xx-F018	(DMA)
Disk controller:	41xx-F011	(FDC, supports 2 DSDD drives, MFM, RAM buffer)



1.4 System Concerns

1.4.1 C64 Compatibility Issues

1.4.1.1 Software

C64 software compatibility is an important goal. To this end, when the system is in "C64 mode" the processor will operate at average 1.02MHz speed and dummy "dead" cycles are emulated by the processor. The C64 ROM is the same except for patches to serial bus routines in the kernel (to interface built-in drive), the removal of cassette code (there is no cassette port), and patches to the C64 initialization routines to boot C65 mode if there is no reason (eg., cartridges) to stay in C64 mode.

Compatibility with C64 software that uses previously unimplemented 6502 opcodes (often associated with many copy-protection schemes) or that implements extremely timing dependent "fast loaders" is iherently impossible. Because the VIC-III timing is slightly different, programs that are extremely timing dependant may not work properly. Also, because the VIC-III does not change display modes until the end of a character line, programs that change displays based strictly upon the raster position may not display things properly. The aspect ratio of the VIC-III display is slightly different than the VIC-II. The use of a 1541-II disk drive (optional) will improve compatibility. C64 BASIC 2.2 compatibility will be 100% (within hardware constraints). C128 BASIC 10 compatibility will be moderate (graphic commands are different, some command parameters different, and there are many new commands).

1.4.1.2 Hardware

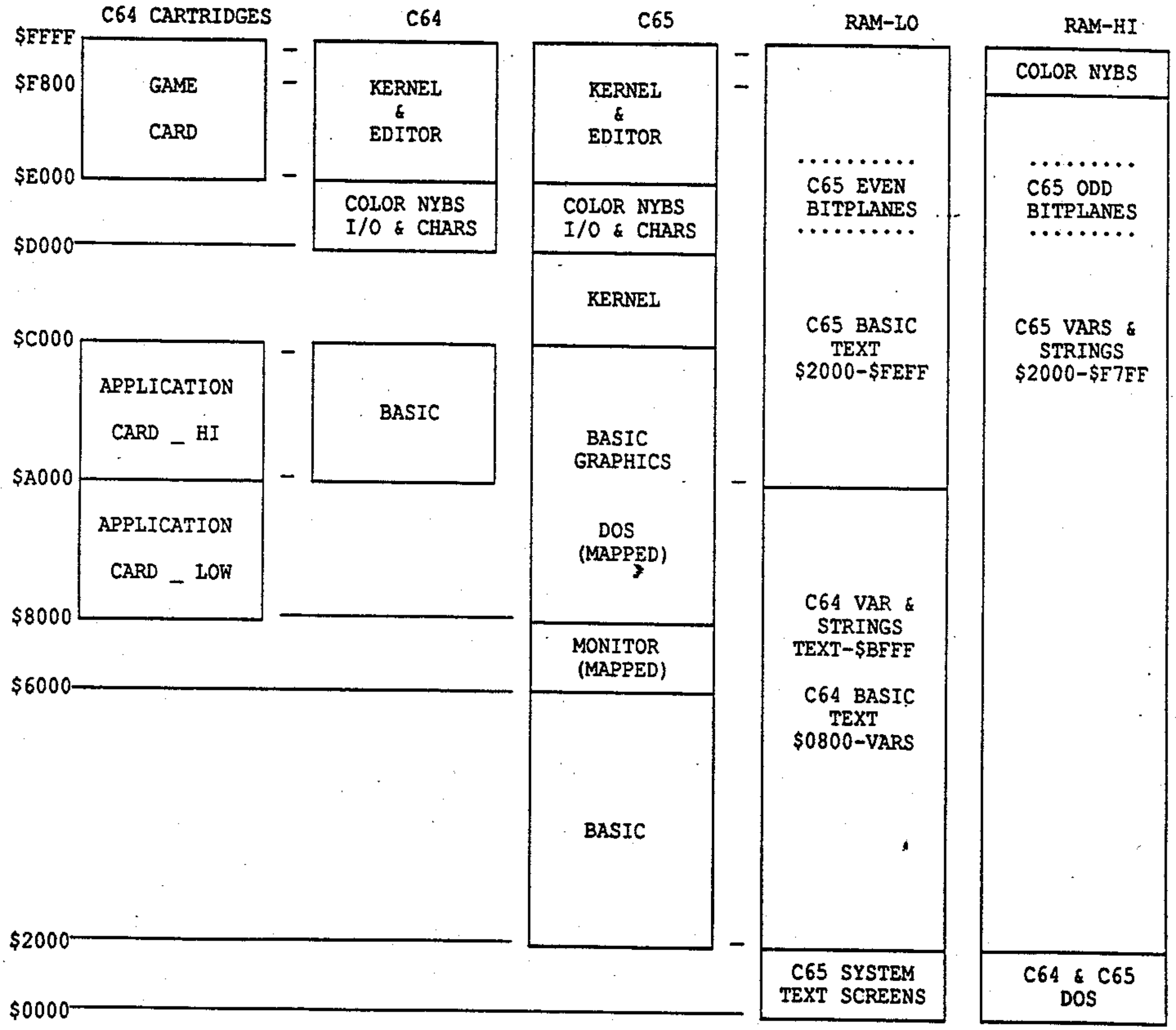
C64 hardware compatibility is limited. Serial bus and control port devices (mouse, joysticks, etc.) are fully supported. Some user port devices are supported such as the newer (4-DIP switch) 1670 modems, but there's no 9VAC so devices which require 9VAC won't function correctly. The expansion port has additional pins (50 total), and the pin spacing is closer than the C64 (it's like the PLUS/4). An adaptor ("WIDGET") will be necessary to utilize C64 cartridges and expansion port devices. Furthermore, timing differences between some C64 and C65 expansion port signals will affect many C64 expansion devices (such as the 1764).

1.4.2 DOS Compatibility

The built-in C65 DOS is a subset of Commodore 1581 DOS. There is no track cache, index sensor, etc. To load and run existing 1541-based applications, the consumer must add a 1541 drive to the system. Many commercial applications cannot be easily ported from 1541/5.25" media to 1581/3.5" media, due to copy protection or "fast loaders". Most C64 applications that directly address DOS memory, specific disk tracks or sectors, or rely on DOS job queues and timing characteristics will not work with the built-in drive and new DOS.

1.5 System Maps

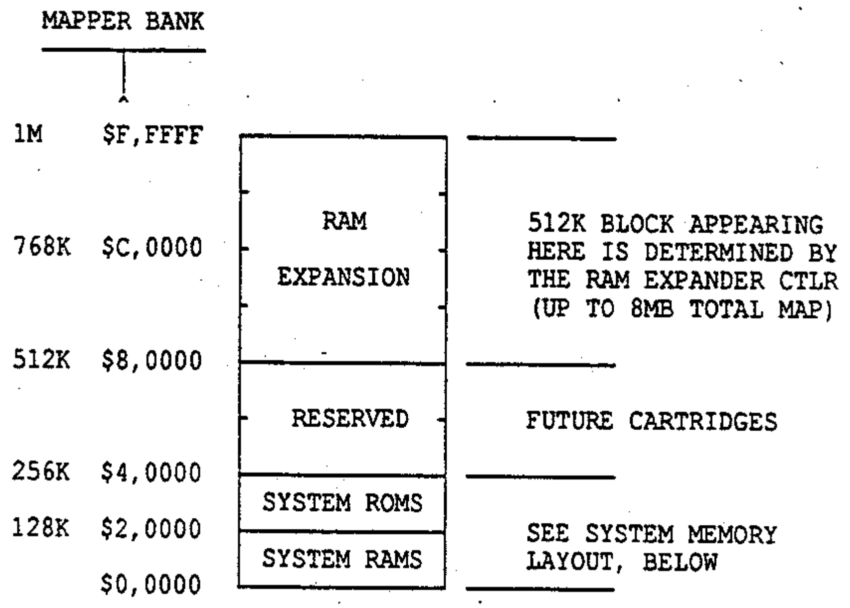
1.5.1 Composite System Memory Map



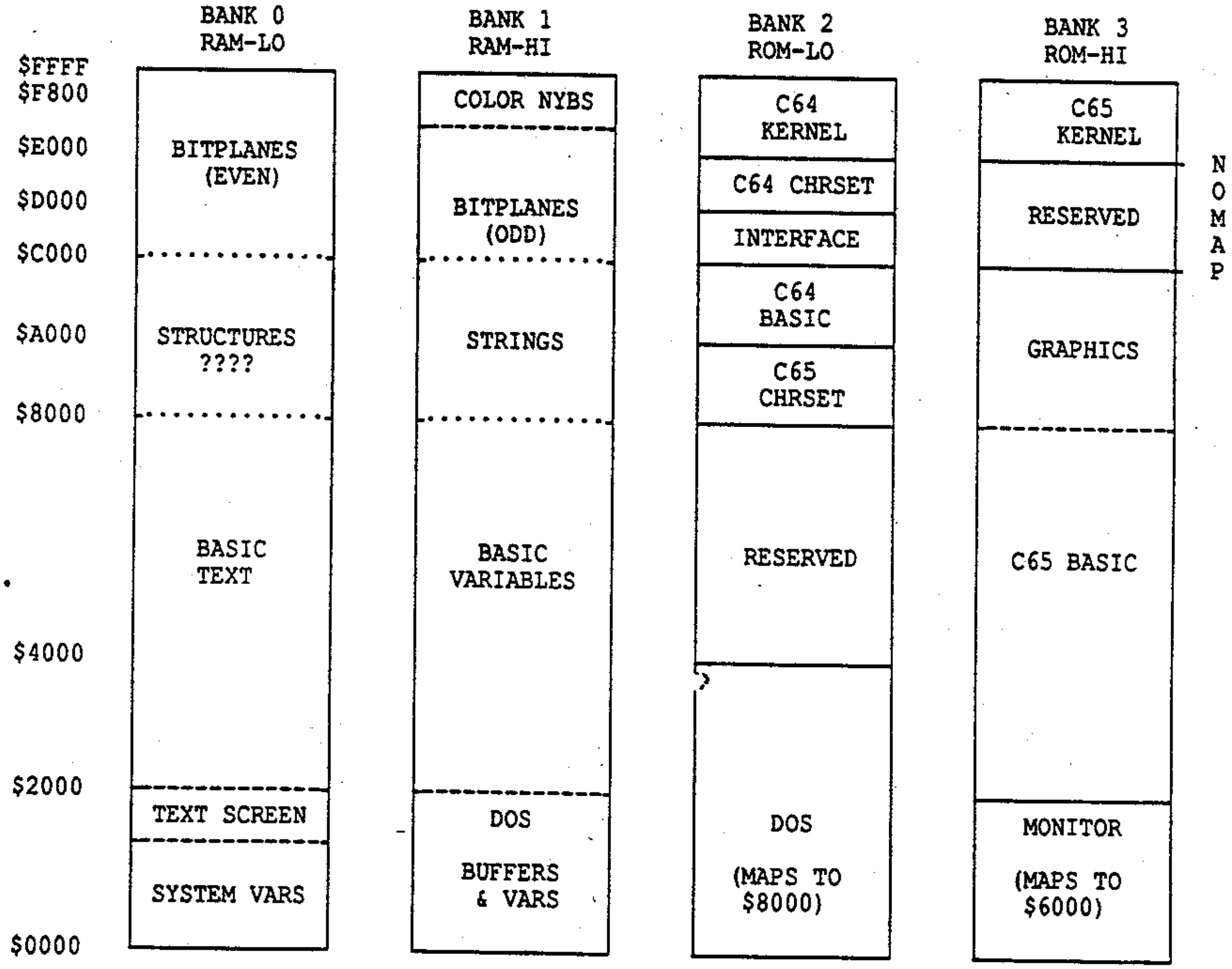
1.4.3 Operating Modes

The C65 powers up in the C64 mode. If there are no conditions present which indicate that C64 mode is desired, such as the C= key depressed or a C64 cartridge signature found, then C65 mode will be automatically brought into context. Unlike the C128, "C64 mode" is escapable. Like the C128, all of the extended features of the C65 system are accessible from "C64 mode" via custom software. Whenever the system initiates C64 mode, new VIC mode is always disabled except when the DOS is required.

1.5.2 C65 System Memory Map



1.5.3 C65 System Memory Layout



What does this Mean? Here is what the 64K memory map looks like in various configurations (i.e., as seen by the processor):

C64 mode:

$E000-$FFFF	Kernel, Editor, BASIC overflow area
$D000-$DFFF	I/O and Color Nybbles, Character ROM
$C000-$CFFF	Application RAM
$A000-$BFFF	BASIC 2.2
$0002-$9FFF	RAMLO. VIC screen at $0400-$7FF. BASIC program & vars from $0800-$9FFF

C65 mode:

$E000-$FFFF	Kernel, Editor ROM code
$D000-$DFFF	I/O and Color Bytes (CHRROM at $29000)
$C000-$CFFF	Kernel Interface, DOS ROM overflow area
$8000-$BFFF	BASIC 10.0 Graphics & Sprite ROM code
$2000-$7FFF	BASIC 10.0 ROM code
$0002-$1FFF	RAMLO. Vic screen at $0800-$0FFF BASIC prgs mapped from $02000-$0FF00 BASIC vars mapped from $12000-$1F7FF

C65 DOS mode:

$E000-$FFFF	Kernel, Editor ROM code
$D000-$DFFF	I/O (CIA's mapped out), Color Bytes
$C800-$CFFF	Kernel Interface
$8000-$C3FF	DOS ROM code
$2000-$7FFF	[don't care]
$0000-$1FFF	DOS RAMHI

C65 Monitor:

$E000-$FFFF	Kernel, Editor ROM code
$D000-$DFFF	I/O and Color Bytes
$C000-$CFFF	Kernel Interface
$8000-$BFFF	[don't care]
$6000-$7FFF	Monitor ROM code
$0002-$5FFF	RAMLO.

It's done this way for a reason. The CPU MAPPER restricts the programmer to one offset for each 32K-byte half of a 64K-byte segment. For one chuck of ROM to MAP in another chuck with a different offset, it must do so into the other half of memory from which it is executing. The OS does this by never mapping the chunk of ROM at $C000-$DFFF, which allows this chunk to contain the Interface/MAP code and I/O (having I/O in context is usually desireable, and you can't map I/O anyhow). The Interface/MAP ROM can be turned on and off via VIC register $30, bit 5 (ROM@$C000), and therefore does not need to be mapped itself. Generally, OS functions (such as the Kernel, Editor, and DOS) live in the upper 32K half of memory, and applications (such as BASIC or the Monitor) live in the lower 32K half. For example, when Monitor mode is entered, the OS maps out BASIC and maps in the Monitor. Each has ready access to the OS, but no built-in access to each other. When a DOS call is made, the OS overlays itself with the DOS (except for the magical $C000 code) in the upper 32K half of memory, and overlays the application area with DOS RAM in the lower 32K half of memory.

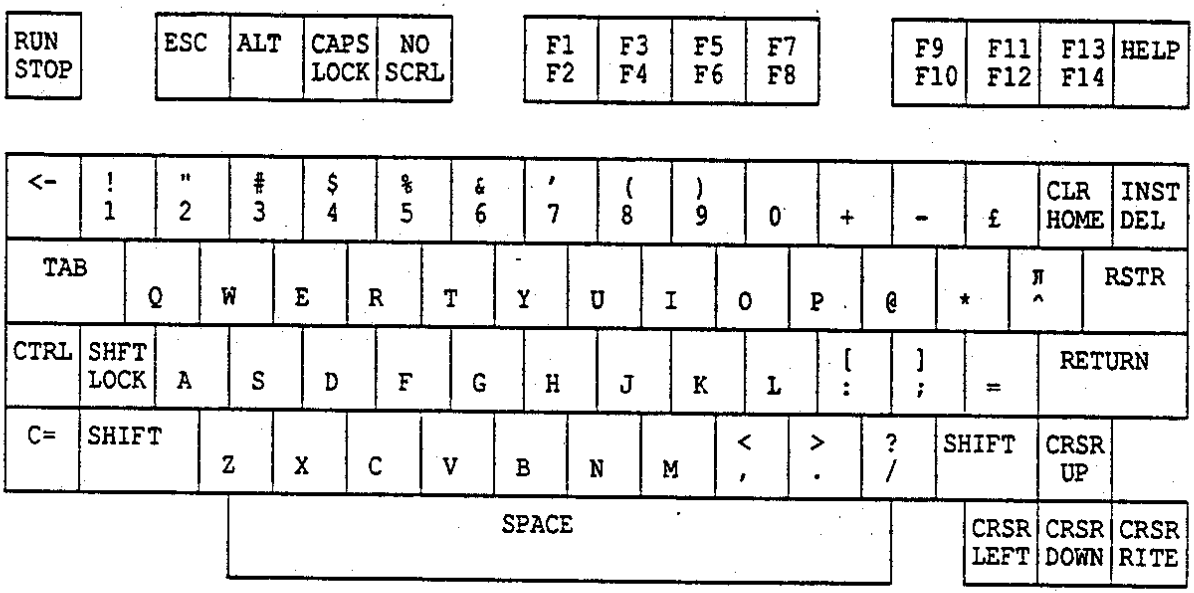
1.5.4 C65 System I/O Memory Map

$DF00	IO-2	EXTERNAL I/O SELECT
$DE00	IO-1	EXTERNAL I/O SELECT
$DD00	CIA-2	SERIAL, USER PORT
$DC00	CIA-1	KEYBOARD, JOYSTICK, MOUSE CONTROL
$D800	COLOR NYB	COLOR MATRIX (*FROM $1F800-1FFFF)
$D700	DMA	*DMA CONTROLLER
$D600	UART	*RS-232, FAST SERIAL, NEW KEY LINES
$D440	SID (L)	AUDIO CONTROLLER (LEFT)
$D400	SID (R)	AUDIO CONTROLLER (RIGHT)
$D300	BLU PALETTE	
$D200	GRN PALETTE	*COLOR PALETTES (NYBBLES)
$D100	RED PALETTE	
$D0A0	REC	*RAM EXPANSION CTRL (OPTIONAL)
$D080	FDC	*DISK CONTROLLER
$D000	VIC-4567	VIDEO CONTROLLER
	⋮	
$0000	4510	MEMORY CONTROL FOR C64 MODE (this register is actually in the VIC-4567 in the C65)

*NOTE: VIC must be in "new" mode to address these devices

2.0 C65 System Hardware

2.1.1 Keyboard Layout



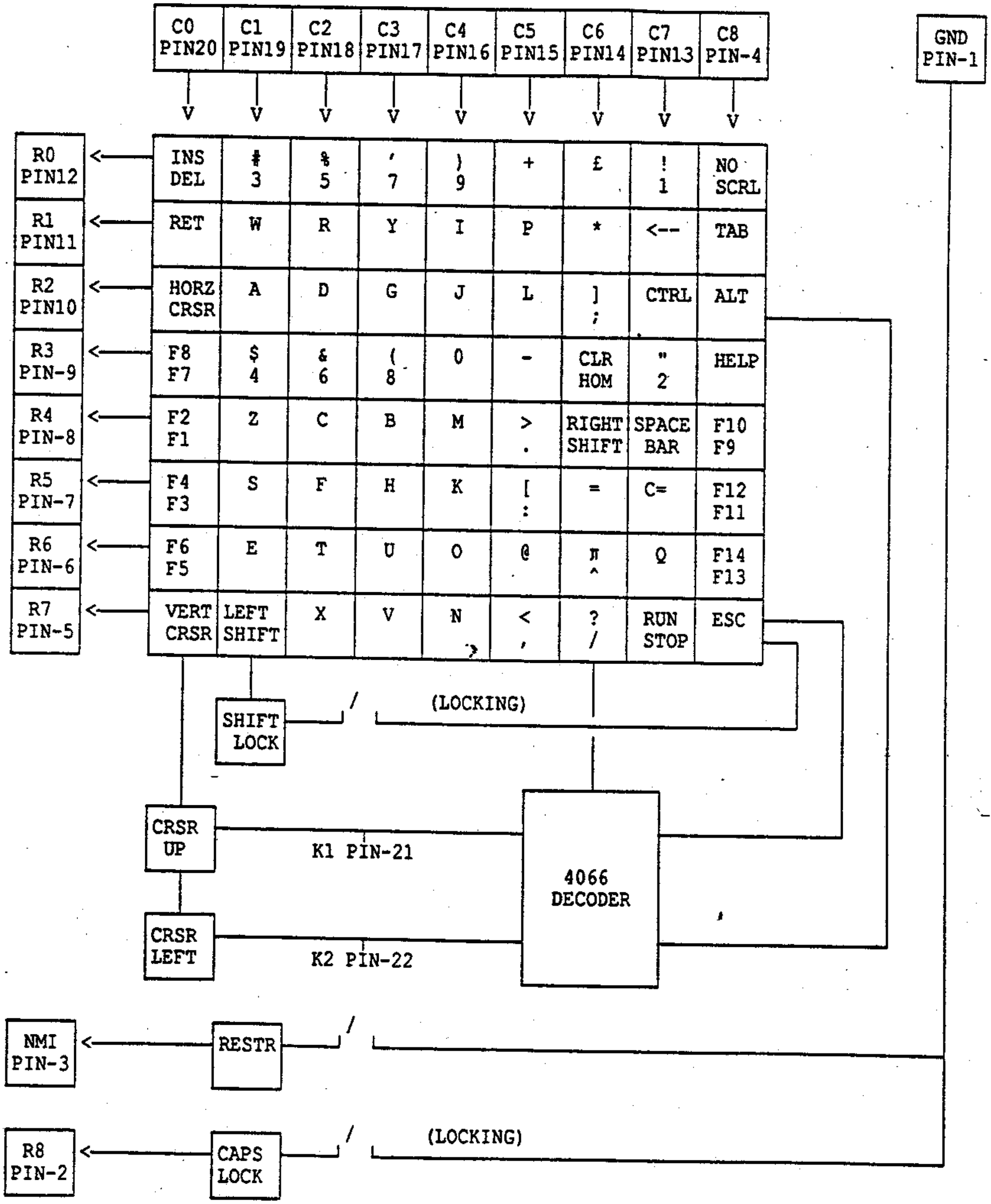
Notes:

1/ The cursor keys are special- the shifted cursor keys appear as separate keys, but in actuality pressing them generates a SHIFT plus the normal cursor code, making them totally compatable with, and therefore functional in, C64 mode.

2/ There are a total of 77 keys, two of which are locking keys.

3/ The NATIONAL keyboards are similar, and their layout and operation is identical to their C128 implementation.

2.1.2 Keyboard Matrix



	C0 PIN20	C1 PIN19	C2 PIN18	C3 PIN17	C4 PIN16	C5 PIN15	C6 PIN14	C7 PIN13	C8 PIN-4
R0 PIN12	INS DEL	# 3	% 5	' 7	) 9	+	£	! 1	NO SCRL
R1 PIN11	RET	W	R	Y	I	P	*	<--	TAB
R2 PIN10	HORZ CRSR	A	D	G	J	L	] ;	CTRL	ALT
R3 PIN-9	F8 F7	$ 4	& 6	(8	0	-	CLR HOM	" 2	HELP
R4 PIN-8	F2 F1	Z	C	B	M	> .	RIGHT SHIFT	SPACE BAR	F10 F9
R5 PIN-7	F4 F3	S	F	H	K	[:	=	C=	F12 F11
R6 PIN-6	F6 F5	E	T	U	O	@	π ^	Q	F14 F13
R7 PIN-5	VERT CRSR	LEFT SHIFT	X	V	N	< ,	? /	RUN STOP	ESC

Keyboard Notes:

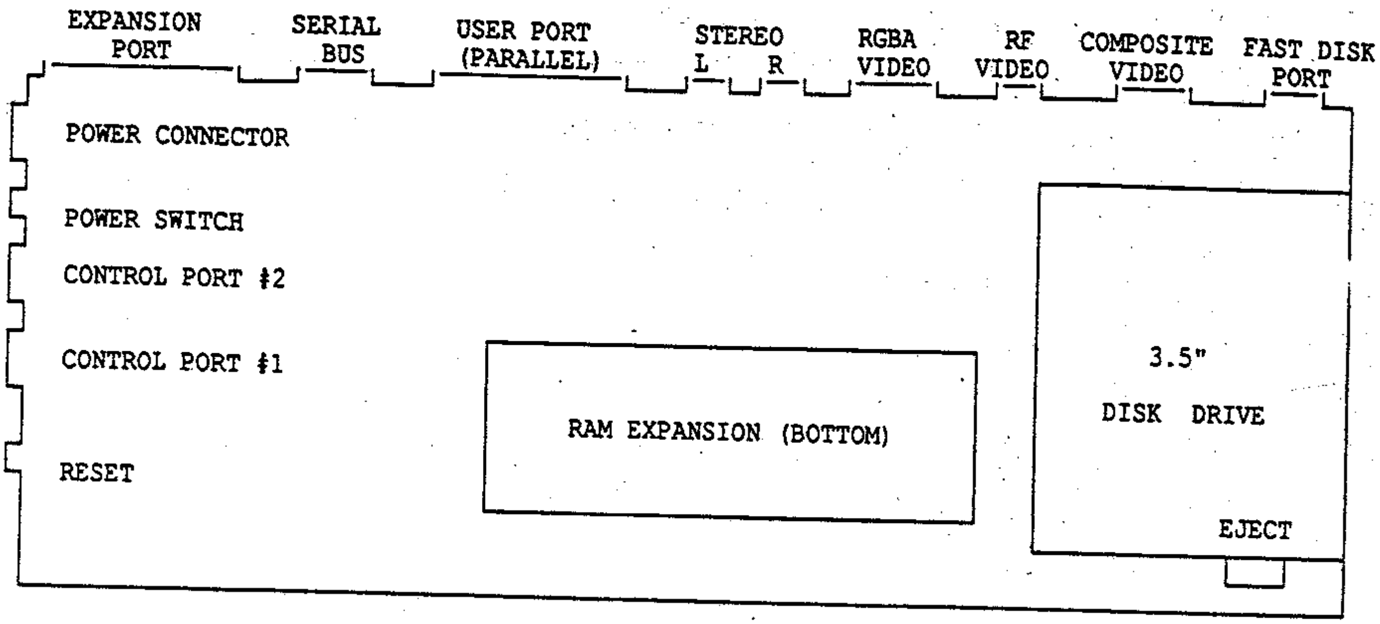
1/ The 64 keys under C0 through C7 occupy the same matrix position as in the C/64, as does the RESTORE key. Including SHIFT-LOCK, there are 66 such keys.

2/ The extended keyboard consists of the 8 keys under the C8 output. Counting the CAPS-LOCK key, there are 9 new keys. The C/64 does not scan these keys.

3/ The new CURSOR LEFT and CURSOR UP keys simulate a CURSOR plus RIGHT SHIFT key combination.

4/ The keyboard mechanism will be mechanically similar to that of the C128.

2.2 Form Factor



Notes:

1. Dimensions: about 18" wide, 8" deep, 2" high
2. Disk unit faces forward.

2.3 The CSG 4510 Microcontroller Chip

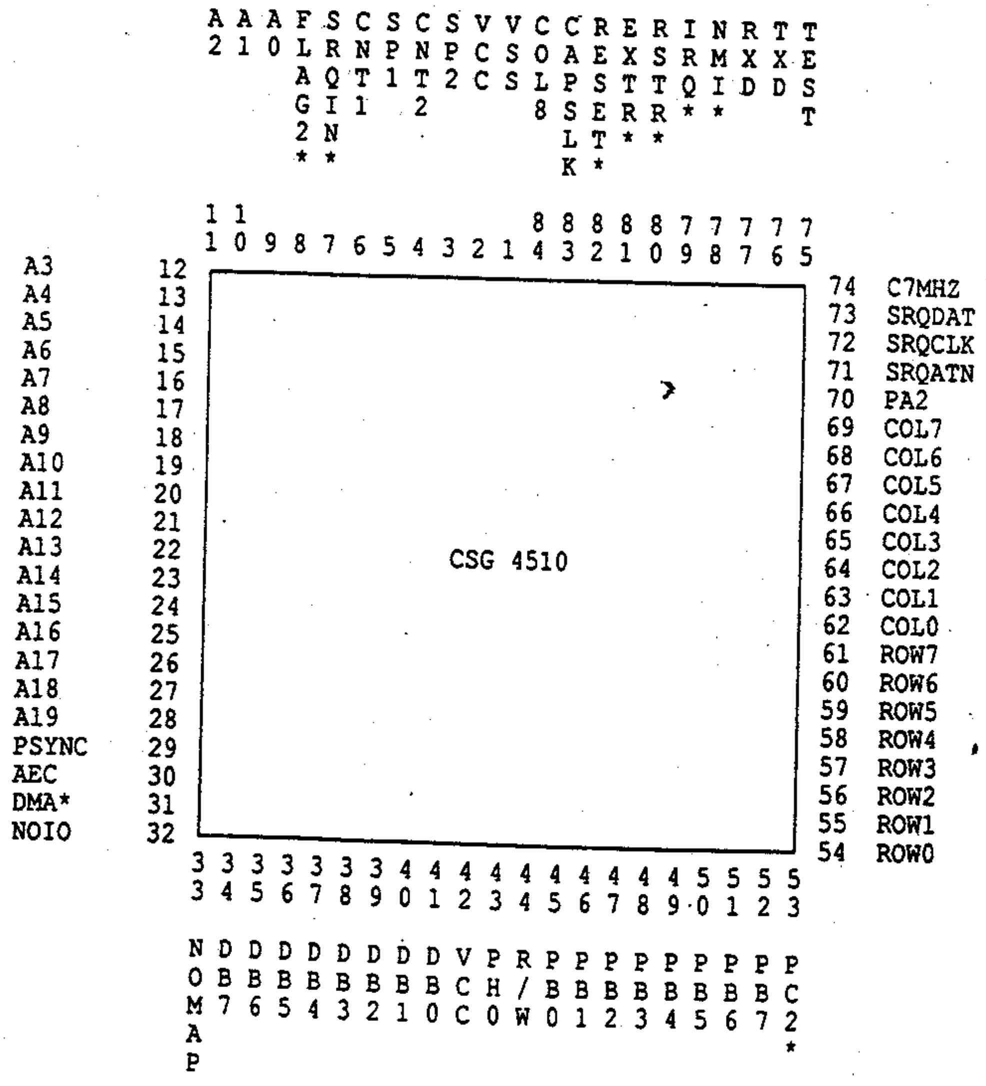
2.3.1 Description

This specification describes the requirements for a single chip 8-bit microcontroller unit fabricated in 2U CMOS double-metal technology for high speed and low power consumption.

The IC is a fully static device that contains an enhanced 6502 microprocessor (65CE02), four independent 16-bit interval timers, two 24-hour (AM/PM) time of day clocks each with programmable alarm, full-duplex serial I/O (UART) channel with programmable baud rate generator, built-in memory map function to access up to 1 megabyte of memory, 2 8-bit shift registers for synchronous serial I/O, and 30 individually programmable I/O lines.

2.3.2 Configuration

This IC device shall be configured in a standard, 84-pin plastic chip carrier package. [*** Pinout below will change for 4510R5 ****]



SYS 38552 - Ele DX mode

2.3.3 Functional Description

2.3.3.1 Pin Description

PIN NAME	PIN NUMBER	SIGNAL DIRECTION	DESCRIPTION
VSS	1	IN	This is the power ground signal (0 volts).
VCC	2,42	IN	This is the power supply signal (+5 volts).
SPB, SPA	3 5	I/O I/O	The SPA and SPB signals are open-drain and bi-directional, each with a 3K ohm (min.) passive pull-up. The SPA and SPB signals are the data lines used by the two 8-bit synchronous serial port registers. In input mode, SPA and SPB are clocked into the device on the rising edge of the CNTA and CNTB clocks, respectively. In the output mode, SPA and SPB change on the falling edge of the CNTA and CNTB clocks, respectively.
CNTB, CNTA,	4 6	I/O I/O	The CNTA and CNTB signals are open-drain and bi-directional, each with a 3K ohm (min.) passive pull-up. These pins are internally synchronized to the PH0 clock and then used to clock the synchronous serial registers, in input mode. In output mode, each pin will reflect the clock signal derived from the corresponding timer.
FLAGA/ FLAGB/	7 8	I/O IN	The FLAGA/ and FLAGB/ inputs are negative edge sensitive input signals. A passive pull-up (3K ohm min) is tied on each of these pins. They are internally synchronized to the PH0 clock and are used as general purpose interrupt inputs. Any negative transition on either of these signals will cause the device to start an interrupt sequence, provided that the proper bit is set in each of the interrupt mask registers. The device will drop the IRQ/ line to indicate that an interrupt sequence is underway.

*** When the FAST SERIAL MODE is enabled the CNTA, SPA and ***
*** FLAGA/ lines will not function as described above. See ***
*** section 2.5.6 for FAST SERIAL MODE description. ***

PIN NAME	PIN NUMBER	SIGNAL DIRECTION	DESCRIPTION
A0-A19	9 thru 28	I/O	Address Bus - This is a 20 bit bi-directional bus with tri-state outputs. The output of each address line is TTL compatible, capable of driving two standard TTL loads and 55 pf. When the AEC or DMA/ line goes low, the bus goes tri-state. If AEC only is low, A17, A18 and A19 will each reflect the state of the A16 line. During an I/O access (IO/ is low), A0-A3, A8 and A9 are used to select an internal I/O register. If AEC is high, the bus will be driven by the CPU and A16-A19 will point to a mapped memory location (if MAP/ is low). If memory is not mapped (MAP/ is high), A16-A19 will be low.

PSYNC	29	OUT	This output line is provided to identify those cycles in which the microprocessor is doing an OP CODE fetch. The PSYNC line goes high during PH1 of an OP CODE fetch and stays high for the remainder of that cycle. If AEC or DMA/ is low during the rising edge of PH1,in which pulse PSYNC went high, the processor will stop in its current state and will remain in the state until either AEC or DMA/ goes high. In this manner, the SYNC signal can be used to control either the AEC or DMA/ line to cause single instruction execution.
AEC	30	IN	This input signal is the Address Enable Control line. When high, the address bus, R/W are valid. When low, the address bus, R/W and MAP/ are in a high-impedance state except for A17, A18 and A19 each of which will be connected to the A16 line.
DMA/	31	IN	This signal is connected to a 3K passive pull-up. When this signal is low the address bus and R/W will be tri-stated. This will allow external DMA devices to assume control of the system bus lines.
(READY)	Internal Signal		This signal is generated internally via the AEC and DMA/ lines. The READY signal goes high when both AEC and DMA/ are high. It goes low if either AEC or DMA/ goes low. The READY signal allows the user to single-cycle the microprocessor on all cycles including write cycles. A low state on either DMA/ or AEC during the rising transition of phase one (PH1) will deassert the READY line and halt the microprocessor with the output address lines holding the current address. This feature allows micro processor interfacing with low speed memory as well as fast (max 2 cycle) Direct Memory Access (DMA).
IO/	32	IN	This input signal is used to select the internal registers of the device, provided memory is not being mapped by the CPU.
MAP/	33	OUT	This signal is passively pulled-up (3 Kohm) whenever DMA/ or AEC is pulled low. This output signal is used to indicate whether or not memory is being mapped by the device. If the CPU is addressing a mapped memory region the MAP/ line will go low and will inhibit the IO/ line from selecting an internal register. If the CPU is not mapping memory the MAP/ line will be high and A16-A19 will be kept low.

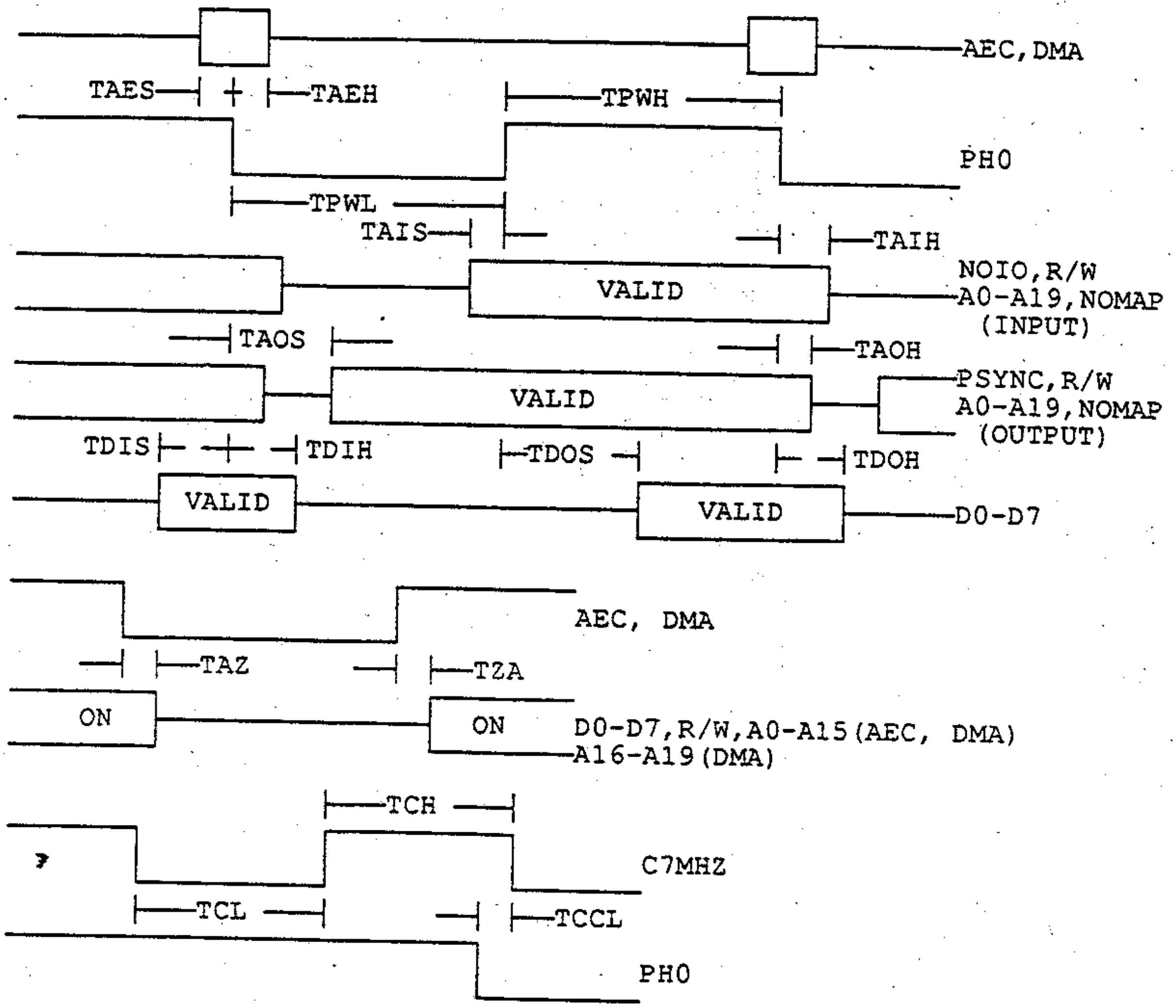
DB7-DB0	34 thru 41	I/O	D0-D7 form an 8 bit bi-directional data bus for data exchanges to and from the internal CPU (the 65CE02) and the device internal registers. It is also used to communicate with external peripheral devices. The output buffers are capable of driving two standard TTL loads and 55pf.
R/W	43	I/O	This signal is generated by the CPU to control the direction of data transfers on the data bus. This line is high except when the CPU is writing to memory, an internal I/O register or an external device. When the AEC or DMA/ signal is low, the R/W becomes tri-state.
PH0	44	IN	This clock is a TTL compatible input used for internal device operation and as a timing reference for communicating with the system data bus. Two internal clocks are generated by the device; phase two (PH2) is in phase with PH0, and phase one (PH1) is 180 degrees out of phase with PH0.
PC/	53	OUT	This output line is a strobe signal and is Centronics interface compatible. The signal goes low following a read or write access of PORT D.
PRD0-PRD7 PRB0-PRB7 PRA0-PRA7	45 thru 52 54 thru 61 62 thru 69	I/O I/O I/O	These are three 8-bit ports with each of their lines having a passive pull-up (min. 3K ohm) as well as active pull-up and pull-down transistors. Each individual port line may be programmed to be either input or output.
PRC2	70	I/O	This line corresponds to PORT C, bit 2. It has passive pull-up (min. 3k ohm) as well as active pull-up and pull-down transistors. The line can be configured as input or output. PRC2 becomes the external shift register clock when the UART is configured to operate in the synchronous mode, otherwise PRC2 operates as normal.
PRC3	71	OUT	This signal is an open drain output with a passive pull-up (1K ohm min). It corresponds to bit 3 of PORT C. When this port bit is set as an input, the PRC3 line is driven low; reading the port bit will give a high. If configured as an output, reading this port bit will not give the status of the PRC3 line but the value previously written on the PORT C data reg. bit 3.
PRC46	72	I/O	This is an open drain bi-directional signal with a passive pull-up (1K ohm min). Bit 6 of PORT C is always configured as an input; the bit will give the status of the PRC46 line anytime the the port is read, regardless of what is written in the data direction register. If bit 4 of PORT C is set as an input, the PRC46 line will be pulled low; reading the port bit will give a high. If bit 4 is configured as an output, PRC46 will be pulled low if bit 4 in the port data register is high, otherwise the PRC46 line will float to a high.

PRC57	73	I/O	This is an open drain bi-directional signal with a passive pull-up (1K ohm min). Bit 7 of PORT C is always configured as an input; the bit will give the status of the PRC57 line anytime the the port is read, regardless of what is written in the data direction register. If bit 5 of PORT C is set as an input, the PRC57 line will be pulled low; reading the port bit will give a high. If bit 5 is configured as an output, PRC57 will be pulled low if bit 5 in the port data register is high, otherwise the PRC57 line will float to a high.
PRE0,PRE1	83, 84	I/O	This a 2-bit port with each line having a passive pull-up (min. 3K ohm) as well as active pull-up and pull-down transistors. Each individual port line may be programmed to be eithe input or output.
BAUDCLK	74	IN	This input is a 7MHz clock used to drive the UART Baud Rate Generator, and is assumed to be synchronous with the PH0 clock. This clock is also divided down to 1MHz to drive the interval timers, and down to 10Hz to drive the TOD timers. This clock is also used to time out the POR and RESTORE (RSTR*) circuits.
TEST	75	IN	When this input goes to a high state, the device will operate in a test mode. The test mode will allow the BAUDCLK dividers to be initialized and the TOD and interval timers to be driven directly by the BAUDCLK clock, bypassing all the dividers.
TXD	76	OUT	This is the UART transmit data output line. The LSB of the Transmit Data Register is the first data bit transmitted. The data transmission rate (baud rate) is determined by the value written to the Baud Rate Timer latches.
RXD	77	IN	This is the UART receive data input line and is connected to a passive pull-up (1K ohm min). The first data bit received is loaded into the LSB of the Receive Data Register. The receiver data rate must be the same as that determined by the value written to the Baud Rate Timer latches.

NMI/	78	I/O	The NMI/ pin is an open drain bi-directional signal. A passive pull-up (3K ohms minimum) is tied on this pin, allowing multiple NMI/ sources to be tied together. A negative transition on this pin requests a non-maskable interrupt sequence to be generated by the microprocessor. The interrupt sequence will begin with the first PSYNC after a multiple-cycle opcode. NMI/ inputs cannot be masked by the processor status register I flag. The two program counter bytes PCH and PCL, and the processor status register P, are pushed onto the stack. Then the program counter bytes PCL and PCH are loaded from memory addresses FFFA and FFFB, respectively. NOTE: Since this interrupt is non-maskable, another NMI/ can occur before the first is finished. Care should be taken to avoid this. The NMI/ line is normally off (high impedance) and the device will activate it low as described in the functional description. AEC and DMA/ must be high for any interrupt to be recognized.
IRQ/	79	I/O	The Interrupt Request line (IRQ/) is an open drain bi-directional signal. A passive pull-up (3K ohms minimum) is tied on this pin, allowing multiple IRQ/ sources to be connected together. This pin is sampled during PH2 and when a negative transition is detected an interrupt will be activated, only if the mask flag (I) in the status register is low. The interrupt sequence will begin with the first PSYNC after a multiple-cycle opcode. The two program counter bytes PCH and PCL, and the processor status register P, are stored onto the stack; the interrupt mask flag is set high so that no further IRQ/'s may occur. At the end of this cycle, the program counter low byte (PCL) will be loaded from address FFFE, and the high byte (PCH) from FFFF, thus transferring program control to the vector located at this addresses. The IRQ/ line is normally off (high impedance) and the device will activate it low as described in the functional description. AEC and DMA/ must be high for any interrupt to be recognized.

RESTR/	80	IN	This input is tied to a 3K ohm (min.) passive pull-up. A bounce eliminator circuit is used on this pin to remove any bounce during its falling transition, if the pin is tied to a contact closure. If the device sees a negative transition on this pin, it will immediately assert the NMI/ line to start a Non-Maskable Interrupt sequence. The device will ignore any subsequent transitions on the RESTR/ line until 4.2ms has elapsed, at which time the NMI/ line is deasserted.
EXTRST/	81	OUT	This output is an open drain output with a min. 1K ohm pull-up. This pin will only go to a low state during power-up, and will stay low until .9 seconds after VDD has reached its operating voltage.
RESET/	82	I/O	The Reset line (RESET/) is an open drain bi-directional signal. A passive pull-up (1K ohm minimum) is tied on this pin, allowing any external source to initialize the device. A low on RESET/ will instantly initialize the internal 65CE02 and all internal registers. All port pins are set as inputs and port registers to zero (a read of the ports will return all highs because of passive pull-ups); all timer control registers are set to zero and all timer latches to ones. All other registers are reset to zero. During power-up RESET/ is held low and will go high .9 seconds after VDD reaches the operating voltage. If pulled low during operation, the currently executing opcode will be terminated. The B and Z registers will be cleared. The stack pointer will be set to "byte" mode, with the stack page set to page 1. The processor status bits E and I will be set. When the high transition is detected,the reset sequence begins on the CPU cycle. The first four cycles of the reset sequence do nothing. Then the program counter bytes PCL and PCH are loaded from memory addresses FFFC and FFFD, and normal program execution begins.

2.3.3.2 4510R3 Timing Description



Param	Description	MIN	TYP	MAX
Tpwh	PH0 clock high time	65	135	-
Tpwl	PH0 clock low time	65	135	-
Taes	AEC, DMA setup to PH0 falling	30	-	-
Taeh	AEC, DMA hold from PH0 falling	10	-	-
Tais	address input setup to PH0 rising	20	-	-
Taih	address input hold from PH0 falling	10	-	-
Taos	address output setup from PH0 falling	-	-	50
Taoh	address output hold from PH0 falling	15	-	-
Tdis	data input setup to PH0 falling	40	-	-
Tdih	data input hold from PH0 falling	10	-	-
Tdos	data output setup from PH0 rising	-	-	50
Tdoh	data output hold from PH0 falling	30	-	-
Taz	address off from AEC or DMA falling	0	15	20
Tza	address on from AEC and DMA rising	15	-	30
Tch	C7MHZ clock high time	65	-	-
Tcl	C7MHZ clock low time	65	-	-
Tccl	C7MHZ delay from PH0	0	-	50

2.3.3.3 Register Description

This device contains a total of 41 I/O peripheral registers which can be accessed after the following conditions are met. In an access cycle, the device must be in a non-mapped mode (MAP/ line is not asserted), the IO/ line must be in an active low state and the A0-A3, A8 and A9 address lines must contain the valid address of the register to be accessed. In addition, the state of the R/W line will indicate whether a read (R/W is "high") or a write (R/W is "low") cycle is under way.

A9	A8	···	A3	A2	A1	A0	HEX ADD	REG SYMBOL	REGISTER NAME
0	0		0	0	0	0	0X0	PRA	Peripheral Data Reg A
0	0		0	0	0	1	0X1	PRB	Peripheral Data Reg B
0	0		0	0	1	0	0X2	DDRA	Data Direction Reg A
0	0		0	0	1	1	0X3	DDRB	Data Direction Reg B
0	0		0	1	0	0	0X4	TA LO	Timer A Low Register
0	0		0	1	0	1	0X5	TA HI	Timer A High Register
0	0		0	1	1	0	0X6	TB LO	Timer B Low Register
0	0		0	1	1	1	0X7	TB HI	Timer B High Register
0	0		1	0	0	0	0X8	TODATS	TODA 10ths Sec Register
0	0		1	0	0	1	0X9	TODAS	TODA Seconds Register
0	0		1	0	1	0	0XA	TODAM	TODA Minutes Register
0	0		1	0	1	1	0XB	TODAH	TODA Hours-AM/PM Reg
0	0		1	1	0	0	0XC	SDRA	SERIALA Data Register
0	0		1	1	0	1	0XD	ICRA	INTERRUPTA Control Reg.
0	0		1	1	1	0	0XE	CRA	Control Register A
0	0		1	1	1	1	0XF	CRB	Control Register B
0	1		0	0	0	0	1X0	PRC	Peripheral Data Reg C
0	1		0	0	0	1	1X1	PRD	Peripheral Data Reg D
0	1		0	0	1	0	1X2	DDRC	Data Direction Reg C
0	1		0	0	1	1	1X3	LDRD	Data Direction Reg D
0	1		0	1	0	0	1X4	TC LO	Timer C Low Register
0	1		0	1	0	1	1X5	TC HI	Timer C High Register
0	1		0	1	1	0	1X6	TD LO	Timer D Low Register
0	1		0	1	1	1	1X7	TD HI	Timer D High Register
0	1		1	0	0	0	1X8	TODBTS	TODB 10ths of Sec Reg.
0	1		1	0	0	1	1X9	TODBS	TODB Seconds Register
0	1		1	0	1	0	1XA	TODBM	TODB Minutes Register
0	1		1	0	1	1	1XB	TODBH	TODB Hours-AM/PM Reg.
0	1		1	1	0	0	1XC	SDRB	SERIALB Data Register
0	1		1	1	0	1	1XD	ICRB	INTERRUPTB Control Reg.
0	1		1	1	1	0	1XE	CRC	Control Register C
0	1		1	1	1	1	1XF	CRD	Control Register D
1	0		0	0	0	0	2X0	DREG	Receive/Transmit Data Reg
1	0		0	0	0	1	2X1	URSR	UART Status Register
1	0		0	0	1	0	2X2	URCR	UART Control Register
1	0		0	0	1	1	2X3	BRLO	Baud Rate Timer LO Reg.
1	0		0	1	0	0	2X4	BRHI	Baud Rate Timer HI Reg.
1	0		0	1	0	1	2X5	URIEN	UART IRQ/NMI Enable Reg.
1	0		0	1	1	0	2X6	URIFG	UART IRQ/NMI Flag Reg.
1	0		0	1	1	1	2X7	PRE	Peripheral Data Reg. E
1	0		1	0	0	0	2X8	DDRE	Data Direction E
1	0		1	0	0	1	2X9	FSERIAL	Fast Serial Bus Control

REGISTER ADDRESS ALLOCATION

TABLE 1

The functional description of the memory mapper follows in section 2.3.4. The Fast Serial register is described in section 2.3.5.6.

2.3.3.3.1 REGISTER BIT ALLOCATION

R/W	REG	NAME		D7	D6	D5	D4	D3	D2	D1	D0
R/W	0X0	PRA		PA7	PA6	PA5	PA4	PA3	PA2	PA1	PA0
R/W	0X1	PRB		PB7	PB6	PB5	PB4	PB3	PB2	PB1	PB0
R/W	0X2	DDRA		DPA7	DPA6	DPA5	DPA4	DPA3	DPA2	DPA1	DPA0
R/W	0X3	DDRB		DPB7	DPB6	DPB5	DPB4	DPB3	DPB2	DPB1	DPB0
READ	0X4	TA LO	TIMER	TAL7	TAL6	TAL5	TAL4	TAL3	TAL2	TAL1	TAL0
READ	0X5	TA HI		TAH7	TAH6	TAH5	TAH4	TAH3	TAH2	TAH1	TAH0
READ	0X6	TB LO		TBL7	TBL6	TBL5	TBL4	TBL3	TBL2	TBL1	TBL0
READ	0X7	TB HI		TBH7	TBH6	TBH5	TBH4	TBH3	TBH2	TBH1	TBH0
WRITE	0X4	TA LO	PRESCALER	PAL7	PAL6	PAL5	PAL4	PAL3	PAL2	PAL1	PAL0
WRITE	0X5	TA HI		PAH7	PAH6	PAH5	PAH4	PAH3	PAH2	PAH1	PAH0
WRITE	0X6	TB LO		PBL7	PBL6	PBL5	PBL4	PBL3	PBL2	PBL1	PBL0
WRITE	0X7	TB HI		PBH7	PBH6	PBH5	PBH4	PBH3	PBH2	PBH1	PBH0
READ	0X8	TODATS	TOD TIMER	0	0	0	0	TA8	TA4	TA2	TA1
READ	0X9	TODAS		(*) 0	SAH4	SAH2	SAH1	SAL8	SAL4	SAL2	SAL1
READ	0XA	TODAM		(*) 0	MAH4	MAH2	MAH1	MAL8	MAL4	MAL2	MAL1
READ	0XB	TODAH		APM	0	0	HAH	HAL8	HAL4	HAL2	HAL1
				(*) IN TEST MODE: WILL READ DIVIDER STAGE OUTPUTS							
WRITE	0X8	TODATS	TOD LATCHES	0	0	0	0	TA8	TA4	TA2	TA1
WRITE	0X9	TODAS		0	SAH4	SAH2	SAH1	SAL8	SAL4	SAL2	SAL1
WRITE	0XA	TODAM		0	MAH4	MAH2	MAH1	MAL8	MAL4	MAL2	MAL1
WRITE	0XB	TODAH		APM	0	0	HAH	HAL8	HAL4	HAL2	HAL1
				IF CRB ALARM BIT=1 , ALARM REGISTER IS WRITTEN IF CRB ALARM BIT=0 , TOD REGISTER IS WRITTEN							

REGISTER BIT ALLOCATION
TABLE 2

R/W	REG	NAME		D7	D6	D5	D4	D3	D2	D1	D0
R/W	0XC	SDRA		SRA7	SRA6	SRA5	SRA4	SRA3	SRA2	SRA1	SRA0
READ	0XD	ICRA (INT DATA)		IRA	0	0	FLGA	SPA	ALRMA	TB	TA
WRITE	0XD	ICRA (INT MASK)		AS/$\overline{C}$	--	--	FLGA	SPA	ALRMA	TB	TA
R/W	0XE	CRA		TODA IN	SPA MODE	TMRA INMODE	LOADA	RUN-A MODE	OUT-A MODE	PRB6 ON	STARTA
R/W	0XF	CRB		ALARM (TODA)	TIMERB CRB6	INMODE CRB5	LOADB	RUN-B MODE	OUT-B MODE	PRB7 ON	STARTB
READ	1X0	PRC		PC7	PC6	PC5	PC4	PC3	PC2	PC1	PC0
R/W	1X1	PRD		PD7	PD6	PD5	PD4	PD3	PD2	PD1	PD0
R/W	1X2	DDRC		DPC7	DPC6	DPC5	DPC4	DPC3	DPC2	DPC1	DPC0
R/W	1X3	DDRD		DPD7	DPD6	DPD5	DPD4	DPD3	DPD2	DPD1	DPD0
READ	1X4	TC LO	TIMER	TCL7	TCL6	TCL5	TCL4	TCL3	TCL2	TCL1	TCL0
READ	1X5	TC HI		TCH7	TCH6	TCH5	TCH4	TCH3	TCH2	TCH1	TCH0
READ	1X6	TD LO		TDL7	TDL6	TDL5	TDL4	TDL3	TDL2	TDL1	TDL0
READ	1X7	TD HI		TDH7	TDH6	TDH5	TDH4	TDH3	TDH2	TDH1	TDH0
WRITE	1X4	TC LO	PRESCALER	PCL7	PCL6	PCL5	PCL4	PCL3	PCL2	PCL1	PCL0
WRITE	1X5	TC HI		PCH7	PCH6	PCH5	PCH4	PCH3	PCH2	PCH1	PCH0
WRITE	1X6	TD LO		PDL7	PDL6	PDL5	PDL4	PDL3	PDL2	PDL1	PDL0
WRITE	1X7	TD HI		PDH7	PDH6	PDH5	PDH4	PDH3	PDH2	PDH1	PDH0
READ	1X8	TODBTS	TOD TIMER	0	0	0	0	TB8	TB4	TB2	TB1
READ	1X9	TODBS		(*) 0	SBH4	SBH2	SBH1	SBL8	SBL4	SBL2	SBL1
READ	1XA	TODBM		0	MBH4	MBH2	MBH1	MBL8	MBL4	MBL2	MBL1
READ	1XB	TODBH		BPM	0	0	HBH	HBL8	HBL4	HBL2	HBL1

(*) IN TEST MODE: WILL READ DIVIDER STAGE OUTPUT

REGISTER BIT ALLOCATION
<u>TABLE 2</u> (CONT'D)

R/W	REG	NAME		D7	D6	D5	D4	D3	D2	D1	D0
WRITE	1X8	TODBTS	TODLATCHES	0	0	0	0	TB8	TB4	TB2	TB1
WRITE	1X9	TODBS		0	SBH4	SBH2	SBH1	SBL8	SBL4	SBL2	SBL1
WRITE	1XA	TODBM		0	MBH4	MBH2	MBH1	MBL8	MBL4	MBL2	MBL1
WRITE	1XB	TODBH		BPM	0	0	HBH	HBL8	HBL4	HBL2	HBL1
				IF CRD ALARM BIT=1 , ALARM REGISTER IS WRITTEN IF CRD ALARM BIT=0 , TOD REGISTER IS WRITTEN							
R/W	1XC	SDRB		SRB7	SRB6	SRB5	SRB4	SRB3	SRB2	SRB1	SRB0
READ	1XD	ICRB (INT DATA)		IRB	0	0	FLGB	SPB	ALRMB	TD	TC
WRITE	1XD	ICRB (INT MASK)		BS/C̄	--	--	FLGB	SPB	ALRMB	TD	TC
R/W	1XE	CRC		TODB IN	SPB MODE	TMRC INMODE	LOADC	RUN-C MODE	OUT-C MODE	PRD6 ON	STARTC
R/W	1XF	CRD		ALARM (TODB)	TIMERD CRD6	INMODE CRD5	LOADD	RUN-D MODE	OUT-D MODE	PRD7 ON	STARTD
READ	2X0	DREG (RECEIVE DATA REG)		RCV7	RCV6	RCV5	RCV4	RCV3	RCV2	RCV1	RCV0
WRITE	2X0	DREG (TRANSMIT DATA REG)		XMT7	XMT6	XMT5	XMT4	XMT3	XMT2	XMT1	XMT0
READ	2X1	URSR		TDONE	EMPTY	ENDT	IDLE	FRME	PRTY	OVR	FULL
WRITE	2X1	URSR		--	--	ENDT	IDLE	--	--	--	--
R/W	2X2	URCR		XMITR EN	RCVER EN	UART UM1	MODE UM0	CHAR CH1	LENGTH CH0	PARITY EN	PARITY EVEN
R/W	2X3	BRLO		BRL7	BRL6	BRL5	BRL4	BRL3	BRL2	BRL1	BRL0
R/W	2X4	BRHI		BRH7	BRH6	BRH5	BRH4	BRH3	BRH2	BRH1	BRH0
R/W	2X5	URIEN		XDIRQ	RDIRQ	XDNMI	RDNMI	--	--	--	--
READ	2X6	URIFG		XDIRQ	RDIRQ	XDNMI	RDNMI	--	--	--	--
R/W	2X7	PRE		--	--	--	--	--	--	PE1	PE0
R/W	2X8	DDRE		--	--	--	--	--	--	DPE1	DPE0
R/W	2X9	FSERIAL		*DMODE	*FSDIR	--	--	--	--	--	--

REGISTER BIT ALLOCATION

TABLE 2 (CONT'D)

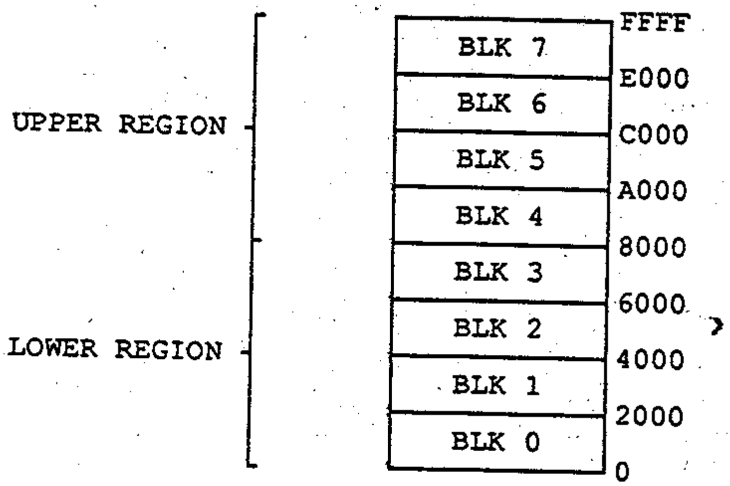
2.3.4 Memory Mapper

The microprocessor core is actually a C4502R1 with some additional instructions, used to operate the memory mapper.

The former AUG (augment) opcode has been changed to MAP (mapper), and the former NOP (no-operation) has been changed to EOM (end-of-mapping-sequence).

The 4510 memory mapper allows the microprocessor to access up to 1 megabyte of memory. Here's how. The 6502 microprocessor can only access 64K bytes of memory because it only uses addresses of 16 bits. The 4502 is no different, nor is the 4510. But the 4510 memory mapper allows these addresses to be redirected to new physical addresses to access different parts of a much larger memory, within the 64K byte confinement window.

The 64K window has been divided into eight blocks, and two regions, with four blocks in each region. Blocks 0 through 3 are in the "lower" region, and blocks 4 through 7 are in the "upper" region, as shown...



Each block can be programmed to be "mapped", or "non-mapped" via bits in the mapper's "mask" registers. NON-MAPPED means, simply, address out equals address in. Therefore, there are still only 64K bytes of non-mapped memory. MAPPED means that address out equals address in plus some offset. The offset is programmed via the mapper's "offset" registers. There are two "offset" registers. One is for the lower region, and one is for the upper region.

The low-order 8 addresses are never mapped. The offsets are only added to the 12 high-order addresses. This means the smallest unit you can map to is 256 bytes, or one page.

The 4510 has an output (NOMAP) which lets the outside world know when the processor is accessing mapped (0) or non-mapped (1) address. This is useful for systems where you may want I/O devices to be at fixed (non-mapped) addresses, and only memory at mapped addresses.

It is possible, and likely, to have mapped, and unmapped memory at the same physical address. And, with offset registers set to zero, mapped addresses will match unmapped ones. The only difference is the NOMAP signal to tell whether the address is mapped or unmapped.

To program the mapper, the operating system must load the A, X, Y, and Z registers with the following information, and execute a MAP opcode.

Mapper Register Data

7	6	5	4	3	2	1	0	BIT
LOWER OFF15	LOWER OFF14	LOWER OFF13	LOWER OFF12	LOWER OFF11	LOWER OFF10	LOWER OFF9	LOWER OFF8	A
MAP BLK3	MAP BLK2	MAP BLK1	MAP BLK0	LOWER OFF19	LOWER OFF18	LOWER OFF17	LOWER OFF16	X
UPPER OFF15	UPPER OFF14	UPPER OFF13	UPPER OFF12	UPPER OFF11	UPPER OFF10	UPPER OFF9	UPPER OFF8	Y
MAP BLK7	MAP BLK6	MAP BLK5	MAP BLK4	UPPER OFF19	UPPER OFF18	UPPER OFF17	UPPER OFF16	Z

After executing the MAP opcode, all interrupts are inhibited. This is done to allow the operating system to complete a mapping sequence without fear of getting an interrupt. An interrupt occurring before the proper stack-pointer is set will cause return address data to be written to an undesired area.

Upon completing the mapping sequence, the operating system must remove the interrupt inhibit by executing a EOM (formerly NOP) opcode. Note that application software may execute NOPs with no effect.

2.3.5 Peripheral Control Functions

2.3.5.1 I/O Ports

Ports A, B and D each consist of an 8-bit Peripheral Data Register (PR) and an 8-bit Data Direction Register (DDR). Port E consists of a 2-bit PR and DDR registers. If a bit in the DDR is set to one, the corresponding bit in the PR is an output, if a DDR bit is set to a zero, the corresponding PR bit is defined as an input. On a READ, the PR bit reflects the information present on the actual port pins (PRA0-PRA7,PRB0-PRB7,PRC2,PRD0-PRD7, PRE0-PRE1) for both input and output bits. All ports have passive pull-up devices as well as active pull-ups, providing both CMOS and TTL compatibility. In addition to normal I/O operation, PRB6,PRB7,PRD6 and PRD7 also provide timer output functions (refer to Control Register section, 2.5.8).

Only bit PC2 and DPC2 of PORT C meet the above description. The other bits function as described in the following.

PC0,PC1	These signals are simply a register bits. When read, they will reflect the value previously written to the PRC register.
PC4	This bit is a "high" if it's configured as input (DPC4 is a "low"). If configured as output (DPC4 is a "high"), the bit will reflect its previous written value when PORT C is read. Then the PRC46 pin is pulled "low" if PC4 is "high"; otherwise, PRC46 is pulled-up through passive resistor.
PC5	This bit is a "high" if it's configured as input (DPC5 is a "low"). If configured as output (DPC5 is a "high"), the bit will reflect its previous written value when PORT C is read. Then the PRC57 pin is pulled "low" if PC5 is "high"; otherwise, PRC57 is pulled-up through passive resistor.
PC6,PC7	These bits are always configured as inputs. When PORT C (PRC) is read, PC6 and PC7 will reflect the values on the PRC46 and PRC57 pins, respectively.

2.3.5.2 Handshaking

Handshaking on data transfers can be accomplished using the PC/ output pin and either the FLAGA/ or FLAGB/ input pin. The PC/ line will go low and stay low for two cycles, two cycles after a read or write to PORT D. This is required to meet Centronics Parallel Interface specs. The PC/ line can be used to indicate "data ready" at PORT D or "data accepted" from PORT D. Handshaking on 16-bit data transfers (using either PORT A or B and then PORT D) is possible by always reading or writing PORT A or PORT B first. The FLAG/ lines are negative edge sensitive inputs which can be used for receiving the PC/ output from other 4510 devices, or as general purpose interrupt inputs. A negative transition on FLAGA/ or FLAGB/ will set the FLAGA or FLAGB interrupt bits, respectively.

2.3.5.3 Interval Timers (Timer A, Timer B, Timer C, Timer D)

Each interval timer consists of a 16-bit read-only Timer Counter and a 16-bit write-only Timer Latch (prescaler). Data written to the timer are latched in the Timer Latch, while data read from the timer are the present contents of the Timer Counter. The timers can be used independently or linked in pairs for extended operations (TIMER A may be linked with Timer B; TIMER C may be linked with TIMER D). The various timer modes allow generation of long time delays, variable width pulses, pulse trains and variable frequency waveforms. Utilizing the CNT inputs, the timers can count external pulses or measure frequency, pulse witdth and delay times of external signals. Each timer has an associated control register, providing independent control of the following functions (see bits functional description in section 2.5.8 below):

Start/Stop

Each timer may be started or stopped by the microprocessor at any time by writing to the START/STOP bit of the corresponding control register (CRA, CRB, CRB or CRC).

PRB, PRD On/Off

Control bits allow any of the timer outputs to appear on a PORT B or PORT D output line (PRB6 for TIMER A, PRB7 for TIMER B, PRD6 for TIMER C and PRD7 for TIMER D). Note that this funtion overrides the DDRB control bit and forces the appropiate PB or PC line to be an output.

Toggle/Pulse

Control bits select the ouputs applied to PORT B and PORT D. On every timer underflow the ouput can either toggle or generate a single positive pulse of one cycle duration. The Toggle output is set high whenever the appropiate timer is started and is set low by RESET/.

One-Shot/Continuous

Control bits select either timer mode. In one-shot mode, the timer will count down from the latched value to zero, generate an interrupt, reload the latched value, then stop. In continuous mode, the timer will count from the latched value to zero, generate an interrupt, reload the latched value and repeat the procedure continuously.

Force Load

A strobe bit allows the timer latch to be loaded into the timer counter at any time, whether the timer is running or not.

Input Mode

Control bits allow selection of the clock used to decrement the timer. TIMER A or TIMER C can count C1MHZ clock pulses or external pulses applied to the CNTA or CNTB, respectively. The C1MHZ clock is obtained after internally dividing the C7MHZ by a factor of seven.

TIMER B can count C1MHZ clock pulses, external pulses applied to the CNTA input, TIMER A underflow pulses or TIMER A underflow pulses while the CNTA pin is held high.

TIMER D can count C1MHZ clock pulses, external pulses applied to the CNTB input, TIMER C underflow pulses or TIMER C underflow pulses while the CNTB pin is held high.

The timer latch is loaded into the timer on any timer underflow, on a force load or following a write to the high byte of the prescaler while the timer is stopped. If the timer is running, a write to the high byte will load the timer latch, but not reload the counter.

2.3.5.4 Time of Day Clocks (TODA, TODB)

The TODA and TODB clocks are special purpose timers for real-time applications. Each clock, TODA or TODB, consists of a 24-hour (AM/PM) clock with 1/10th second resolution. Each is organized into four registers: 10ths of seconds (TODATS, TODBTS), Seconds (TODAS, TODBS), Minutes (TODAM, TODBM) and Hours (TODAH, TODBH). The AM/PM flag is in the MSB of the Hours register for easy testing. Each register reads out in BCD format to simpl fy conversion for driving displays, etc. Each TOD requires a 10HZ clock input to keep accurate timing. This 10HZ clock is generated by dividing the C7MHz clock input by a factor of 102273 for NTSC (60Hz) applications, or a factor of 101339 for PAL (50Hz) applications. The divider ratio is selected by the TODA IN and the TODB IN bits of the Control Registers, CRA and CRC, respectively (see 2.5.8).

In addition to time-keeping, a programmable ALARM is provided for generating an interrupt at the desired time, from either of the TOD clocks. The ALARM registers are located at the same addresses as the corresponding TODA and TODB registers. Access to the ALARM is governed by bit 7 in the Control Registers CRB and CRD. The ALARM registers are write-only; any read of a TOD address will read time regardless of the state of the ALARM access control bits.

A specific sequence of events must be followed for proper setting and reading of each TOD. A TOD is automatically stopped whenever a write to the corresponding Hours register occurs. The TOD will not start again until after a write to the proper 10ths of seconds register. This assures that a TOD will always start at the desired time. Since a carry from one stage to the next can occur at any time with respect to a read operation, a latching function is included to keep all Time of Day information constant during a read sequence. All four registers of each TOD latch on a read of the corresponding Hours register and remain latched until after a read of the corresponding 10ths of second register. A TOD continues to count when the output registers are latched. If only one register is to be read, there is no carry problem and the register can be read "on the fly", provided that any read of the Hours register if followed by a read of the proper 10ths of seconds, to disable the latching.

2.3.5.5 Serial Ports (SDRA, SDRB)

Each serial port is a buffered, 8-bit synchronous shift register system. A control bit (CRA SPA bit, CRC SPB bit) selects input or output mode for either the SDRA or SDRB port.

In input mode, data on the SPA or SPB pin is shifted into the corresponding shift register on the rising edge of the signal applied to the CNTA or CNTB pin, respectively. After 8 CNTA pulses , the data in the shift register is dumped into the SERIALA Data Register (SDRA) and an interrupt is generated, SPA bit is set in register ICRA. After 8 CNTB pulses , the data in the shift register is dumped into the SERIALB Data Register (SDRB) and an interrupt is generated, SPB bit is set in register ICRB.

In the output mode, TIMER A is used for the baud rate generator of serial port A, Timer C for serial port B. Data is shifted on an SP pin at half the underflow rate of the TIMER used. The maximum baud rate possible is C1MHz divided by four, but the maximum useable baud rate will be determined by line loading and the speed at which the receiver responds to input data. Transmission will start following a write to Serial Data Register (provided the proper TIMER used is running and in continuous mode). The clock signal derived from TIMER A would appear as an output on the CNTA pin; the one from TIMER C would appear otn the CNTB pin. The data in the Serial Data Register will be loaded into its corresponding shift register then shift out to the SPA or SPB pin when a CNTA or CNTB pulse occurs, respectively. Data shifted out becomes valid on the falling edge of its CNT clock and remains valid until the next falling edge. After 8 CNT pulses, an interrupt is generated to indicate more data can be sent. If the Serial Data Register was loaded with new information prior to this interrupt, the new data will automatically be loaded into the shift register and transmission will continue. If the microprocessor stays one byte ahead of the shift register, transmission will be continuous. If no further data is to be transmitted, after the 8th CNT pulse, CNT will return high and SP will remain at the level of the last data bit transmitted. SDR data is shifted out MSB first and serial input data should also appear on this format.

The bidirectional capability of each of the Serial Ports and CNT clocks allows many 4510 to be connected to a common serial communication bus on which one Serial Port would act as a master, sourcing data and shift clock, while the other Serial Port (and all other ports from other 4510 devices) would act as slaves. All the CNT and SP outputs are open drain to allow such a common bus. Protocol for master/slave selection can be transmitted over the serial bus, or via dedicated handshaking lines.

2.3.5.6 FAST SERIAL MODE

The FAST SERIAL logic consists of a 2-bit write-only register, which resides in location 0001 (hex). This register may only be accessed by the CPU if neither the AEC or DMA/ line is low. Upon reset, both bits in the register are forced low which allows the device to operate as normal (the CNTA, SPA, PRC57 and FLAGA/ lines will not be affected).

Bit 7 of the FAST SERIAL register is the Fast Serial Mode disable bit (DMODE* bit).

Bit 6 of the FAST SERIAL register is the FSDIR* bit. When the DMODE* bit is set high, the FSDIR* bit will be used as an output to control the fast serial data direction buffer hardware, and as an input to sense a fast disk enable signal. This function will affect the CNTA, SPA, PRC57 and FLAGA/ lines as summarized in the following table.

DMODE*	**FSDIR***	**FUNCTION**
0	0	Fast Serial mode is disabled.
x	1	Both the FLAGA/ and the PRC57 lines will behave as outputs. The FLAGA/ output will reflect the state of the CNTA pin, whereas the PRC57 output will reflect the state of the SPA pin.
1	0	Both the CNTA and SPA lines will behave as outputs. The CNTA ouput will reflect the state of the FLAGA/ pin, whereas the SPA output will reflect that of the PRC57 pin.

2.3.5.7 Interrupt Control Registers (ICRA, ICRB)

These registers control the following sources of interrupts:

i. Underflows from TIMER A, TIMER B, TIMER C and TIMER D
ii. TODA ALARM and TODB ALARM.
iii. SERIALA and SERIALB Port full/empty conditions.
iv. FLAGA/ and FLAGB/ low transitions.

The ICRA and ICRB registers each provides masking and interrupt information. ICRA and ICRB each consists of a write-only MASK register and a read-only DATA register. Any interrupt will set the corresponding bit in the DATA register. Any interrupt which is enabled by the MASK register will set the IR bit (MSB) of its corresponding DATA register and bring the IRQ/ pin low. In a multi-chip system, the IR bit (IRA of ICRA or IRB of ICRB) can be polled to detect which chip has generated an interrupt request. The interrupt DATA register is cleared and the IRQ/ line returns high following a read of the DATA register. Since each interrupt sets and interrupt bit regardless of the MASK, and each interrupt bit can be selectively masked to prevent the generation of a processor interrupt, it is possible to intermix polled interrupts with true interrupts. However, polling either of the IR bits will cause its corresponding DATA register to clear, therefore, it is up to the user to preserve the information contained in the DATA registers if any polled interrupts were present.

Both MASK (ICRA, ICRB) registers provide convenient control of individual mask bits. When writing to a MASK register, if bit 7 of the data written (corresponding to AS/C in ICRA, or BS/C in ICRB) is a ZERO, any mask bit written with a one will be cleared, while those bits written with a zero will be unaffected. In order for an interrupt flag to set the IR bit and generate an Interrupt Request, the corresponding MASK bit must be set in the corresponding MASK Register.

2.3.5.8 Control Registers (CRA, CRB, CRC, CRD)

CRA (0XE):

BIT	Bit Name	Function
0	STARTA	1=START TIMER A, 0=STOP TIMER A. This bit is automatically reset when TIMER A underflow occurs during one-shot mode.
1	PRB6 ON	1=TIMER A output appears on PRB6, 0=PRB6 normal port operation.
2	OUT-A MODE	1=TOGGLE output applied on port PRB6, 0=PULSE output applied on port PRB6.
3	RUN-A MODE	1=ONE-SHOT TIMER A operation, 0=CONTINUOUS TIMER A operation.
4	LOADA	1=FORCE LOAD on TIMER A (this is a STROBE input, there is no data storage, bit 4 will always read back a zero and writing a zero has no effect).
5	TMRA INMODE	1=TIMER A counts positive CNTA transitions, 0=TIMER A counts internal C1MHZ pulses.
6	SPA MODE	1=SERIAL A PORT output mode (CNTA sources shift clock), 0=SERIAL A PORT input mode (external shift clock on CNTA)
7	TODA IN	1=50 Hz operation. C7MHZ divided down by 101339 to generate TODA input of 10 Hz. 0=60 Hz operation. C7MHZ divided down by 102273 to generate TODA input of 10 Hz

CRB (0XF):

(Bits 0-4 of the CRB register operate identically to bits 0-4 of the CRA register, except that functions now apply to TIMER B and bit 1 controls the output of TIMER B on PRB7).

BIT	Bit Name	Function
5,6	TIMERB INMODE	Bits 5 and 6 select one of four input modes for TIMER B as follows:

CRB6	CRB5	
0	0	TIMER B counts C1MHz pulses.
0	1	TIMER B counts positive CNTA transitions.
1	0	TIMER B counts TIMERA underflow pulses.
1	1	TIMER B counts TIMERA underflows while CNTA is high.

BIT	Bit Name	Function
7	ALARM TODA	1=writing to TODA registers sets ALARM, 0=writing to TODA registers sets TODA clock.

CRC (1XE):

BIT	Bit Name	Function
0	STARTC	1=START TIMER C, 0=STOP TIMER C. This bit is automatically reset when TIMER C underflow occurs during one-shot mode.
1	PRD6 ON	1=TIMER C output appears on PRD6, 0=PRD6 normal port operation.
2	OUT-C MODE	1=TOGGLE output applied on port PRD6, 0=PULSE output applied on port PRD6.
3	RUN-C MODE	1=ONE-SHOT TIMER C operation, 0=CONTINUOUS TIMER C operation.
4	LOADC	1=FORCE LOAD on TIMER C (this is a STROBE input, there is no data storage, bit 4 will always read back a zero and writing a zero has no effect).
5	TMRC INMODE	1=TIMER C counts positive CNTB transitions, 0=TIMER C counts internal C1MHZ pulses.
6	SPB MODE	1=SERIAL B PORT output mode (CNTB sources shift clock), 0=SERIAL B PORT input mode (external shift clock on CNTB)
7	TODB IN	1=50 Hz operation. C7MHZ divided down by 101339 to generate TODB input of 10 Hz. 0=60 Hz operation. C7MHZ divided down by 102273 to generate TODB input of 10 Hz

CRD (1XF):

(Bits 0-4 of the CRD register operate identically to bits 0-4 of the CRD register, except that functions now apply to TIMER D and bit 1 controls the output of TIMER D on PRD7).

BIT	Bit Name	Function
5,6	TIMERD INMODE	Bits 5 and 6 select one of four input modes for TIMER D as follows:

CRD6	CRD5	
0	0	TIMER D counts C1MHz pulses.
0	1	TIMER D counts positive CNTB transitions.
1	0	TIMER D counts TIMERC underflow pulses.
1	1	TIMER D counts TIMERC underflows while CNTB is high.

7	ALARM TODB	1=writing to TODB registers sets ALARM, 0=writing to TODB registers sets TODA clock.

C65 Peripheral Control Utilization

```
6526 cia  complex interface adapter #1
  keyboard / joystick / paddles / mouse / lightpen / fast serial

  pra0 : keybd output c0 / joystick #1 up      / mouse right button
  pra1 : keybd output c1 / joystick #1 down
  pra2 : keybd output c2 / joystick #1 left    / paddle "A" fire button
  pra3 : keybd output c3 / joystick #1 right   / paddle "B" fire button
  pra4 : keybd output c4 / joystick #1 fire    / mouse left button
  pra5 : keybd output c5 /
  pra6 : keybd output c6 /                     / select port #1 paddles|mouse
  pra7 : keybd output c7 /                     / select port #2 paddles|mouse

  prb0 : keybd input  r0 / joystick #2 up      / mouse right button
  prb1 : keybd input  r1 / joystick #2 down    / paddle "A" fire button
  prb2 : keybd input  r2 / joystick #2 left    / paddle "B" fire button
  prb3 : keybd input  r3 / joystick #2 right
  prb4 : keybd input  r4 / joystick #2 fire    / mouse left button
  prb5 : keybd input  r5 /
  prb6 : keybd input  r6 / timer b: toggle/pulse output
  prb7 : keybd input  r7 / timer a: toggle/pulse output

  timer 1 & cra : fast serial
  timer 2 & crb :

  tod    :
  sdr    :
  icr    :


6526 cia  complex interface adapter #2
  user port / rs232 / serial bus / VIC bank / NMI

  pra0 : va14   VIC 16K bank select
  pra1 : va15
  pra2 : rs232  DATA output                    (C64 mode only)
  pra3 : serial ATN  output
  pra4 : serial CLK  output
  pra5 : serial DATA output
  pra6 : serial CLK  input
  pra7 : serial DATA input

  prb0 : user port / rs232 received data       (C64 mode only)
  prb1 : user port / rs232 request to send
  prb2 : user port / rs232 data terminal ready
  prb3 : user port / rs232 ring indicator
  prb4 : user port / rs232 carrier detect
  prb5 : user port
  prb6 : user port / rs232 clear to send
  prb7 : user port / rs232 data set ready

  timer 1 & cra :    rs232 baud rate           (C64 mode only)
  timer 2 & crb :    rs232 bit check           (C64 mode only)

  tod    :
  sdr    :
  icr    : nmi (/irq)
```

2.3.6 UART Operation

The device contains seven registers to control the different UART modes of operation. Section 2.2 describes how to access these registers.

The UART modes can be programmed by accessing the UART control register, URCR, whose bits function as described below.

2.3.6.1 UART Control Register (URCR)

BIT	Bit Name	Function
0	PARITY EVEN	1=Even Parity. If parity is enabled, the transmitter will assert the parity bit (P) to a low when "even" parity data is transmitted, otherwise it will pull it high. The receiver checks that the parity bit is asserted, or low, if the data received has even parity; if the bit is not asserted, the device will indicate a parity error. 0=Odd Parity. If parity is enabled, the transmitter will pull the parity bit (P) low, when "odd" parity data is transmitted, otherwise it will pull it high. The receiver checks that the parity bit is asserted if the data received has odd parity; if the bit is not asserted when data had odd parity, the device will indicate a parity error.
1	PARITY EN	1= Parity Enabled. 0= Parity Disabled. The transmitter and receiver will not allocate a parity bit in the data, instead a stop bit will be used in its place. See the Data Configuration chart below.
2,3	CHAR LENGTH	These two bits are used to select the number of bits per character to be transmitted or received. 5,6,7 or 8 bits per character may be selected as follows:

CH1	CH0	
0	0	eight bits per character
0	1	seven bits per character
1	0	six bits per character
1	1	five bits per character

4,5	UART MODE	These two bits select whether operations will be asynchronous or synchronous for the transmitter and/or receiver. The actual selection is done as follows:

UM1	UM0	
0	0	both transmitter and receiver operate in asynchronous mode.
0	1	receiver operates in synchronous mode, transmitter in asynchronous mode.
1	x	receiver operates in asynchronous mode, transmitter in synchronous mode.

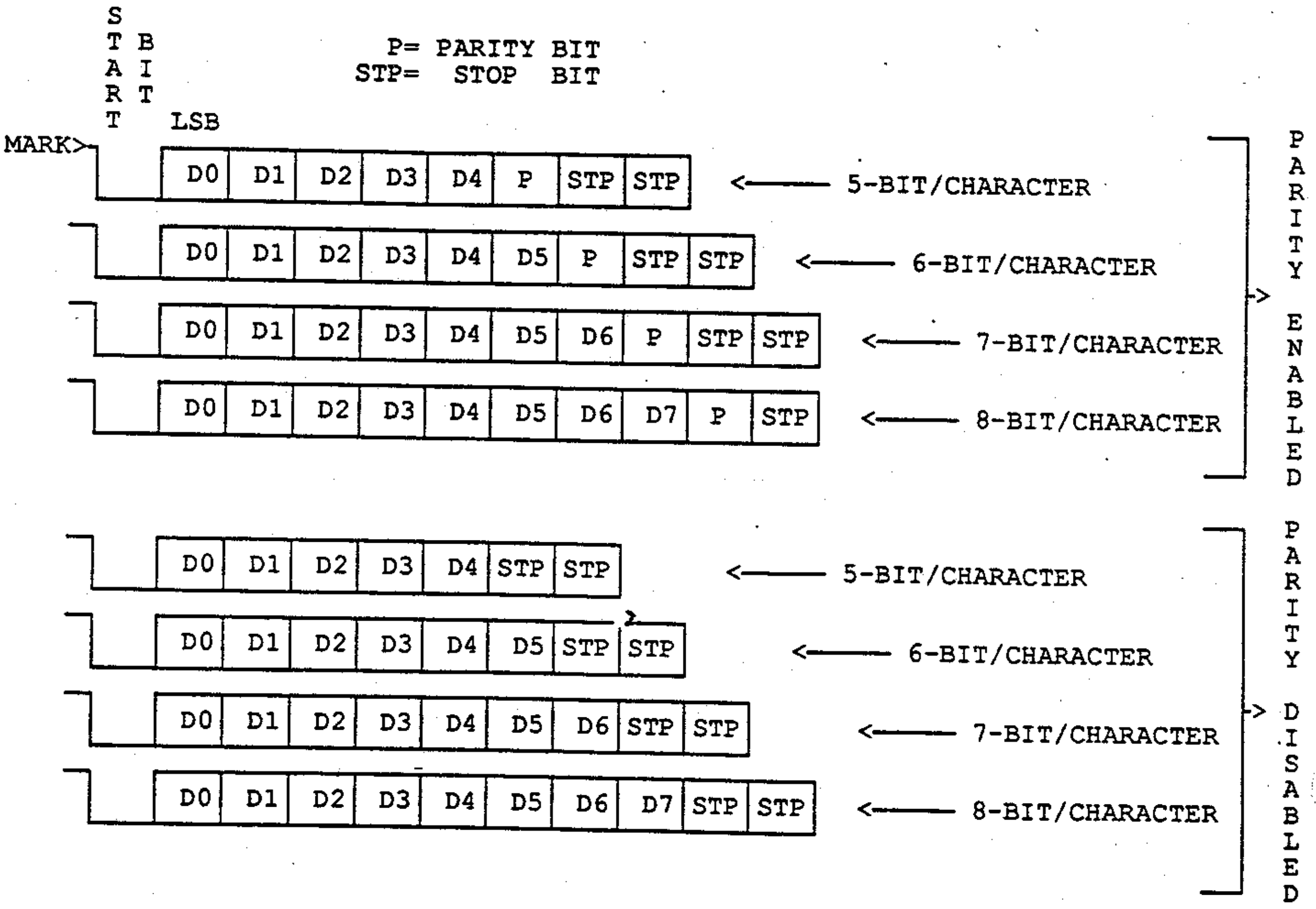
BIT	Bit Name	Function
6	RCVR EN	0= Receiver is disabled. 1= Receiver is Enabled. To provide noise immunity, the duration of a bit interval is segmented into 16 sub-intervals. This is also used to verify that a high to low transition (START bit) on the RXD line is valid (stays low) at the half point of a bit duration; if not valid, operation will not start. If after an idle period, a high to low transition is detected on the RXD line and is verified to be low, the receiver will synchronized itself to the incoming character for the duration of the character. Received data is then sampled or latched in the center of a bit time to determine the value of the remaining bits. The LSB of the data is the leading bit received. Any unused high order register bits will be set "high". The receiver expects the data to have only one parity bit (when parity is enabled) and one stop bit. At the end of the character reception, the receiver will check whether any errors have occured and will update the status register (URSR) accordingly. In addition, if no errors were encountered the receiver will load the contents of the shift register into the Receiver Data Register, eliminating parity and stop bits. In synchronous mode, the receiver will reconfigure its Data Register and Shift Register so that only 8 data bits are always accepted on the RXD line. This mode only works if an external clock is applied on the PRC2 input line, which is used to shift the bits into the Receiver Shift Register. Data on the RXD is latched at the rising edge of the external clock applied in PRC2.
7	XMITR EN	0= Transmitter is disabled. 1= Transmitter is Enabled. Transmitter will start operation once the microprocessor writes data to the transmitter data register (DREG), after which the Transmitter Shift Register is loaded and the start bit is placed on the TXD line. The LSB of the data is the leading bit being transmitted. The Transmitter is "doubled buffered" which means that the CPU can load a new character as soon as the previous one starts transmission. This is indicated by the status register, bit 6 (URSR6-EMPTY Data Register), which when set, it indicates that the data register is ready to accept the next character. The character data format is illustrated by figure 1.3. In synchronous mode, the transmitter will reconfigure its Data Register and Shift Register so that only 8 data bits are always transmitted on the TXD line, eliminating all parity and stop bits. The external clock output will be placed in the PRC2 line and will shift the data out of the transmitter shift register. Data on the TXD line will change on the falling edge of the PRC2 signal, the external clock.

2.3.6.2 UART Status Register (URSR)

BIT	Bit Name	Function
0	FULL	Receiver Data Register Full bit. This bit is forced to a low upon reset, or after the data register (DREG) is read. This bit is enabled only if the RCVER EN bit is set in the URCR register. The FULL bit is set when the character being received is transferred from the receiver shift register into the receiver data register. If an error is encountered in the character data, this bit will not be set and the proper error bit will be set in the URSR register.
1	OVR	Receiver Over-Run Error bit. This bit is cleared upon reset or after reading the receiver data register. This bit is set if the new received charater is attempted to be transferred from the receiver shift register before reading the last character from the data register. Therefore, the last character is preserved in the data register while the new received character is lost.
2	PRTY	Receiver Parity Error bit. This bit is cleared upon reset or after reading the receiver data register. The PRTY bit will be set when a parity error is detected on the received character, provided the PARITY EN bit is set and receiver is running asynchronously.
3	FRME	Receiver Frame Error bit. This bit is cleared upon reset or after reading the receiver data register. The FRME bit is set whenever the received character contains a low in the first stop-bit slot.
4	IDLE	Receiver Idle bit. When this bit is written to a "high", the status register bits 0-3 are disabled until the receiver detects 10 consecutive marks, highs, on the RXD line, at which time the IDLE bit is cleared. This bit is also cleared upon reset. This bit allows the microprocessor, or any external microprocessor device, to ignore the transmission of a character until the start of the next character.
5	ENDT	Transmitter End of Transmission bit. This bit is cleared upon reset or whenever data is written into the transmitter data register, DREG. Setting this bit would disable the Transmitter Empty bit, EMPTY, until device completes transmission.

2.3.6.3 Character Configuration

ASYNC MODE



CHARACTER CONFIGURATION
TABLE 3

2.3.6.4 Register Map

C65 UART

R/W	REG	NAME	D7	D6	D5	D4	D3	D2	D1	D0
R/W	0	DATA	R/X7	R/X6	R/X5	R/X4	R/X3	R/X2	R/X1	R/X0
R	1	STATUS	XMIT DONE	XMIT EMPTY	ENDT (R/W)	IDLE (R/W)	FRAME	PARITY	OVER RUN	RCVR FULL
R/W	2	CONTROL	XMIT ON	RCVR ON	UART MODE		WORD LENGTH		PARITY ON	EVEN
R/W	3	BAUD LO	BRL7	BRL6	BRL5	BRL4	BRL3	BRL2	BRL1	BRL0
R/W	4	BAUD HI	BRH7	BRH6	BRH5	BRH4	BRH3	BRH2	BRH1	BRH0
R/W	5	INT MASK	XMIT IRQ	RCVR IRQ	XMIT NMI	RCVR NMI	--	--	--	--
R	6	INT FLAG	XMIT IRQ	RCVR IRQ	XMIT NMI	RCVR NMI	--	--	--	--

The BAUD RATE can be generated using the following formulas:

$$\text{BaudRate} = \frac{\text{URCLK}}{16\ (\ \text{COUNT}+1\ )} \quad \text{or,} \quad \text{COUNT} = \frac{\text{URCLK}}{16 \times \text{BaudRate}} - 1$$

Where:
COUNT = value loaded into BAUD RATE register
URCLK = C7Mhz input, 7.15909 MHz NTSC
7.09375 MHz PAL

The following tables show some of the most common data rates. Data rate errors of less than +/-1.5% are acceptable for most purposes.

A. NTSC URCLK = 7.15909 MHZ

BR #	BAUD RATE REQUIRED	COUNT (HEX)	BAUD RATE OBTAINED	PERCENT ERROR	
1	50	22F4	49.999	.0015	
2	75	174D	74.999	.0015	
3	110	0FE3	109.991	.0080	
4	134.5	0CFE	134.488	.0090	
5	150	0BA6	149.998	.0015	
6	300	05D2	299.895	.035	
7	600	02E9	599.79	.035	
8	1200	0174	1199.58	.035	
9	1800	00F8	1796.96	.17	
10	2400	00B9	2392.74	.30	
11	3600	007B	3608.41	.23	
12	4800	005C	4811.22	.23	
13	7200	003D	7216.82	.23	
14	9600	002E	9520.07	.83	
15	19200	0016	19454.0	1.323	
16	31250	000D	31960.2	1.023	(MIDI)
0	56000	0007	55930.4	.124	

B. PAL URCLK = 7.09375 MHZ

BR #	BAUD RATE REQUIRED	COUNT (HEX)	BAUD RATE OBTAINED	PERCENT ERROR	
1	50	22A2	50.001	.0020	
2	75	1716	75.005	.0080	
3	110	0FBE	109.987	.010	
4	134.5	0CDF	134.514	.010	
5	150	0B8B	149.986	.009	
6	300	05C5	299.973	.009	
7	600	02E2	599.75	.009	
8	1200	0170	1198.27	.144	
9	1800	00F5	1802.27	.126	
10	2400	00B8	2396.54	.144	
11	3600	007A	3604.55	.126	
12	4800	005B	4819.12	.398	
13	7200	003D	7150.96	.68	
14	9600	002D	9638.25	.40	
15	19200	0016	19276.5	.40	
16	31250	000D	31668.5	1.01	(MIDI)
0	56000	0007	55419.9	1.04	

2.3.7 CPU

2.3.7.1 Introduction

The 4502, upon reset, looks and acts like any other CMOS 6502 processor, with the exception that many instructions are shorter or require less cycles than they used to. This causes programs to execute in less time that older versions, even at the same clock frequency.

The stack pointer has been expanded to 16 bits, but can be used in two different modes. It can be used as a full 16-bit (word) stack pointer, or as an 8-bit (byte) pointer whose stack page is programmable. On reset, the byte mode is selected with page 1 set as the stack page. This is done to make it fully 65C02 compatible.

The zero page is also programmable via a new register, the "B" or Base Page" register. On reset, this register is cleared, thus giving a true "zero" page for compatability reasons, but the user can define any page in memory as the "zero" page.

A third index register, "Z", has been added to increase flexability in data manipulation. This register is also cleared, on reset, so that the STZ instructions still do what they used to, for compatability.

This is a list of opcodes that have been added to the 210 previously defined MOS, Rockwell, and GTE opcodes.

1. Branches and Jumps

BCC label	word-relative
BCS label	word-relative
BEQ label	word-relative
BMI label	word-relative
BNE label	word-relative
BPL label	word-relative
BRA label	word-relative
BVC label	word-relative
BVS label	word-relative

BSR label	Branch to subroutine (word relative)
JSR (ABS)	Jump to subroutine absolute indirect
JSR (ABS,X)	Jump to subroutine absolute indirect, X
RTN #	Return from subroutine and adjust stack pointer.

2. Arithmetic Operations

NEG A	Negate (or 2's complement) accumulator.

ASR A	Arithmetic Shift right accumulator or memory
ASR ZP	
ASR ZP,X	

INW ZP	Increment Word
DEW ZP	Decrement Word

INZ	Increment and
DEZ	Decrement Z register

ASW ABS	Arithmetic Shift Left Word
ROW ABS	Rotate Left Word

ORA (ZP),Z	These were formerly (ZP) non-indexed
AND (ZP),Z	now are indexed by Z register
EOR (ZP),Z	(when .Z=0, operation is the same)

ADC (ZP),Z	
CMP (ZP),Z	
SBC (ZP),Z	
CPZ IMM	Compare Z register with memory immediate,
CPZ ZP	zero page, and
CPZ ABS	absolute.

3. Loads, Stores, Pushes, Pulls and Transfers

LDA (ZP),Z	formerly (ZP)
LDZ IMM	Load Z register immediate,
LDZ ABS	absolute,
LDZ ABS,X	absolute,X.
LDA (d,SP),Y	Load Accum via stack vector indexed by Y
STA (d,SP),Y	and Store
STX ABS,Y	Store X Absolute, Y
STY ABS,X	Store Y Absolute, X
STZ ZP	Store Z register (formerly store zero)
STZ ABS	
STZ ZP,X	
STZ ABS,X	
STA (ZP),Z	formerly (ZP)
PHD IMM	Push Data Immediate (word)
PHD ABS	Push Data Absolute (word)
PHZ	Push Z register onto stack
PLZ	Pull Z register from stack
TAZ	Transfer Accumulator to Z register
TZA	Transfer Z register to Accumulator
TAB	Transfer Accumulator to Base page register
TBA	Transfer Base page register to Accumulator
TSY	Transfer Stack Pointer High byte to Y register and set "byte" stack-pointer mode
TYS	Transfer Y register to Stack Pointer High byte and set "word" stack-pointer mode

2.3.7.2 CPU Operation

The 4502 has the following 8 user registers:

A	accumulator
X	index-X
Y	index-Y
Z	index-Z
B	Base-page
P	Processor status
SP	Stack pointer
PC	Program counter

Accumulator

The accumulator is the only general purpose computational register. It can be used for arithmetic functions add, subtract, shift, rotate, negate, and for Boolean functions and, or, exclusive-or, and bit operations. It cannot, however, be used as an index register.

Index X

The index register X has the largest number of opcodes pertaining to, or using it. It can be incremented, decremented, or compared, but not used for arithmetic or logical (Boolean) operations. It differs from other index registers in that it is the only register that can be used in indexed-indirect or (bp,X) operations. It cannot be used in indirect-indexed or (bp),Y mode.

Index Y

The index register Y has the same computational constraints as the X register, but finds itself in a lot less of the opcodes, making it less generally used. But the index Y has one advantage over index X, in that it can be used in indirect-indexed operations or (bp),Y mode.

Index Z

The index register Z is the most unique, in that it is used in the smallest number of opcodes. It also has the same computation limitations as the X and Y registers, but has an extra feature. Upon reset, the Z register is cleared so that the STZ (store zero) opcodes and non-indexed indirect opcodes from previous 65C02 designs are emulated. The Z register can also be used in indirect-indexed or (bp),Z operations.

Base page B register

Early versions of 6502 microprocessors had a special subset of instructions that required less code and less time to execute. These were referred to as the "zero page" instructions. Since the addressing page was always known, and known to be zero, addresses could be specified as a single byte, instead of two bytes.

The CSG4502 also implements this same "zero page" set of instructions, but goes one step further by allowing the programmer to specify which page is to be the "zero page". Now that the programmer can program this page, it is now, not necessarily page zero, but instead, the "selected page". The term "base page" is used, however.

The B register selects which page will be the "base page", and the user sets it by transferring the contents of the accumulator to it. At reset, the B register is cleared, giving initially a true "zero page".

Processor status P register

The processor status register is an 8-bit register which is used to indicate the status of the microprocessor. It contains 8 processor "flags". Some of the flags are set or reset based on the results of various types of operations. Others are more specific. The flags are...

Flag	Name	Typical indication
N	Negative	result of operation is negative
V	Overflow	result of add or subtract causes signed overflow
E	Extend	disables stack pointer extension
B	Break	interrupt was caused by BRK opcode
D	Decimal	perform add/subtract using BCD math
I	Interrupt	disable IRQ interrupts
Z	Zero	result of operation is zero
C	Carry	operation caused a carry

Stack Pointer SP

The stack pointer is a 16 bit register that has two modes. It can be programmed to be either an 8-bit page programmable pointer, or a full 16-bit pointer. The processor status E bit selects which mode will be used. When set, the E bit selects the 8-bit mode. When reset, the E bit selects the 16-bit mode.

Upon reset, the CSG 4502 will come up in the 8-bit page-programmable mode, with the stack page set to 1. This makes it compatible with earlier 6502 products. The programmer can quickly change the default stack page by loading the Y register with the desired page and transferring its contents to the stack pointer high byte, using the TYS opcode. The 8-bit stack pointer can be set by loading the X register with the desired value, and transferring its contents to the stack pointer low byte, using the TXS opcode.

To select the 16-bit stack pointer mode, the user must execute a CLE (for CLear Extend disable) opcode. Setting the 16-bit pointer is done by loading the X and Y registers with the desired stack pointer low and high bytes, respectively, and then transferring their contents to the stack pointer using TXS and TYS. To return to 8-bit page mode, simple execute a SEE (SEt Extend disable) opcode.

```
************************************************************
*                          WARNING                         *
*                                                          *
*  If you are using Non-Maskable-Interrupts, or Interrupt  *
*  Request is enabled, and you want to change BOTH stack   *
*  pointer bytes, do not put any code between the TXS and  *
*  TYS opcodes. Taking this precaution will prevent any    *
*  interrupts from occuring between the setting of the two *
*  stack pointer bytes, causing a potential for writing    *
*  stack data to an unwanted area.                         *
************************************************************
```

Program Counter PC

The program counter is a 16-bit up-only counter that determines what area of memory that program information will be fetched from. The user generally only modifies it using jumps, branches, subroutine calls, or returns. It is set initially, and by interrupts, from vectors at memory addresses FFFA through FFFF (hex). See "Interrupts" below.

2.3.7.3 65CE02 Interrupts

There are four basic interrupt sources on the CSG 4502. These are RES*, IRQ*, NMI*, and SO, for Reset, Interrupt Request, Non-Maskable

Interrupt, and Set Overflow. The Reset is a hard non-recoverable interrupt that stops everything. The IRQ is a "maskable" interrupt, in that its occurance can be prevented. The NMI is "non-maskable", and if such an event occurs, cannot be prevented. The SO, or Set Overflow, is not really an interrupt, but causes an externally generated condition, which can be used for control of program flow.

One important design feature, which must be remembered is that no interrupt can occur immediately after a one-cycle opcode. This is very important, because there are times when you want to temporarily prevent interrupts from occurring. The best example of this is, when setting a 16-bit stack pointer, you do not want an interrupt to occur between the times you set the low-order byte, and the high-order byte. If it could happen, the interrupt would do stack writes using a pointer that was only partially set, thus, writing to an unwanted area.

IRQ*

The IRQ* (Interrupt ReQuest) input will cause an interrupt, if it is at a low logic level, and the I processor status flag is reset. The interrupt sequence will begin with the first SYNC after a multiple-cycle opcode. The two program counter bytes PCH and PCL, and the processor status register P, are pushed onto the stack. (This causes the stack pointer SP to be decremented by 3.) Then the program counter bytes PCL and PCH are loaded from memory addresses FFFE and FFFF, respectively.

An interrupt caused by the IRQ* input, is similar to the BRK opcode, but differs, as follows. The program counter value stored on the stack points to the opcode that would have been executed, had the interrupt not occurred. On return from interrupt, the processor will return to that opcode. Also, when the P register is pushed onto the stack, the B or "break" flag pushed, is zero, to indicate that the interrupt was not software generated.

NMI*

The NMI* (Non-Maskable Interrupt) input will cause an interrupt after receiving a high to low transition The interrupt sequence will begin with the first SYNC after a multiple-cycle opcode. NMI* inputs cannot be masked by the processor status register I flag. The two program counter bytes PCH and PCL, and the processor status register P, are pushed onto the stack. (This causes the stack pointer SP to be decremented by 3.) Then the program counter bytes PCL and PCH are loaded from memory addresses FFFA and FFFB.

As with IRQ*, when the P register is pushed onto the stack, the B or "break" flag pushed, is zero, to indicate that the interrupt was not software generated.

RES*

The RES* (reset) input will cause a hard reset instantly as it is brought to a low logic level. This effects the following conditions. The currently executing opcode will be terminated. The B and Z registers will be cleared. The stack pointer will be set to "byte" mode, with the stack page set to page 1. The processor status bits E and I will be set.

The RES* input should be held low for at least 2 clock cycles. But once brought high, the reset sequence begins on the CPU cycle. The first four cycles of the reset sequence do nothing. Then the program counter bytes PCL and PCH are loaded from memory addresses FFFC and FFFD, and normal program execution begins.

SO

The SO (set overflow) input does, as its name implies, set the overflow or V processor status flag. The effect is immediate as this active low signal is brought or held at a low logic level. Care should be taken if this signal is used, as some of the opcodes can set or reset the overflow flag, as well. NOTE: The SO pin has been removed for C65.

2.3.7.4 65CE02 Addressing Modes

It should be noted that all 8-bit addresses are referred to as "byte" addresses, and all 16-bit addresses are referred to as "word" addresses. In all word addresses, the low-order byte of the address is fetched from the lower of two consecutive memory addresses, and the high-order byte of the address is fetched the higher of the two. So, in all operations, the low-order address is fetched first.

Implied OPR

The register or flag affected is identified entirely by the opcode in this (usually) single cycle instruction. In this document, any implied operation, where the implied register is not explicitly declared, implies the accumulator. Example: INC with no arguments implies "increment the accumulator".

Immediate (byte, word) OPR #xx

The data used in the operation is taken from the byte or bytes immediately following the opcode in the 2-byte or 3-byte instruction.

Base Page OPR bp (formerly Zero Page)

The second byte of the two-byte instruction contains the low-order address byte, and the B register contains the high-order address byte of the memory location to be used by the operation.

Base Page, indexed by X OPR bp,X (formerly Zero Page,X)

The second byte of the two-byte instruction is added to the X index register to form the low-order address byte, and the B register contains the high-order address byte of the memory location to be used by the operation.

Base Page, indexed by Y OPR bp,Y (formerly Zero Page,Y)

The second byte of the two-byte instruction is added to the Y index register to form the low-order address byte, and the B register contains the high-order address byte of the memory location to be used by the operation.

Absolute OPR abs

The second and third bytes of the three-byte instruction contain the low-order and high-order address bytes, respectively, of the memory location to be used by the operation.

Absolute, indexed by X OPR abs,X

The second and third bytes of the three-byte instruction are added to the unsigned contents of the X index register to form the low-order and high-order address bytes, respectively, of the memory location to be used by the operation.

Absolute, indexed by Y OPR abs,Y

The second and third bytes of the three-byte instruction are added to the unsigned contents of the Y index register to form the low-order and high-order address bytes, respectively, of the memory location to be used by the operation.

Indirect (word)   OPR (abs)   (JMP and JSR only)

The second and third bytes of the three-byte instruction contain the low-order and high-order address bytes, respectively, of two memory locations containing the low-order and high-order JMP or JSR addresses, respectively.

Indexed by X, indirect (byte)   OPR (bp,X)   (formerly (zp,X))

The second byte of the two-byte instruction is added to the contents of the X register to form the low-order address byte, and the contents of the B register contains the high-order address byte, of two memory locations that contain the low-order and high-order address of the memory location to be used by the operation.

Indexed by X, indirect (word).   OPR (abs,X)   (JMP and JSR only)

The second and third bytes of the three-byte instruction are added to the unsigned contents of the X index register to form the low-order and high-order address bytes, respectively, of two memory locations containing the low-order and high-order JMP or JSR address bytes.

Indirect, indexed by Y   OPR (bp),Y   (formerly (zp),Y)

The second byte of the two-byte instruction contains the low-order byte, and the B register contains the high-order address byte of two memory locations whose contents are added to the unsigned Y index register to form the address of the memory location to be used by the operation.

Indirect, indexed by Z   OPR (bp),Z   (formerly (zp))

The second byte of the two-byte instruction contains the low-order byte, and the B register contains the high-order address byte of two memory locations whose contents are added to the unsigned Z index register to form the address of the memory location to be used by the operation.

Stack Pointer Indirect, indexed by Y   OPR (d,SP),Y   (new)

The second byte of the two-byte instruction contains an unsigned offset value, d, which is added to the stack pointer (word) to form the address of two memory locations whose contents are added to the unsigned Y register to form the address of the memory location to be used by the operation.

Relative (byte)   Bxx LABEL   (branches only)

The second byte of the two-byte branch instruction is sign-extended to a full word and added to the program counter (now containing the opcode address plus two). If the condition of the branch is true, the sum is stored back into the program counter.

Relative (word)   Bxx LABEL   (branches only)

The second and third bytes of the three-byte branch instruction are added to the low-order and high-order program counter bytes, respectively. (the program counter now contains the opcode address plus two). If the condition of the branch is true, the sum is stored back into the program counter.

2.3.7.5 65CE02 Instruction Set

Add memory to accumulator with carry **ADC**

A=A+M+C

Addressing Mode	Abbrev.	Opcode
immediate	IMM	69
base page	BP	65
base page indexed X	BP,X	75
absolute	ABS	6D
absolute indexed X	ABS,X	7D
absolute indexed Y	ABS,Y	79
base page indexed indirect X	(BP,X)	61
base page indirect indexed Y	(BP),Y	71
base page indirect indexed Z	(BP),Z	72

Bytes	Cycles	Mode
2	2	immediate
2	3	base page non-indexed, or indexed X or Y
3	4	absolute non-indexed, or indexed X or Y
2	5	base page indexed indirect X, or indirect indexed Y or Z

The ADC instructions add data fetched from memory and carry to the contents of the accumulator. The results of the add are then stored in the accumulator. If the "D" or Decimal Mode flag, in the processor status register, then a Binary Coded Decimal (BCD) add is performed.

The "N" or Negative flag will be set if the sum is negative, otherwise it is cleared. The "V" or Overflow flag will be set if the sign of the sum is different from the sign of both addends, indicating a signed overflow. Otherwise, it is cleared. The "Z" or Zero flag is set if the sum (stored into the accumulator) is zero, otherwise, it is cleared. The "C" or carry is set if the sum of the unsigned addends exceeds 255 (binary mode) or 99 (decimal mode).

Flags

N	V	E	B	D	I	Z	C
N	V	-	-	-	-	Z	C

And memory logically with accumulator **AND**

A=A.and.M

Addressing Mode	Abbrev.	Opcode
immediate	IMM	29
base page	BP	25
base page indexed X	BP,X	35
absolute	ABS	2D
absolute indexed X	ABS,X	3D
absolute indexed Y	ABS,Y	39
base page indexed indirect X	(BP,X)	21
base page indirect indexed Y	(BP),Y	31
base page indirect indexed Z	(BP),Z	32

Bytes	Cycles	Mode
2	2	immediate
2	3	base page non-indexed, or indexed X or Y
3	4	absolute non-indexed, or indexed X or Y
2	5	base page indexed indirect X, or indirect indexed Y or Z

The AND instructions perform a logical "and" between data bits fetched from memory and the accumulator bits. The results are then stored in the accumulator. For each accumulator and corresponding memory bit that are both logical 1's, the result is a 1. Otherwise it is 0.

The "N" or Negative flag will be set if the bit 7 result is a 1. Otherwise it is cleared. The "Z" or Zero flag is set if all result bits are zero, otherwise, it is cleared.

Flags

N	V	E	B	D	I	Z	C
N	-	-	-	-	-	Z	-

Arithmetic shifts, memory or accumulator, left or right **ASL ASR ASW**

ASL	Arithmetic shift left A or M	A<A<<1 or M<M<<1
ASR	Arithmetic shift right A or M	A<A>>1 or M<M>>1
ASW	Arithmetic shift left M (word)	Mx<Mw<<1

		Opcodes		
Addressing Mode	Abbrev.	ASL	ASR	ASW
register (A)		0A	43	
base page	BP	06	44	
base page indexed X	BP,X	16	54	
absolute	ABS	0E		CB
absolute indexed X	ABS,X	1E		

Bytes	Cycles	Mode
1	1	register (ASL)
1	2	register (ASR)
2	4	base page (byte) non-indexed, or indexed X
3	5	absolute non-indexed, or indexed X
3	7	absolute (ASW)

The ASL instructions shift a single byte of data in memory or the accumulator left (towards the most significant bit) one bit position. A 0 is shifted into bit 0.

The "N" or Negative bit will be set if the result bit 7 is (operand bit 6 was) a 1. Otherwise, it is cleared. The "Z" or Zero flag is set if ALL result bits are zero. The "C" or Carry flag is set if the bit shifted out is (operand bit 7 was) a 1. Otherwise, it is cleared.

The ASR instructions shift a single byte of data in memory or the accumulator right (towards the least significant bit) one bit position. Since this is an arithmetic shift, the sign of the operand will be maintained.

The "N" or Negative bit will be set if bit 7 (operand and result) a 1. Otherwise, it is cleared. The "Z" or Zero flag is set if ALL result bits are zero. The "C" or Carry flag is set if the bit shifted out is (operand bit 0 was) a 1. Otherwise, it is cleared.

The ASW instruction shifts a word (two bytes) of data in memory left (towards the most significant bit) one bit position. A zero is shifted into bit 0.

The "N" or Negative bit will be set if the result bit 15 is (operand bit 14 was) a 1. Otherwise, it is cleared. The "Z" or Zero flag is set if ALL result bits (both bytes) are zero. The "C" or Carry flag is set if the bit shifted out is (operand bit 15 was) a 1. Otherwise, it is cleared.

Flags

N	V	E	B	D	I	Z	C
N	-	-	-	-	-	Z	C

Branch conditional or unconditional

BCC BCS BEQ BMI BNE
BPL BRA BVC BVS

Opcode Title	Opcode Byte Relative	Opcode Word Relative	Opcode Purpose
BCC	90	93	Branch if Carry Clear
BCS	B0	B3	Branch if Carry Set
BEQ	F0	F3	Branch if EQual (Z flag set)
BMI	30	33	Branch if MInus (N flag set)
BNE	D0	D3	Branch if Not Equal (Z flag clear)
BPL	10	13	Branch if PLus (N flag clear)
BRA	80	83	BRanch Always
BVC	50	53	Branch if oVerflow Clear
BVS	70	73	Branch if oVerflow Set

Bytes	Cycles	Mode
2	2	byte-relative
3	3	word-relative

All branches of this type are taken, if the condition indicated by the opcode is true. All branch relative offsets are referenced to the branch opcode location+2. This means that for byte-relative, the offset is relative to the location after the two instruction bytes. For word-relative, the offset is relative to the last of the three instruction bytes.

Flags

N	V	E	B	D	I	Z	C
-	-	-	-	-	-	-	-

Break (force an interrupt)

BRK

Bytes	Cycles	Mode	Opcode	
2	7	implied	00	(stack)<PC+1w,P SP<SP-2

The BRK instruction causes the processor to enter the IRQ or Interrupt ReQuest state. The program counter (now incremented by 2), bytes PCH and PCL, and the processor status register P, are pushed onto the stack. (This causes the stack pointer SP to be decremented by 3.) Then the program, counter bytes PCL and PCH are loaded from memory addresses FFFE and FFFF, respectively.

The BRK differs from an externally generated interrupt request (IRQ) as follows. The program counter value stored on the stack is PC+2, or the address of the BRK opcode+2. On return from interrupt, the processor will return to the BRK address+2, thus skipping the opcode byte, and a following "dummy" byte. A normal IRQ will not add 2, so that a return will execute the interrupted opcode. Also, when the P register is pushed onto the stack, the B or "break" flag is set, to indicate that the interrupt was software generated. All outside interrupts push P with the B flag cleared.

Flags

N	V	E	B	D	I	Z	C
-	-	-	-	-	-	-	-

Branch to subroutine

BSR

Bytes	Cycles	Mode	Opcode	
3	5	word-relative	63	(stack)<PC+2w SP<SP-2

The BSR Branch to SubRoutine instruction pushes the two program counter bytes PCH and PCL onto the stack. It then adds the word-relative signed offset to the program counter. The relative offset is referenced to the address of the BSR opcode+2, hence, it is relative to the third byte of the three-byte BSR instruction. The return address, on the stack, also points to this address. This was done to make it compatible with the RTS functionality, and to be consistant will other word-relative operations.

Flags							
N	V	E	B	D	I	Z	C
-	-	-	-	-	-	-	-

Clear processor status bits

CLC CLD CLE CLI CLV

		Opcode	Cycles	Flags							
				N	V	E	B	D	I	Z	C
CLC	Clear the Carry bit	18	1	-	-	-	-	-	-	-	R
CLD	Clear the Decimal mode bit	D8	1	-	-	-	-	R	-	-	-
CLE	Clear stack Extend disable bit	02	2	-	-	R	-	-	-	-	-
CLI	Clear Interrupt disable bit	58	2	-	-	-	-	-	R	-	-
CLV	Clear the Oveflow bit	B8	1	-	R	-	-	-	-	-	-

Bytes	Mode
1	implied

All of the P register bit clear intructions are a single byte long. Most of them require a single CPU cycle. The CLI and CLE require 2 cycles. The purpose of extending the CLI to 2 cycles, is to enable an interrupt to occur immediately, if one is pending. Interrupts cannot occur after single cycle instructions.

Compare registers with memory CMP CPX CPY CPZ

CMP	Compare accumulator with memory	(A-M)
CPX	Compare index X with memory	(X-M)
CPY	Compare index Y with memory	(Y-M)
CPZ	Compare index Z with memory	(Z-M)

		Opcodes			
Addressing Mode	Abbrev.	CMP	CPX	CPY	CPZ
immediate	IMM	C9	E0	C0	C2
base page	BP	C5	E4	C4	D4
base page indexed X	BP,X	D5			
absolute	ABS	CD	EC	CC	DC
absolute indexed X	ABS,X	DD			
absolute indexed Y	ABS,Y	D9			
base page indexed indirect X	(BP,X)	C1			
base page indirect indexed Y	(BP),Y	D1			
base page indirect indexed Z	(BP),Z	D2			

Bytes	Cycles	Mode
2	2	immediate
2	3	base page non-indexed, or indexed X or Y
3	4	absolute non-indexed, or indexed X or Y
2	5	base page indexed indirect X, or indirect indexed Y or Z

Compares are performed by subtracting a value in memory from the register being tested. The results are not stored in any register, except the following status flags are updated.

The "N" or Negative flag will be set if the result is negative (assuming signed operands), otherwise it is cleared. The "Z" or Zero flag is set if the result is zero, otherwise it is cleared. The "C" or carry flag is set if the unsigned register value is greater than or equal to the unsigned memory value.

Flags							
N	V	E	B	D	I	Z	C
N	-	-	-	-	-	Z	C

Compare registers with memory CMP CPX CPY CPZ

CMP	Compare accumulator with memory	(A-M)
CPX	Compare index X with memory	(X-M)
CPY	Compare index Y with memory	(Y-M)
CPZ	Compare index Z with memory	(Z-M)

		Opcodes			
Addressing Mode	Abbrev.	CMP	CPX	CPY	CPZ
immediate	IMM	C9	E0	C0	C2
base page	BP	C5	E4	C4	D4
base page indexed X	BP,X	D5			
absolute	ABS	CD	EC	CC	DC
absolute indexed X	ABS,X	DD			
absolute indexed Y	ABS,Y	D9			
base page indexed indirect X	(BP,X)	C1			
base page indirect indexed Y	(BP),Y	D1			
base page indirect indexed Z	(BP),Z	D2			

Bytes	Cycles	Mode
2	2	immediate
2	3	base page non-indexed, or indexed X or Y
3	4	absolute non-indexed, or indexed X or Y
2	5	base page indexed indirect X, or indirect indexed Y or Z

Compares are performed by subtracting a value in memory from the register being tested. The results are not stored in any register, except the following status flags are updated.

The "N" or Negative flag will be set if the result is negative (assuming signed operands), otherwise it is cleared. The "Z" or Zero flag is set if the result is zero, otherwise it is cleared. The "C" or carry flag is set if the unsigned register value is greater than or equal to the unsigned memory value.

Flags

N	V	E	B	D	I	Z	C
N	-	-	-	-	-	Z	C

Exclusive OR accumulator logically with memory **EOR**

A=A.or.M.and..not.(A.and.M)

Addressing Mode	Abbrev.	Opcode
immediate	IMM	49
base page	BP	45
base page indexed X	BP,X	55
absolute	ABS	4D
absolute indexed X	ABS,X	5D
absolute indexed Y	ABS,Y	59
base page indexed indirect X	(BP,X)	41
base page indirect indexed Y	(BP),Y	51
base page indirect indexed Z	(BP),Z	52

Bytes	Cycles	Mode
2	2	immediate
2	3	base page non-indexed, or indexed X or Y
3	4	absolute non-indexed, or indexed X or Y
2	5	base page indexed indirect X, or indirect indexed Y or Z

The EOR instructions perform an "exclusive or" between bits fetched from memory and the accumulator bits. The results are then stored in the accumulator. For each accumulator or corresponding memory bit that are different (one 1, and one 0) the result is a 1. Otherwise it is 0.

The "N" or Negative flag will be set if the bit 7 result is a 1. Otherwise it is cleared. The "Z" or Zero flag is set if all result bits are zero, otherwise, it is cleared.

Flags							
N	V	E	B	D	I	Z	C
N	-	-	-	-	-	Z	-

Jump to subroutine

JSR

Addressing Mode	Abbrev.	Opcode	bytes	cycles
absolute	ABS	20	3	5
absolute indirect	(ABS)	22	3	7
absolute indexed indirect X	(ABS,X)	23	3	7

The JSR Jump to SubRoutine instruction pushes the two program counter bytes PCH and PCL onto the stack. It then loads the program counter with the new address. The return address, stored on the stack, is actually the address of the JSR opcode+2, or is pointing to the third byte of the three-byte JSR instruction.

Flags

N	V	E	B	D	I	Z	C
-	-	-	-	-	-	-	-

Load registers

LDA LDX LDY LDZ

LDA	Load Accumulator from memory	A<M
LDX	Load index X from memory	X<M
LDY	Load index Y from memory	Y<M
LDZ	Load index Z from memory	Z<M

Addressing Mode	Abbrev.	LDA	LDX	LDY	LDZ
immediate	IMM	A9	A2	A0	A3
base page	BP	A5	A6	A4	
base page indexed X	BP,X	B5		B4	
base page indexed Y	BP,Y		B6		
absolute	ABS	AD	AE	AC	AB
absolute indexed X	ABS,X	BD		BC	BB
absolute indexed Y	ABS,Y	B9	BE		
base page indexed indirect X	(BP,X)	A1			
base page indirect indexed Y	(BP),Y	B1			
base page indirect indexed Z	(BP),Z	B2			
stack vector indir indexed Y	(d,SP),Y	E2			

Bytes	Cycles	Mode
2	2	immediate
2	3	base page non-indexed, or indexed X or Y
3	4	absolute non-indexed, or indexed X or Y
2	5	base page indexed indirect X, or indirect indexed Y or Z
2	6	stack vector indirect indexed Y

These instructions load the specified register from memory. The "N" or Negative flag will be set if the bit 7 loaded is a 1. Otherwise it is cleared. The "Z" or Zero flag is set if all bits loaded are zero, otherwise, it is cleared.

Flags

N	V	E	B	D	I	Z	C
7	-	-	-	-	-	Z	-

Negate (twos complement) accumulator

NEG

A=-A

Addressing Mode	Opcode	Bytes	Cycles
implied	42	1	2

The NEG or "negate" instruction performs a two's-complement inversion of the data in the accumulator. For example, 1 becomes -1, -5 becomes 5, etc. The same can be achieved by subtracting A from zero.

The "N" or Negative flag will be set if the accumulator bit 7 becomes a 1. Otherwise it is cleared. The "Z" or Zero flag is set if the accumulator is (and was) zero.

Flags

N	V	E	B	D	I	Z	C
N	-	-	-	-	-	Z	-

No-operation

NOP

Addressing Mode	Opcode	Bytes	Cycles
implied	EA	1	1

The NOP no-operation instruction has no effect, unless used following a MAP opcode. Then its is interpreted as a EOM end-of-map instruction. (See EOM)

Flags

N	V	E	B	D	I	Z	C
-	-	-	-	-	-	-	-

Or memory logically with accumulator ORA

A=A.or.M

Addressing Mode	Abbrev.	Opcode
immediate	IMM	09
base page	BP	05
base page indexed X	BP,X	15
absolute	ABS	0D
absolute indexed X	ABS,X	1D
absolute indexed Y	ABS,Y	19
base page indexed indirect X	(BP,X)	01
base page indirect indexed Y	(BP),Y	11
base page indirect indexed Z	(BP),Z	12

Bytes	Cycles	Mode
2	2	immediate
2	3	base page non-indexed, or indexed X or Y
3	4	absolute non-indexed, or indexed X or Y
2	5	base page indexed indirect X, or indirect indexed Y or Z

The ORA instructions perform a logical "or" between data bits fetched from memory and the accumulator bits. The results are then stored in the accumulator. For either accumulator or corresponding memory bit that is a logical 1's, the result is a 1. Otherwise it is 0.

The "N" or Negative flag will be set if the bit 7 result is a 1. Otherwise it is cleared. The "Z" or Zero flag is set if all result bits are zero, otherwise, it is cleared.

Flags

N	V	E	B	D	I	Z	C
N	-	-	-	-	-	Z	-

Pull register data from stack

PLA PLP PLX PLY PLZ

		Opcode
PLA	Pull Accumulator from stack	68
PLX	Pull index X from stack	FA
PLY	Pull index Y from stack	7A
PLZ	Pull index Z from stack	FB
PLP	Pull Processor status from stack	28

Bytes	Cycles	Mode
1	3	register

The Pull register operations, first, increment the stack pointer SP, and then, load the specified register with data from the stack.

Except in the case of PLP, the "N" or Negative flag will be set if the bit 7 loaded is a 1. Otherwise it is cleared. The "Z" or Zero flag is set if all bits loaded are zero, otherwise, it is cleared.

In the case of PLP, all processor flags (P register bits) will be loaded from the stack, except the "B" or "break" flag, which is always a 1, and the "E" or "stack pointer Extend disable" flag, which can only be set by SEE, or cleared by CLE instructions.

Flags

N	V	E	B	D	I	Z	C	
N	-	-	-	-	-	Z	-	(except PLP)
7	6	-	-	3	2	1	0	(PLP only)

Push registers or data onto stack **PHA PHP PHW PHX PHY PHZ**

PHA	Push Accumulator onto stack
PHP	Push Processor status onto stack
PHW	Push a word from memory onto stack
PHX	Push index X onto stack
PHY	Push index Y onto stack
PHZ	Push index Z onto stack

		Opcodes					
Addressing Mode	Abbrev.	PHA	PHP	PHW	PHX	PHY	PHZ
register		48	08		DA	5A	DB
word immediate	IMMw			F4			
word absolute	ABSw			FC			

Bytes	Cycles	Mode
1	3	register
3	5	word immediate
3	7	word absolute

These instructions push either the contents of a register onto the stack, or push two bytes of data from memory (PHW) onto the stack. If a register is pushed, the stack pointer will decrement a single address. If a word from memory is pushed ([SP]<-PC(LO), [SP-1]<-PC(HI)), the stack pointer will decrement by 2. No flags are changed.

Flags

N	V	E	B	D	I	Z	C
-	-	-	-	-	-	-	-

Reset memory bits **RMB**

M=M.and.-bit

Opcode to reset bit

0	1	2	3	4	5	6	7
07	17	27	37	47	57	67	77

Bytes	Cycles	Mode
2	4	base-page

These instructions reset a single bit in base-page memory, as specified by the opcode. No flags are modified.

Flags

N	V	E	B	D	I	Z	C
-	-	-	-	-	-	-	-

Rotate memory or accumulator, left or right **ROL ROR ROW**

ROL	Rotate memory or accumulator left throught carry
ROR	Rotate memory or accumulator right throught carry
ROW	Rotate memory (word) left throught carry

		Opcodes		
Addressing Mode	Abbrev.	ROL	ROR	ROW
register (A)		2A	6A	
base page	BP	26	66	
base page indexed X	BP,X	36	76	
absolute	ABS	2E	6E	EB
absolute indexed X	ABS,X	3E	7E	

Bytes	Cycles	Mode
1	1	register
2	4	base page (byte) non-indexed, or indexed X
3	5	absolute non-indexed, or indexed X
2	6	absolute (word)

The ROL instructions shift a single byte of data in memory or the accumulator left (towards the most significant bit) one bit position. The state of the "C" or "carry" flag is shifted into bit 0.

The "N" or Negative bit will be set if the result bit 7 is (operand bit 6 was) a 1. Otherwise, it is cleared. The "Z" or Zero flag is set if ALL result bits are zero. The "C" or Carry flag is set if the bit shifted out is (operand bit 7 was) a 1. Otherwise, it is cleared.

The ROR instructions shift a single byte of data in memory or the accumulator right (towards the least significant bit) one bit position. The state of the "C" or "carry" flag is shifted into bit 7.

The "N" or Negative bit will be set if bit 7 is (carry was) a 1. Otherwise, it is cleared. The "Z" or Zero flag is set if ALL result bits are zero. The "C" or Carry flag is set if the bit shifted out is (operand bit 0 was) a 1. Otherwise, it is cleared.

The ROW instruction shifts a word (two bytes) of data in memory left (towards the most significant bit) one bit position. The state of the "C" or 'carry" flag is shifted into bit 0.

The "N" or Negative bit will be set if the result bit 15 is (operand bit 14 was) a 1. Otherwise, it is cleared. The "Z" or Zero flag is set if ALL result bits (both bytes) are zero. The "C" or Carry flag is set if the bit shifted out is (operand bit 15 was) a 1. Otherwise, it is cleared.

Flags

N	V	E	B	D	I	Z	C
N	-	-	-	-	-	Z	C

Return from BRK, interrupt, kernal, or subroutine RTI RTN RTS

Operation	description	Opcode	bytes	cycles	
RTI	Return from interrupt	40	1	5	P,PCw<(SP),SP<SP+3
RTN #n	Return from kernal	62	2	7	PCw<(SP)+1,SP<SP+2+N
RTS	Return from subroutine	60	1	4	PCw<(SP)+1,SP<SP+2

The RTI or ReTurn from Interrupt instruction pulls P register data and a return address into program counter bytes PCL and PCH from the stack. The stack pointer SP is resultantly incremented by 3. Execution continues at the address recovered from the stack.

Flags

N	V	E	B	D	I	Z	C	
7	6	-	-	3	2	1	0	(RTI only)

The RTS or ReTurn from Subroutine instruction pulls a return address into program counter bytes PCL and PCH from the stack. The stack pointer SP is resultantly incremented by 2. Execution continues at the address recovered + 1, since BSR and JSR instructions set the return address one byte short of the desire return address.

The RTN or ReTurn from kerNal subroutine is similar to RTS, except that it contains an immediate parameter N indicating how many extra bytes to discard from the stack. This is useful for returning from subroutines which have arguments passed to them on the stack. The stack pointer SP is incremented by 2 + N, instead of by 2, as in RTS.

Flags

N	V	E	B	D	I	Z	C	
-	-	-	-	-	-	-	-	(RTN and RTS)
7	6	-	-	3	2	1	0	(RTI)

Set memory bits

SMB

M=M.or.bit

Opcode to set bit

0	1	2	3	4	5	6	7
87	97	A7	B7	C7	D7	E7	F7

Bytes	Cycles	Mode
2	4	base-page

These instructions set a single bit in base-page memory, as specified by the opcode. No flags are modified.

Flags

N	V	E	B	D	I	Z	C
-	-	-	-	-	-	-	-

Store registers

STA STX STY STZ

STA	Store Accumulator to memory	M<A
STX	Store index X to memory	M<X
STY	Store index Y to memory	M<Y
STZ	Store index Z to memory	M<Z

		Opcodes			
Addressing Mode	Abbrev.	STA	STX	STY	STZ
base page	BP	85	86	84	64
base page indexed X	BP,X	95		94	74
base page indexed Y	BP,Y		96		
absolute	ABS	8D	8E	8C	9C
absolute indexed X	ABS,X	9D		8B	9E
absolute indexed Y	ABS,Y	99	9B		
base page indexed indirect X	(BP,X)	81			
base page indirect indexed Y	(BP),Y	91			
base page indirect indexed Z	(BP),Z	92			
stack vector indir indexed Y	(d,SP),Y	82			

Bytes	Cycles	Mode
2	3	base page non-indexed, or indexed X or Y
3	4	absolute non-indexed, or indexed X or Y
2	5	base page indexed indirect X, or indirect indexed Y or Z
2	6	stack vector indirect indexed Y

These instructions store the specified register to memory. No flags are affected.

Flags

N	V	E	B	D	I	Z	C
-	-	-	-	-	-	-	-

Transfers (between registers)

TAB TAX TAY TAZ
TBA TSX TSY TXA
TXS TYA TYS TZA

Operation Symbol	Code	N	V	E	B	D	I	Z	C	Transfer from	to
TAB	5B	-	-	-	-	-	-	-	-	accumulator	base page reg
TAX	AA	N	-	-	-	-	-	Z	-	accumulator	index X reg
TAY	A8	N	-	-	-	-	-	Z	-	accumulator	index Y reg
TAZ	4B	N	-	-	-	-	-	Z	-	accumulator	index Z reg
TBA	7B	N	-	-	-	-	-	Z	-	base page reg	accumulator
TSX	BA	N	-	-	-	-	-	Z	-	stack ptr low	index X reg
TSY	0B	N	-	-	-	-	-	Z	-	stack ptr high	index Y reg
TXA	8A	N	-	-	-	-	-	Z	-	index X reg	accumulator
TXS	9A	-	-	-	-	-	-	-	-	index X reg	stack ptr low
TYA	98	N	-	-	-	-	-	Z	-	index Y reg	accumulator
TYS	2B	-	-	-	-	-	-	-	-	index Y reg	stack ptr high
TZA	6B	N	-	-	-	-	-	Z	-	index Z reg	accumulator

These instructions transfer the contents of the specified source register to the specified destination register. Any transfer to A, X, Y, or Z will affect the flags as follows. The "N" or "negative" flag will be set if the value moved is negative (bit 7 set), otherwise, it is cleared. The "Z" or "zero" flag will be set if the value moved is zero (all bits 0), otherwise, it is cleared. Any transfer to SPL or SPH will not alter any flags.

```
**************************************************************
*                          WARNING                           *
*                                                            *
*  If you are using Non-Maskable-Interrupts, or Interrupt    *
*  Request is enabled, and you want to change BOTH stack     *
*  pointer bytes, do not put any code between the TXS and    *
*  TYS opcodes. Taking this precaution will prevent any      *
*  interrupts from occuring between the setting of the two   *
*  stack pointer bytes, causing a potential for writing      *
*  stack data to an unwanted area.                           *
**************************************************************
```

Bytes	Cycles	Mode
1	1	register

Test and reset or set memory bits

TRB	Test and reset memory bits with accumulator	(M.or.A),M<M.and.-A
TSB	Test and set memory bits with accumulator	(M.or.A),M<M.or.A

		Opcodes	
Addressing Mode	Abbrev.	TRB	TSB
base page	BP	14	04
absolute	ABS	1C	0C

These instructions test and set or reset bits in memory, using the accumulator for both a test mask, and a set or reset mask. First, a logical AND is performed between memory and the accumulator. The "Z" or "zero" flag is set if all bits of the result of the AND are zero. Otherwise it is reset.

The TSB then performs a logical OR between the bits of the accumulator and the bits in memory, storing the result back into memory.

The TRB, instead, performs a logical AND between the inverted bits of the accumulator and the bits in memory, storing the result back into memory.

Bytes	Cycles	Mode
2	4	base page non-indexed
3	5	absolute non-indexed

Flags

N	V	E	B	D	I	Z	C
-	-	-	-	-	-	Z	-

2.3.7.6 4502 Opcode Table

0	1	2	3	4	5	6	7	8	9	A	B	C	D	E	F	
BRK	ORA INDX	CLE └	SEE └	TSB ZP	ORA ZP	ASL ZP	RMB0 ZP	PHP	ORA IMM	ASL	TSY └	TSB ABS	ORA ABS	ASL ABS	BBR0 ZP	0
BPL REL	ORA INDY	ORA INDZ	BPL └ WREL	TRB ZPX	ORA ZPX	ASL ZPX	RMB1 ZP	CLC	ORA ABSY	INC	INZ └	TRB ABS	ORA ABSX	ASL ABSX	BBR1 ZP	1
JSR ABS	AND INDX	JSR └ IND	JSR └ INDX	BIT ZP	AND ZP	ROL ZP	RMB2 ZP	PLP	AND IMM	ROL	TYS └	BIT ABS	AND ABS	ROL ABS	BBR2 ZP	2
BMI REL	AND INDY	AND INDZ	BMI └ WREL	BIT ZPX	AND ZPX	ROL ZPX	RMB3 ZP	SEC	AND ABSY	DEC	DEZ └	BIT ABSX	AND ABSX	ROL ABSX	BBR3 ZP	3
RTI	EOR INDX	NEG └	ASR └	ASR └ ZP	EOR ZP	LSR ZP	RMB4 ZP	PHA	EOR IMM	LSR	TAZ └	JMP ABS	EOR ABS	LSR ABS	BBR4 ZP	4
BVC REL	EOR INDY	EOR INDZ	BVC └ WREL	ASR └ ZPX	EOR ZPX	LSR ZPX	RMB5 ZP	CLI	EOR ABSY	PHY	TAB └	MAP └	EOR ABSX	LSR ABSX	BBR5 ZP	5
RTS	ADC INDX	RTN └	BSR └ WREL	STZ ZP	ADC ZP	ROR ZP	RMB6 ZP	PLA	ADC IMM	ROR	TZA └	JMP IND	ADC ABS	ROR ABS	BBR6 ZP	6
BVS REL	ADC INDY	ADC INDZ	BVS └ WREL	STZ ZPX	ADC ZPX	ROR ZPX	RMB7 ZP	SEI	ADC ABSY	PLY	TBA └	JMP INDX	ADC ABSX	ROR ABSX	BBR7 ZP	7
BRU REL	STA INDX	STA └ IDSP	BRU └ WREL	STY ZP	STA ZP	STX ZP	SMB0 ZP	DEY	BIT IMM	TXA	STY └ ABSX	STY ABS	STA ABS	STX ABS	BBS0 ZP	8
BCC REL	STA INDY	STA INDZ	BCC └ WREL	STY ZPX	STA ZPX	STX ZPY	SMB1 ZP	TYA	STA ABSY	TXS	STX └ ABSY	STZ ABS	STA ABSX	STZ ABSX	BBS1 ZP	9
LDY IMM	LDA INDX	LDX IMM	LDZ └ IMM	LDY ZP	LDA ZP	LDX ZP	SMB2 ZP	TAY	LDA IMM	TAX	LDZ └ ABS	LDY ABS	LDA ABS	LDX ABS	BBS2 ZP	A
BCS REL	LDA INDY	LDA INDZ	BCS └ WREL	LDY ZPX	LDA ZPX	LDX ZPY	SMB3 ZP	CLV	LDA ABSY	TSX	LDZ └ ABSX	LDY ABSX	LDA ABSX	LDX ABSY	BBS3 ZP	B
CPY IMM	CMP INDX	CPZ └ IMM	DEW └ ZP	CPY ZP	CMP ZP	DEC ZP	SMB4 ZP	INY	CMP IMM	DEX	ASW └ ABS	CPY ABS	CMP ABS	DEC ABS	BBS4 ZP	C
BNE REL	CMP INDY	CMP INDZ	BNE └ WREL	CPZ └ ZP	CMP ZPX	DEC ZPX	SMB5 ZP	CLD	CMP ABSY	PHX	PHZ └	CPZ └ ABS	CMP ABSX	DEC ABSX	BBS5 ZP	D
CPX IMM	SBC INDX	LDA └ IDSP	INW └ ZP	CPX ZP	SBC ZP	INC ZP	SMB6 ZP	INX	SBC IMM	EOM NOP	ROW └ ABS	CPX ABS	SBC ABS	INC ABS	BBS6 ZP	E
BEQ REL	SBC INDY	SBC INDZ	BEQ └ WREL	PHD └ IMM	SBC ZPX	INC ZPX	SMB7 ZP	SED	SBC ABSY	PLX	PLZ └	PHD └ ABS	SBC ABSX	INC ABSX	BBS7 ZP	F

2.4 The CSG 4567 System/Video Controller

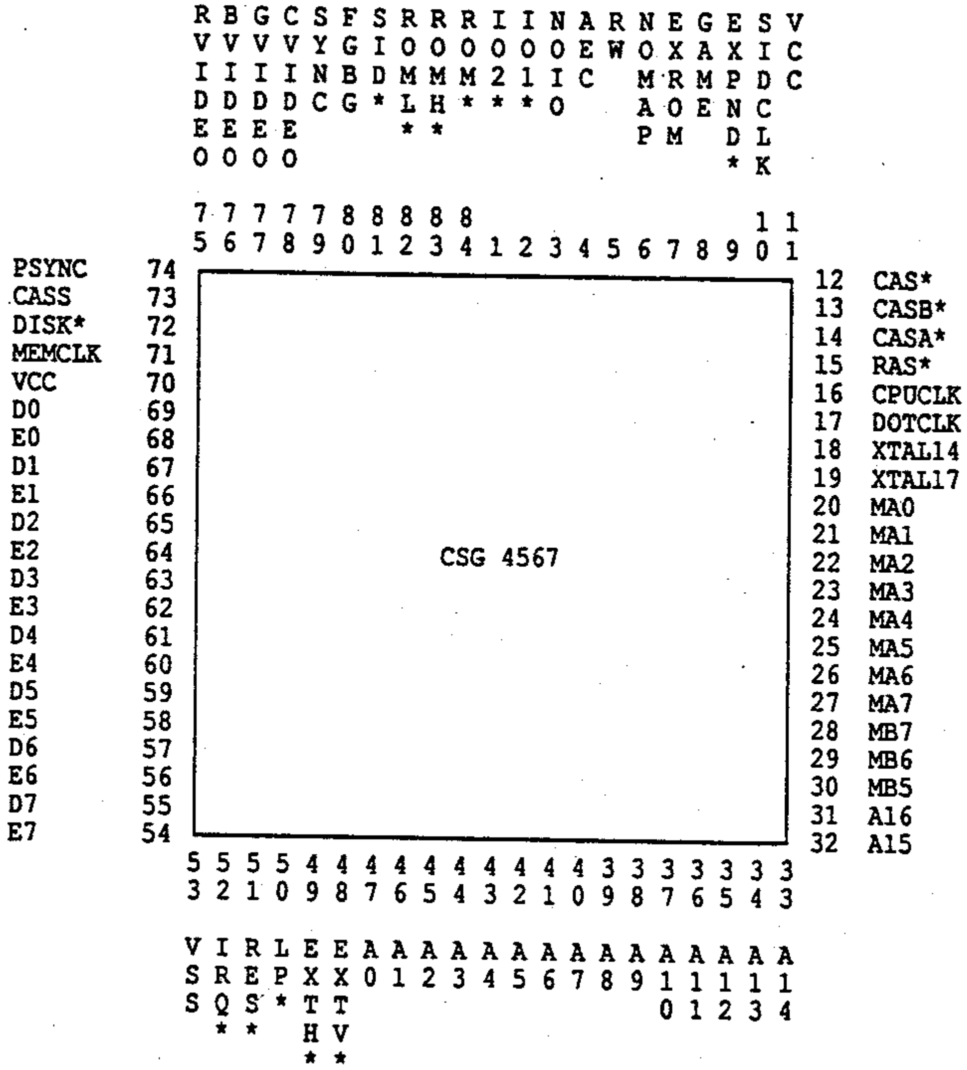
2.4.1 Description

The CSG 4567 is a low-cost high-peformance system/video controller, designed to be used in a wide variety of low-end home-computer type systems ranging from joystick controlled video games to high-end home-productivity machines with built-in disk drives and monitor. The 4567 was designed with Commodore-64 (C64) architecture as a subset of its advanced features. In addition to having all of the C64 video modes, it also supports the character attributes - blink, bold, reverse video, and underline, and can display any of the new or old video modes in 80 column or 640 horizontal pixel format, as well as the older 40 column 320 pixel format.

A new "bitplane" video mode was added to allow the displaying of true bitplane type video, with up to eight bitplanes in 320 pixel mode and up to four in 640 pixel mode. The 4567 can also time-multiplex the bitplanes to give a true four-color 1280 pixel picture. Vertical resolution is maintained at 200 lines as standard, but can be doubled to 400 with interlace.

2.4.2 CSG 4567 Pin Assignments

(*** Pinout will change with 4567R7 ***)



2.4.3 CSG 4567 Operation

The 4567 accesses two 8-bit memory blocks, which are up to 64K each, via two 8-bit bidirectional busses. These are D0-D7 and E0-E7. The D0-D7 bus is common with the CPU chip, ROM, SID, and the expansion port, and is used for system memory and bitplanes. The E0-E7 port is only connected to RAM. This RAM is used for COLOR RAM, attribute RAM, system memory, and bitplanes.

To access these RAMs, the 4567 has two multiplexed address busses. These are MA0-MA7, and MB5-MB7. Lines MA0-MA4 are common to both 64K banks of RAM, but MA5-MA7 go only to bank A, and MB5-MB7 go only to bank B.

There are four types of DMA accesses which the 4567 can perform. Remember that RAS* is asserted on every memory clock cycle. These are...

mode	operation	CASA*	CASB*	ROM*
1. 4567	reading both banks.	X	X	
2. 4567	reading bank "A"	X		
3. 4567	reading ROM			X
4. 4567	doing refresh.			

There are six types of CPU routings to RAM and peripheral devices that re handled by the 4567.

mode	operation	CASA*	CASB*	ROM*
2. CPU	reading bank "A".	X		
3. CPU	reading bank "B".		X	
4. CPU	writing bank "A".	X		
5. CPU	writing bank "B".		X	
6. CPU	reading ROM			X
7. CPU	accessing I/O1, I/O2, SID, ROMH, ROML			

There are four basic data routings through the 4567 chip. Three internal signals rout the data busses. WTREG (write 4567 register) enables routing the external D0-D7 bus to the internal register data bus. It is normally a logic 1. When it is brought low, the internal bus disconnects, and the D0-D7 bus output drivers turn on. This is for CPU reads of 4567 registers or "B" bank RAM. DBMEM (read "B" bank memory) routs the E0-E7 data bus to the inputs of the 0-D7 bus output drivers when at logic level 1. This is for CPU reads of "B" bank RAM. When 0, (normal) the internal register data bus is routed to the D0-D7 bus output driver inputs, instead. WTBMEM (write B" bank memory) turns on the E0-E7 bus drivers, which directly routs the D0-D7 data bus to the E0-E7 bus when 1. This is for CPU writes to the "B" bank RAM. When 0, (normal) the 0-E7 bus is input only.

mode	operation	Wtreg	RdBmem	WtBmem	
1.	CPU write 4567 register, CPU access external, 4567 DMA, etc	1	0	0	(default)
2.	CPU read 4567 register	0	0	0	
3.	CPU read B RAM	0	1	0	
4.	CPU write B RAM	1	0	1	

VMF -- Video Matrix Fetch

The 4567 performs Video Matrix Fetches, during displayed video times, in all of the original VIC-II modes (SCM, MCM, ECM, BMM). This is true for both 40 and 80 column (320 and 640 pixel) modes. During VMF, the 4567 reads both banks (A & B) of memory over both data busses D0-D7 and E0-E7. The D0-D7 bus provides the video matrix data, E0-E3 provides color data, and E4-E7 provides character attribute data.

CDF -- Character Data Fetch

The 4567 performs Character Data Fetches immediately after each Video Matrix Fetch in the original VIC-II modes except bitmap mode. During this fetch Character image data is fetched from ROM or RAM bank A over the D0-D7 bus.

BMF -- BitMap Fetch

The 4567 performs Bitmap Data Fetches immediately after each Video Matrix Fetch, only in the bitmap mode. During this fetch, Bitmap image data is fetched from RAM bank A over the D0-D7 bus.

BPF -- BitPlane Fetch

The 4567 can perform Bitplane image fetches during displayed video times, if the Bitplane mode (BPM) is enabled. The number and position of these fetches is determined by which bitplanes are enabled. During bitplane fetches, even numbered bitplane data is fetched over D0-D7 and odd numbered bitplane data is fetched over E0-E7.

RF -- RAM refresh

The 4567 performs six cycles of dynamic RAM refresh every scanned video line. During this time no data is fetched and CASA* and CASB* are not activated.

SPF -- Sprite Pointer Fetch

Up to eight Sprite Pointer Fetches can occur each scanned video line. One SPF is generated for each sprite that is enabled and currently being displayed. During an SPF, the pointer to the sprite image data is fetched from the video matrix area of memory for the sprite in question over the D0-D7 data bus.

SDF -- Sprite Data Fetch

Three Sprite Data Fetches follow each Sprite Pointer Fetch. During this time, sprite image data for the sprite in question is fetched over the D0-D7 data bus.

DAT -- Display Address Translation

Display Address Translation, or DAT fetches, are not actually DMA-type accesses, but rather CPU address redirections to RAM. In this case, the unmultiplexed address bus is totally separated from the multiplexed address bus.

COL -- Color RAM accesses

Color RAM is also accessed by the CPU via an address translation. This is because color RAM would otherwise be located in the I/O area.

Contents of the Internal A and B Memory Address Busses Prior to Multiplexing

Signal	"VMF"	"CDF"	"BMF"	"BPF"	"RF"	"SPF"	"SDF"	"DAT"	"COL"
IA0	VC0	RC0	RC0	RC0	RF0	SF0	SD0	DT0	A0
IA1	VC1	RC1	RC1	RC1	RF1	SF1	SD1	DT1	A1
IA2	VC2	RC2	RC2	RC2	RF2	SF2	SD2	DT2	A2
IA3	VC3	D0	VC0	VC0	RF3	1	SD3	DT3	A3
IA4	VC4	D1	VC1	VC1	RF4	1	SD4	DT4	A4
IA5	VC5	D2	VC2	VC2	1	1	SD5	DT5	A5
IA6	VC6	D3	VC3	VC3	1	1	D0	DT6	A6
IA7	VC7	D4	VC4	VC4	1	1	D1	DT7	A7
IA8	VC8	D5	VC5	VC5	1	1	D2	DT8	A8
IA9	VC9	D6	VC6	VC6	1	1	D3	DT9	A9
IA10	VM0/VC10	D7	VC7	VC7	RF5	VM0/1	D4	DT10	A10
IA11	VM1	CB0	VC8	VC8	RF6	VM1	D5	DT11	1
IA12	VM2	CB1	VC9	VC9	RF7	VM2	D6	DT12	1
IA13	VM3	CB2	CB2/VC10	BE13/VC10	1	VM3	D7	BE13/DT13	1
IA14	VB0	VB0	VB0	BE14	1	VB0	VB0	BE14	1
IA15	VB1	VB1	VB1	BE15	1	VB1	VB1	BE15	1
A16	A16	A16	A16	A16	RF8	A16	A16	DT16	1
IB10	0/*	*	*	*	*	*	*	*	*
IB11	1	*	*	*	*	*	*	*	1
IB12	1	*	*	*	*	*	*	*	1
IB13	1	*	*	BO13/*	*	*	*	BO13/*	1
IB14	1	*	*	BO14	*	*	*	BO14	1
IB15	1	*	*	BO15	*	*	*	BO15	1
DMA	1	1	1	1	1	1	1	0	0

Legend :

VC = Video Matrix Counter
RC = Row Counter
VM = Video Matrix Address
VB = Video Bank Address
CB = Character Generator Bank Address
RF = Refresh Counter
SF = Sprite Pointer Fetch Counter
SD = Sprite Data Fetch Counter
DT = Display Address Translator
BE = Bitplane Even Pointer
BO = Bitplane Odd Pointer
A = Address Out = Address In
D = Data fetched from previous fetch
* = "B" bus contents, same as "A" bus
xxx/yyy = contents for 320/640 pixel modes

Multiplexed Address Bus Generation

The A and B memory address busses are multiplexed 2:1 to generate the MA and MB multiplexed address busses. Listed below are the primary addresses used to generate the multiplexed row and column addresses.

signal	row	column
MA0	A0	A5
MA1	A1	A6
MA2	A2	A7
MA3	A3	A8
MA4	A4	A9
MA5	A10	A13
MA6	A11	A14
MA7	A12	A15
MB5	B10	B13
MB6	B11	B14
MB7	B12	B15

ROM physical addresses

0000	New area A
2000	Basic
4000	New area B
5000	Character sets
6000	Kernal

ROM can appear (to the 4567) at 1000-1FFF (bank 0)
and 9000-9FFF (bank 2)
The ROM address translates to 5000-5FFF

Contents of Memory map based on Loram, Hiram, Game, and Exrom

						Area			
LORAM	HIRAM	GAME	EXROM	0000- 7FFF	/ROML 8000- 9FFF	/ROMH A000- BFFF	C000- CFFF	D000- DFFF	/ROMH E000- FFFF
X	X	0	1	4KRAM	EXT	NADA	NADA	I/O	EXT
0	0	1	X	RAM	RAM	RAM	RAM	RAM	RAM
0	0	X	0	RAM	RAM	RAM	RAM	RAM	RAM
0	1	0	0	RAM	RAM	EXT	RAM	I/O	ROM
0	1	1	X	RAM	RAM	RAM	RAM	I/O	ROM
1	0	0	0	RAM	RAM	RAM	RAM	I/O	RAM * CG ROM off
	0	1	X	RAM	RAM	RAM	RAM	I/O	RAM
	1	0	0	RAM	EXT	EXT	RAM	I/O	ROM
1	1	1	0	RAM	EXT	ROM	RAM	I/O	ROM
1	1	1	1	RAM	RAM	ROM	RAM	I/O	ROM

Color Palette ROM Programming

index	red	green	blue	fg/bg	I	Q	Y	color
0	0	0	0	0	0	0	0	black
1	15	15	15	1	0	0	1.0	white
2	15	0	0	1	.60	.21	.30	red
3	0	15	15	1	-.60	-.21	.70	cyan
4	15	0	15	1	.28	.52	.41	magenta
5	0	15	0	1	-.28	-.52	.59	green
6	0	0	15	1	-.32	.31	.11	blue
7	15	15	0	1	.32	-.31	.89	yellow
8	15	6	0	1	.49	0	.54	orange
9	10	4	0	1	.33	0	.36	brown
1	15	7	7	1	.32	.11	.63	pink
1	5	5	5	1	0	0	.33	dark grey
2	8	8	8	1	0	0	.53	medium grey
13	9	15	9	1	-.11	-.21	.84	light green
14	9	9	15	1	-.13	-.12	.64	light blue
15	11	11	11	1	0	0	.73	light grey

Horizontal Sync Counter Events
(assuming HPOS reg=0)

For NTSC the first 390 HCOUNT steps are at half the primary clock rate, and 390 are at the primary clock rate, giving 520 counts for 910 clocks. For PAL the first 388 HCOUNT steps are at the slow rate, and 132 are at the faster clock rate, giving 520 counts for 908 clocks.

EVENT	Clock	+256	/2	HCOUNT	Duration
VSYNC1 START	513	769	384	384	846 59us
VSYNC1 STOP	449	705	352	352	
VSYNC2 START	58	314	157	157	846 59us
VSYNC2 STOP	904	250 W	125	125	
HSYNC START	513	769	384	384	63 4.4us
HSYNC STOP	576	832	416	442	
HEQU1 START	513	769	384	384	36 2.5us
HEQU1 STOP	549	805	402	414	
HEQU2 START	58	314	157	157	36 2.5us
HEQU2 STOP	94	350	175	175	
BURST START	576	832	416	442	47 3.3us
BURST STOP	623	879	439	488	
HBLANK START	478	734	367	367	175 12.2us
HBLANK STOP	653	909	454	518	

Horizontal DMA Counter Events
(these are actual counts -- decode 1 count earlier)

Event	HCOUNT	
HDMAEN START	15	19 (640 mode)
HDMAEN STOP	335	339 (640 mode)
HDEN START	25	32 (38 col)
HDEN STOP	345	336 (38 col)
HPIXEN START	24	
HPIXEN STOP	344	
SPR GO	358	
SPR STOP	359	
SPR CLOCK DIS	360	
SPR CLOCK ENA	488	
SPR DMA START	372 (and EOL)	
SPR DMA STOP	482	
REFRESH START	482	
REFRESH STOP	506	
VINC	370	
HRES	15	
DOG START	16	
DOG STOP	376	
SYNC0	0	
SYNC1	1	
SYNC2	3	
FAST	390 NTSC	388 PAL

Vertical Timings

When the vertical position register VPOS is set to zero by the CPU, it actually is storing a compare value of 128, since the MSB of VPOS is inverted. This actually corresponds to raster count 256, since the vertical event counter is counting half-lines. When the vertical event counter matches the VPOS register, the vertical sync counter is reset to zero. Multiply the desired line for each event by 2 and subtract the nominal VPOS value of 256 to get the desired decode. If the result is negative add the modulo of the vertical event counter, which is 525 for NTSC and 625 for PAL. The "line" in these tables refer to raster lines, where line 50 is the first displayed line in a 25 row display.

NTSC

Event	line	v count	- vpos	decode
VSYNC START	11	22	-234	291
VSYNC STOP	14	28	-228	297
VEQU START	8	16	-240	285
VEQU STOP	17	34	-222	303
VBLANK START	8	16	-240	285
VBLANK STOP	28	56	-200	325
EARLY START	64	128	-128	397
EARLY STOP	11	22	-234	291
LATE START	11	23	-233	292
LATE STOP	3	6	-250	275

PAL -- timings begin 25 lines before NTSC because of 50 extra lines

Event	line	v count	- vpos	decode	
VSYNC START	-14	-29	-285	340	
VSYNC STOP	-11	-24	-280	345	
VEQU START	-17	-34	-290	335	*equ/sync is 15 half-lines
VEQU STOP	-9	-19	-275	350	*for pal
VBLANK START	-17	-34	-290	335	
VBLANK STOP	3	6	-250	375	
EARLY START	39	78	-176	447	
EARLY STOP	-14	-29	-285	340	
LATE START	-14	-28	-284	341	
LATE STOP	-22	-44	-300	325	

Note : EARLY and LATE active concurrently indicate GROSS.

Divide ratios (including external sync values)

Counter	Normal	Early	Late	Gross
NTSC vertical	525	524	526	540
PAL vertical	625	624	626	640
NTSC horiz	910	908	912	
PAL horiz	908	906	910	
horiz counter	520	519	521	

Number of cycles per line

In "slow" CPU mode...

Total cycles no video		65
40 column SCM, MCM, ECM, BMM, 320 pixel BPM, BP0-BP3 only, or 640 pixel BPM, BP0-BP1 only	no cost	0
80 column SCM, MCM, ECM, BMM, 320 pixel BPM, BP0-BP7, or 640 pixel BPM, BP0-BP3	subtract	40
Sprites	subtract	2 per active sprite

Examples...

No video on line	65
40 column text or equiv. BPs (no sprites)	65
80 column text or equiv. BPs (no sprites)	25
80 column text or equiv. BPs, all sprites	9 -- worst case

227 memory cycles/line
6 refresh
0-32 sprite
0,40,80,120,160 video

fast	slow	
277	138	total cycles/line
-6	-3	refresh
-32	-16	sprites
239	119	avail CPU cycles/line (no video)

	no video	1 fetch	2 fetch	3 fetch	4 fetch	
cpucyc	239	199	159	119	79	all sprites (fast)
cpucyc	271	231	191	151	111	no sprites (fast)
cpucyc	119	79	79	39	39	all sprites (slow)
cpucyc	135	95	95	55	55	no sprites (slow)

2.4.4 Programming the new VIC (4567)

The C4567R6 is a high performance single chip video controller designed to bring exceptional graphics to low cost computer and game systems. It presently is available in NTSC and PAL versions to match European and North American television standards.

The following are new features that are added as a superset of the old VIC-II video controller functions incorporated in the C4567R6.

a. NewVic mode
b. 80 column character and 640 horizontal pixel mode
c. Scan interlace and 400 line mode
d. Character attributes (blink, highlight, underline, reverse)
e. Fast clock mode (3.58 vs. 1.02 MHz)
f. Bitplane mode
g. Color palettes
h. Additional ROM
i. 1280H pixel mode
j. Display Address Translator (DAT)
k. Horizontal and vertical positioning
l. External sync (Genlock)
m. Alternate character set
n. Chroma killer

NewVic Mode

After power-up and reset, the C4567R6 performs as if it were the "old" VIC chip. In this mode, none of the new features are accessible. The old VIC II registers appear at addresses $D000-$D3FF, echoed 16 times, every 64 addresses, and any new registers within the 64 byte block will not exist.

To put the C4567R6 into "NewVic" mode, the user must write first an $A5 and then a $96 to the KEY register. Once these values have been entered the C4567R6 will be in "NewVic" mode, and access to the "NewVic" registers and modes will be possible.

To take the C4567R6 out of "NewVic" mode, simply write any value to the KEY register. After doing this, all of the new modes will be disabled. The registers that were programmed in "NewVic" mode will retain their current values. It should be noted, however, that since all old modes are available in new mode, there is little reason to exit new mode.

Key 53295
165 → 150

80 Column (character) or 640 Pixel (bitmap or bitplane) Mode

You can put the C4567R6 into "80 Column Mode" or "640 horizontal pixel mode" by setting the H640 bit in control register "B". The normal horizontal rendering is 40 columns or 320 pixels.

In 80 column character mode, several things change. The Video Matrix becomes 2K bytes long, where it used to be 1K in 40 column mode. The character color RAM also becomes 2K bytes long. The locations of these areas do not change from the prior convention, except that the low order video matrix address bit is not used in 80 column mode. Where the programmer used to have 16 choices for locating the Video Matrix within a video bank, in 80 column mode there are only 8 choices.

Although the color RAM doubles in size to 2K bytes, the area provided for color RAM in the I/O map only allows for 1K of color RAM. To read or write the second 1K of color RAM requires that you move CIA1, CIA2, I/O1, and I/O2 out of the way. To do this, set the "COLOR RAM @DC00" bit in Control Register "A".

In 640 pixel bitmap mode, similar changes occur. The video matrix and color RAM double in size and are positioned in the memory map exactly as is done in 80 column character mode. The bitmap must now also double in size from 8K to 16K bytes. Because the total memory that the video matrix and the bitmap would require now exceeds the normal 16K byte video bank size, the video bank size has been doubled from 16K to 32K for the bitmap only. The least significant video bank bit is ignored, and the high order character generator bank bit selects which half of the 32K video bank that bitmaps will be fetched from. The video matrix is still fetched from the normal 16K video bank.

In 80 column or 640 pixel mode, the sprite pointers are at the end of the 2K byte video matrix, where they used to be at the end of the 1K byte video matrix, in 40 column or 320 pixel mode. The size, location, and resolution of sprites are not affected by any of the mode switches.

Interlace, and 400 Line Vertical mode

The C4567R6 can interlace scan lines to give a true NTSC, 525 line screen (625 lines on PAL versions), although the default, however, is a 262 line non-interlaced screen (312 lines on PAL versions). Set the INT bit in control register "B" to a "1" if you want interlacing.

The C4567R6 can also give a 400 line vertical resolution, which is useful in the new Bitplane mode. Set the V400 bit, and the INT bit in control register "B" to a "1" to enable 400 line bitplanes. (see Bitplanes, below) The V400 switch will have no effect if the display is not interlacing. Also, although interlacing is permitted in all of the old video modes, the same data will appear on both odd and even rasters, even if the V400 switch is on.

280 Horizontal Pixel mode

The C4567R6 supports ultra-high resolution graphics by permitting the programmer to use 1280 pixel lines. This is enabled by setting the H1280 and H640 bits in control register "B" to a "1".

The 1280 pixels are acheived by time-multiplexing bitplane bits. This s done by substituting the pixel clock for bitplane 7. This means that for the first half of each pixel, the color palette will be fed the normal color index. For the second half of the same pixel, it will fed the normal index, plus 128. To utilize this feature, the user must program the color palette to perform the multiplexing function.

The H1280 bit can also be set H640 off. This is a unique mode that allows the use of 320 and 640 horizontal pixel bitplanes simultaneously.

Character Attributes

In NewVic mode, the C4567R6 supports four new character attributes which can be enabled by setting the ATTR bit in Control Register "B". These are Blink, Highlight, Underlined, and Reverse Video characters. Any combination of these attributes can be enabled on a character by character basis, at any time. Certain combinations will have varying effects. (See table below) Attributes can also be applied to bitmap mode, and, to a limited extent, to the new bitplane mode. (see Bitplanes, below)

Blink is enabled by setting bit 4 of the Color RAM location for each character requiring this attribute. The Blink attribute will either flash the character on and off, or will alternately enable and disable the other attributes, if any are selected. The blink rate is approximately 1 Hz.

Reverse Video is enabled by setting bit 5 of the Color RAM location for each character requiring this attribute. Reverse Video is achieved by simply complementing the character image data for each character with this attribute. If the character is also underlined, the underline will be reversed, as well. Highlighted characters also will reverse. Blink, if enabled, will alternately enable and disable this attribute.

Highlight is enabled by setting bit 6 of the Color RAM location for each character requiring this attribute. Highlight is achieved by adding 16 to the color index value. As in the past, the character color is determined by the index value stored in bits 0-3 of the color RAM. In many respects, bit 6 is merely another color select bit. What differs is that the Blink attribute can be used to blink between the "normal" color, and the "highlight" color. Both the character image, and its background can have unique highlight colors.

To use the highlight attribute, effectively, color palette locations 16 through 31 should be programmed to "highlight" colors. (see Palette, below). Highlight colors don't have to be related to normal colors, but can be anything.

Underline is enabled by setting bit 7 of the Color RAM location for each character requiring this attribute. Underline is accomplished by forcing "1" character image data on the eighth raster line for each character with this attribute. If the Blink attribute is also selected, the underline will blink.

Summary of Character Attributes and their Effects

Underline	Hilite	Reverse	Blink	Effect
off	off	off	off	normal character
off	off	off	on	blinking character
off	off	on	off	reverse video character
off	off	on	on	alternate reverse/normal
off	on	off	off	highlight character
off	on	off	on	alternate highlight/normal
off	on	on	off	highlight, reverse video
off	on	on	on	alternate highlight-reverse/normal
on	off	off	off	underlined character
on	off	off	on	normal char with blinking underline
on	off	on	off	underlined reverse-video
on	off	on	on	alternate underline-reverse/normal
on	on	off	off	highlight underlined character
on	on	off	on	alternate highlight-underline/normal
on	on	on	off	highlight underlined reversed
on	on	on	on	alternate hilite-underlined-rev/normal

Fast Clock

To permit the new system to run certain types of the old C64 software, the C4567R6 provides a normal (slow) CPU clock with a long term (63us) average of 1.02 Mhz (exactly the C64 clock rate). This is accomplished by setting up a pattern of 1.79Mhz (560ns) cycles to give a total of 65 cycles be horizontal scanning line (also, like C64). In addition, logic is provided on the C4567R6 to determine when the microprocessor chip is executing an enhanced opcode, and, if so, subtracts a clock cycle from it.

By setting the FAST bit in Control Register "B", you can instruct the C4567R6 to clock the CPU at 3.58 Mhz, and permit the microprocessor to execute its enhanced instructions at full speed. This can increase CPU speed up to 400%.

BitPlane mode

In addition to the usual video modes provided by the old VIC chip, the C4567R6 provides a bitplane mode, which allows up to eight bitplanes to be used in the 320, or up to four bitplanes to be used in the 640 horizontal pixel modes.

Enabling BitPlane mode is done by setting the BPM bit in Control Register "B". Doing this will override all of the other video modes. To specify which bitplanes (0-7) to use, set the corresponding bit for each bitplane you want, in the Bitplane Enable register. Bitplane mode may be used with sprites. Bitplane 2 is the foreground/background plane used for sprite/background collision detection and priority.

The bitplanes, whether enabled, or not, provide the eight color value bits used to define what color will be displayed for any pixel on the screen. Bitplane 0 provides the least significant bit of the color value, and bitplane 7 provides the most significant bit. Bitplanes that are not enabled will contribute a "0" to their bit position in the color select code, unless the complement bit for that bitplane, in the complement register, is set.

Any bitplane's data can be inverted, whether or not the bitplane is enabled by setting its respective bit in the Bitplane Complement register. Inversion on unenabled bitplanes will cause them to contribute a "1" instead of their usual "0".

In BitPlane mode, the C4567R6 does not use the Video Bank select bits, like the old VIC chip did. Instead, You can specify which 8k block (in 320 mode), or which 16k block (in 640 mode) of memory you want a bitplane to come out of. Specify where you want the bitplanes to be fetched from, using Bitplane Address registers 0 through 7. Note, however, that the least significant bits of these registers are ignored in 640 pixel mode, and that register 4 through 7 are never used in 640 pixel mode. Even numbered bitplanes can only be fetched from memory bank 0 (addresses 0-FFFF hex), and odd numbered bitplanes can only be fetched from memory bank 1 (addresses 10000-1FFFF hex). So, the bitplane pointers define which section within the confined bank that bitplane data will be fetched from.

In the Bitplane address registers, there are two bit-fields. One field of bits is for the even vertical scan, and the other field of bits is for the odd scan. The odd scan bits are not used unless both INT and V400 bits are set in control register "B".

Attributes can be enabled in bitplane mode by setting the ATTR bit in control register "B". If this is done, the most significant nybble of bytes fetched for bitplane 3 will contain the attribute specification for each 8 by 8 pixel cell, exactly as is done in character modes. One exception is that the "hilite" attribute will be disabled. The attributes are only applied to bitplane 2, which is also the foreground/background plane for sprite collisions and priority purposes.

To properly utilize this feature, bitplane 2 must be enabled to provide attributed bitplane data, and bitplane 3 must be disabled, since it will be providing attribute data. Data fetches for the attribute data will occur, because bitplanes 2 and 3 are both fetched in the same memory cycle. You may also enable any other bitplanes as needed. Bitplane 2, and any other bitplane may be complemented, but complementing bitplane 3 will only cause its bit weight to contribute a "1", and will not invert the attribute data.

Note:

Addresses 1F800-1FFFF hex are the Color and Attribute RAM used in the old video modes. You can use this area for bitplane if you do not plan on switching between old and new video modes and expect the data for both modes to be there.

Color Palette

The C4567R6, allows the programmer to use the sixteen standard "C64" colors, or define up to 256 custom colors and/or use the palette to perform boolean operations on the bitplane data. The C4567R6 incorporates a 16 word palette ROM and a has a 256 word palette RAM. Each palette location is an index, which can specify one of sixtten possible intensity values (4 bits) each, of Red, Green, and Blue primary colors, plus a single control bit (FGBG) which can be used for foreground/background control for video mixing applications, or to drive a separate monochrome screen.

The first 16 locations of the palette default to the C64 colors in ROM. The remaining 240 locations are programmable RAM. The first 16 locations can also be replaced with RAM, however, by setting the PAL bit in control register "B". All old video modes, including sprites and exterior, can only access the lowest 16 palette locations (except hilite cells), so you may want to reserve these indices for such features.

Only bitplane mode can make full use of all palette locations. Even when less than eight bitplanes are used, the bitplane complement bits of the unused bitplanes can be used to specify which part of the palette is to be used. This feature allows the programmer to define multiple sub-palettes, which can be switched between quickly, or to specify an offset in the color table for the bitplanes, allowing separate colors for exterior and sprites.

To set the color palette, the user must simply write to the color palette RAM. Addresses D100-D1FF (hex) program the 256 Red values, addresses D200-D2FF (hex) program the 256 Green values, and addresses D300-D3FF (hex) program the 256 Blue values. All 256 locations of both the blue and green palettes are only 4 bits wide, so the upper four data bits do nothing. Bit 4 of every red palette location is the FGBG programming bit, the remaining 3 bits are not used. The palette locations are not readable by the CPU.

C4567R6 Registers

MEMORY MAP SELECT AND ENABLE REGISTERS
(EN BIT MUST BE 1 FOR SELECT TO BE 0)
"4510" PORT

					EN2	EN1	EN0	0000
					CHREN	HIRAM	LORAM	0001

VIC-II MODE REGISTERS

								$D000+
S0X7	S0X6	S0X5	S0X4	S0X3	S0X2	S0X1	S0X0	00 SPRITE 0 X
S0Y7	S0Y6	S0Y5	S0Y4	S0Y3	S0Y2	S0Y1	S0Y0	01 SPRITE 0 Y
S1X7	S1X6	S1X5	S1X4	S1X3	S1X2	S1X1	S1X0	02 SPRITE 1 X
S1Y7	S1Y6	S1Y5	S1Y4	S1Y3	S1Y2	S1Y1	S1Y0	03 SPRITE 1 Y
S2X7	S2X6	S2X5	S2X4	S2X3	S2X2	S2X1	S2X0	04 SPRITE 2 X
S2Y7	S2Y6	S2Y5	S2Y4	S2Y3	S2Y2	S2Y1	S2Y0	05 SPRITE 2 Y
S3X7	S3X6	S3X5	S3X4	S3X3	S3X2	S3X1	S3X0	06 SPRITE 3 X
S3Y7	S3Y6	S3Y5	S3Y4	S3Y3	S3Y2	S3Y1	S3Y0	07 SPRITE 3 Y
S4X7	S4X6	S4X5	S4X4	S4X3	S4X2	S4X1	S4X0	08 SPRITE 4 X
S4Y7	S4Y6	S4Y5	S4Y4	S4Y3	S4Y2	S4Y1	S4Y0	09 SPRITE 4 Y
S5X7	S5X6	S5X5	S5X4	S5X3	S5X2	S5X1	S5X0	0A SPRITE 5 X
S5Y7	S5Y6	S5Y5	S5Y4	S5Y3	S5Y2	S5Y1	S5Y0	0B SPRITE 5 Y
S6X7	S6X6	S6X5	S6X4	S6X3	S6X2	S6X1	S6X0	0C SPRITE 6 X
S6Y7	S6Y6	S6Y5	S6Y4	S6Y3	S6Y2	S6Y1	S6Y0	0D SPRITE 6 Y
S7X7	S7X6	S7X5	S7X4	S7X3	S7X2	S7X1	S7X0	0E SPRITE 7 X
S7Y7	S7Y6	S7Y5	S7Y4	S7Y3	S7Y2	S7Y1	S7Y0	0F SPRITE 7 Y
S7X8	S6X8	S5X8	S4X8	S3X8	S2X8	S1X8	S0X8	10 SPRITE X 8

RC8	ECM	BMM	BLNK	RSEL	YSCL2	YSCL1	YSCL0	11 Y SCROLL
RC7	RC6	RC5	RC4	RC3	RC2	RC1	RC0	12 RASTER CNT
LPX7	LPX6	LPX5	LPX4	LPX3	LPX2	LPX1	LPX0	13 LITEPEN X
LPY7	LPY6	LPY5	LPY4	LPY3	LPY2	LPY1	LPY0	14 LITEPEN Y
SE7	SE6	SE5	SE4	SE3	SE2	SE1	SE0	15 SPRITE ENA
		RST	MCM	CSEL	XSCL2	XSCL1	XSCL0	16 X SCROLL
SEXY7	SEXY6	SEXY5	SEXY4	SEXY3	SEXY2	SEXY1	SEXY0	17 SPR EXP Y
VS13	VS12	VS11	VS10	CB13	CB12	CB11		18 VS/CB BASES
IRQ				LPIRQ	ISSC	ISBC	RIRQ	19 INTERRUPTS
				MLPI	MISSC	MISBC	MRIRQ	1A INT MASKS
BSP7	BSP6	BSP5	BSP4	BSP3	BSP2	BSP1	BSP0	1B BK/SPR PRI
SCM7	SCM6	SCM5	SCM4	SCM3	SCM2	SCM1	SCM0	1C MC SPR
SEXX7	SEXX6	SEXX5	SEXX4	SEXX3	SEXX2	SEXX1	SEXX0	1D SPR EXP X
SSC7	SSC6	SSC5	SSC4	SSC3	SSC2	SSC1	SSC0	1E SPR-SPR COL
SBC7	SBC6	SBC5	SBC4	SBC3	SBC2	SBC1	SBC0	1F SPR-BK COL
				BORD3	BORD2	BORD1	BORD0	20 EXT COLOR
				BK0C3	BK0C2	BK0C1	BK0C0	21 BK0 COLOR
				BK1C3	BK1C2	BK1C1	B10C0	22 BK1 COLOR
				BK2C3	BK2C2	BK2C1	BK2C0	23 BK2 COLOR
				BK3C3	BK3C2	BK3C1	BK3C0	24 BK3 COLOR
				SM0C3	SM0C2	SM0C1	SM0C0	25 SPR MC0
				SM1C3	SM1C2	SM1C1	SM1C0	26 SPR MC1
				S0C3	S0C2	S0C1	S0C0	27 SPR0 COLOR
				S1C3	S1C2	S1C1	S1C0	28 SPR1 COLOR
				S2C3	S2C2	S2C1	S2C0	29 SPR2 COLOR
				S3C3	S3C2	S3C1	S3C0	2A SPR3 COLOR
				S4C3	S4C2	S4C1	S4C0	2B SPR4 COLOR
				S5C3	S5C2	S5C1	S5C0	2C SPR5 COLOR
				S6C3	S6C2	S6C1	S6C0	2D SPR6 COLOR
				S7C3	S7C2	S7C1	S7C0	2E SPR7 COLOR

VIC-III MODE REGISTERS

								D000+
KEY7	KEY6	KEY5	KEY4	KEY3	KEY2	KEY1	KEY0	2F KEY
ROM @E000	CROM @9000	ROM @C000	ROM @A000	ROM @8000	PAL	EXT SYNC	CRAM @DC00	30 CONTROL A
H640	FAST	ATTR	BPM	V400	H1280	MONO	INT	31 CONTROL B
BP7EN	BP6EN	BP5EN	BP4EN	BP3EN	BP2EN	BP1EN	BP0EN	32 BP ENABS
B0AD15 ODD	B0AD14 ODD	B0AD13 ODD		B0AD15 EVEN	B0AD14 EVEN	B0AD13 EVEN		33 BITPLANE 0 ADDRESS
1AD15 ODD	B1AD14 ODD	B1AD13 ODD		B1AD15 EVEN	B1AD14 EVEN	B1AD13 EVEN		34 BITPLANE 1 ADDRESS
B2AD15 ODD	B2AD14 ODD	B2AD13 ODD		B2AD15 EVEN	B2AD14 EVEN	B2AD13 EVEN		35 BITPLANE 2 ADDRESS
3AD15 ODD	B3AD14 ODD	B3AD13 ODD		B3AD15 EVEN	B3AD14 EVEN	B3AD13 EVEN		36 BITPLANE 3 ADDRESS
B4AD15 ODD	B4AD14 ODD	B4AD13 ODD		B4AD15 EVEN	B4AD14 EVEN	B4AD13 EVEN		37 BITPLANE 4 ADDRESS
B5AD15 ODD	B5AD14 ODD	B5AD13 ODD		B5AD15 EVEN	B5AD14 EVEN	B5AD13 EVEN		38 BITPLANE 5 ADDRESS
B6AD15 ODD	B6AD14 ODD	B6AD13 ODD		B6AD15 EVEN	B6AD14 EVEN	B6AD13 EVEN		39 BITPLANE 6 ADDRESS
B7AD15 ODD	B7AD14 ODD	B7AD13 ODD		B7AD15 EVEN	B7AD14 EVEN	B7AD13 EVEN		3A BITPLANE 7 ADDRESS
BP7COMP	BP6COMP	BP5COMP	BP4COMP	BP3COMP	BP2COMP	BP1COMP	BP0COMP	3B BP COMPS
BPY8	BPX6	BPX5	BPX4	BPX3	BPX2	BPX1	BPX0	3C BITPLANE X
BPY7	BPY6	BPY5	BPY4	BPY3	BPY2	BPY1	BPY0	3D BITPLANE Y
HPOS7	HPOS6	HPOS5	HPOS4	HPOS3	HPOS2	HPOS1	HPOS0	3E HORIZ POS
VPOS7	VPOS6	VPOS5	VPOS4	VPOS3	VPOS2	VPOS1	VPOS0	3F VERT POS

DAT MEMORY PORTS

								D000+
B0PIX7	B0PIX6	B0PIX5	B0PIX4	B0PIX3	B0PIX2	B0PIX1	B0PIX0	40 BITPLANE 0
B1PIX7	B1PIX6	B1PIX5	B1PIX4	B1PIX3	B1PIX2	B1PIX1	B1PIX0	41 BITPLANE 1
B2PIX7	B2PIX6	B2PIX5	B2PIX4	B2PIX3	B2PIX2	B2PIX1	B2PIX0	42 BITPLANE 2
B3PIX7	B3PIX6	B3PIX5	B3PIX4	B3PIX3	B3PIX2	B3PIX1	B3PIX0	43 BITPLANE 3
B4PIX7	B4PIX6	B4PIX5	B4PIX4	B4PIX3	B4PIX2	B4PIX1	B4PIX0	44 BITPLANE 4
B5PIX7	B5PIX6	B5PIX5	B5PIX4	B5PIX3	B5PIX2	B5PIX1	B5PIX0	45 BITPLANE 5
B6PIX7	B6PIX6	B6PIX5	B6PIX4	B6PIX3	B6PIX2	B6PIX1	B6PIX0	46 BITPLANE 6
B7PIX7	B7PIX6	B7PIX5	B7PIX4	B7PIX3	B7PIX2	B7PIX1	B7PIX0	47 BITPLANE 7

COLOR PALETTES

			FG/BG	RED3	RED2	RED1	RED0	100-1FF RED
				GRN3	GRN2	GRN1	GRN0	200-2FF GREEN
				BLU3	BLU2	BLU1	BLU0	300-3FF BLUE

COLOR/ATTRIBUTE RAM

UNDER	HILIT	REVRS	BLINK	INDX3	INDX2	INDX1	INDX0	D800-DBFF (DC00-DFFF)

VIDEO BANK SELECT AND ENABLE

(EN BIT MUST BE 1 FOR VB TO BE 0)

						VB1	VB0	DD00 (WRITE)
						EN1	EN0	DD02 (WRITE)

Limitations of the C4567R6 and How to Avoid Them

Watch carefully, when particular mode changes take effect. You may change PAL, H1280, V400, BPM, ATTR, and H640 modes anytime. However, the new mode selection will not take effect until after the last line of the current character row. This is intended to simplify split-screen programming. But, if you are using the DAT to access bitmaps or bitplanes, you must wait long enough after selecting a new H640 or V400 mode to guarantee that the C4567R6 is in the mode you intended before doing any DAT accesses. The DAT uses these bits to determine how to draw the image.

If you want to use all four 640x400 bitplanes, you will be limited to a maximum of 5 sprites having unique data. You can have more sprites, if they re permitted to share data. This limitation is due to the fact that sprite pointers and data must be fetched from the 16K video matrix which must also be shared with one of the bitplanes. The bitplane will use 16000 of the 16384 bytes. This leaves 384 bytes, which would support 6 sprite data blocks of 64 bytes, each. But the sprite pointers must come out of the highest addressed block, thus leaving only 5 sprite data blocks available.

If you really need 8 unique sprites, you can use four 640x384 pixel bitplanes. This is done by setting the row select bit to 24 row mode. This will give you a total of 16 blocks of 64. This is more than enough, so you can even have alternate sprite data blocks.

Note that Sprites and Sprite coordinates are unaffected by screen resolution, meaning that in 640x400 screens, for example, the sprites are still the same size on the screen and are still positioned as if the display map were 320x200. In an 80-column text, or 640-wide bitplane, screen a "dot" on a sprite will cover 2 pixels.

Note also that, in bitplane mode, sprites will only collide with "background" data which has bits "on" in bitplane 2. All other bitplanes will NOT cause a sprite-to-background-data collision.

Sprite Data bei Bitmap-Mods: $00800

An Example of How to Program the Color Palette for 1280 Pixel Resolution and Driving FGBG

In 1280 mode you must use 2 bitplanes to time-multiplex into 1. So, for example, lets use BP0 for "early" bytes and BP1 for "late" bytes.

```
+-----+-----+-----+-----+-----+-----+-----+-----+
|  7  |  6  |  5  |  4  |  3  |  2  |  1  |  0  |   early BP0
+-----+-----+-----+-----+-----+-----+-----+-----+
+-----+-----+-----+-----+-----+-----+-----+-----+
|  7  |  6  |  5  |  4  |  3  |  2  |  1  |  0  |   late BP1
+-----+-----+-----+-----+-----+-----+-----+-----+
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
|7E|7L|6E|6L|5E|5L|4E|4L|3E|3L|2E|2L|1E|1L|0E|0L|   final output
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
```

The early pixels will be interleaved with the late ones, as shown. So, if you want to alter 1 pixel, you must decide which bitplane it will be in, and operate on its byte.

Make sure the H1280 control bit is set. If it is, BP7 will be forced low for an early pixel, and high for a late pixel. Let's program the palette to multiplex BP0 early and BP1 late and ignore BP2 and BP3. I want my background to be black, and image to be white, and, at the same time have BP3 drive a 640 pixel monochrome screen with the FGBG pin. (it too could be 1280 pixels).

Display Address Translator (DAT)

The C4567R6 contains a special piece of hardware, known as the Display Address Translator, or DAT, which allows the programmer to access the bitplanes directly. In the old VIC configuration, the bitmap was organized as 25 rows of 40 stacks of 8 sequential bytes. This is great for displaying 8 x 8 characters, but difficult for displaying graphics.

The DAT overcomes the original burden by allowing the programmer to specify the (X,Y) location of the byte of bitplane memory to be read, modified, or written. This is done by writing the (X,Y) coordinates to the BPX and BPY register, respectively. The user can then read, modify, or write the specified location by reading, modifying, or writing one of the eight Bitplane registers. There is one bitplane register for each bitplane.

The DAT automatically determines whether to use 320 or 640 pixel mode, d whether to use 200 or 400 line mode. It will also use the areas specified or the bitplanes, using the Bitplane Address registers.

Horizontal and Vertical Positioning

The C4567R6 has two registers to allow the programmer to alter the sitioning of the display relative to the borders of his CRT (television or monitor). Initially the positioning registers are set to zero, to give C64 standard positioning. These registers are signed, two's complement values which specify an offset from the default positions.

Chroma Killer

The C4567R6 provides analog RGB video, with sync on all colors, an analog luminance output, with sync, and an analog NTSC (or PAL on PAL versions) chrominance output. It also provides a separate digital video signal, and a separate digital sync. When using the C4567R6 with a black and white television receiver, it may be best to suppress the chrominance information. This can be done by setting the MONO bit in control register "B".

dditional ROM

The C4567R6 does all decoding for ROMs. It supports a total of 32K of ROM, which is 12K over what the C64 is configured for. This 12K of extra ROM is available in one 8K block at 8000 (hex), and one 4K block at C000 (hex). To enable ROM at these areas, set the ROM@8000 or ROM@C000 bits in Control Register "A". (Note that there are other chips in the C65 which extend this ddressing limitation. The C65 has a 1MB ROM built-in.)

Alternate Character Set

Ordinarily, the C4567R6 will always fetch ROM-based character data from addresses D000-DFFF. If the CROM@9000 bit is set in control register "A", ROM-based character data will be fetched from addresses 9000-9FFF. This allows for an alternate ROM-based character set.

Future Document Topics

At a later time, this document may also describe the following C4567R6 enhancements and features...

Weatherfax Mode
Multiple (2-8) playfields
Playfield prioritization
Multiple CRT configurations using the digital and analog video
Multiple sub-palettes
Mixing 1280 pixel and 640 pixel bitplanes
Using all 272 palette locations
Transparency, highlighting, and palette logic functions
Use of the priority/collision bitplane with the sprites
Use of external Video RAM

palette addresses	palette outputs			
BBBBBBBB PPPPPPPP 76543210	RRRR 3210	GGGG 3210	BBBB 3210	FGBG
00000000	0000	0000	0000	0
00000001	1111	1111	1111	0
00000010	0000	0000	0000	0
00000011	1111	1111	1111	0
00000100	0000	0000	0000	1
00000101	1111	1111	1111	1
00000110	0000	0000	0000	1
00000111	1111	1111	1111	1
00001000	0000	0000	0000	0
00001001	1111	1111	1111	0
00001010	0000	0000	0000	0
00001011	1111	1111	1111	0
00001100	0000	0000	0000	1
00001101	1111	1111	1111	1
00001110	0000	0000	0000	1
00001111	1111	1111	1111	1
10000000	0000	0000	0000	0
10000001	0000	0000	0000	0
10000010	1111	1111	1111	0
10000011	1111	1111	1111	0
10000100	0000	0000	0000	1
10000101	0000	0000	0000	1
10000110	1111	1111	1111	1
10000111	1111	1111	1111	1
10001000	0000	0000	0000	0
10001001	0000	0000	0000	0
10001010	1111	1111	1111	0
10001011	1111	1111	1111	0
10001100	0000	0000	0000	1
10001101	0000	0000	0000	1
10001110	1111	1111	1111	1
10001111	1111	1111	1111	1

Since BP7 is low, the early pixel matters. Only care about BP0 data, since it supplies the early data. Notice how the RGB output is all 1's only when BP0 is a 1, regardless of what the other BP's are doing. This is how you program the palette to ignore certain bitplanes.

Did you see how FGBG is a 1 only when BP3 is a 1 regardless of other BPs?

Now BP7 is high. The late pixels are being output. Now, the RGB output is all 1's only when BP1 (the late BP) is a 1, regardless of what the other BPs are doing. This is how to time multiplex between planes.

Notice, now, that FGBG is still a 1 only if BP3 is a 1, regardless of the other BPs, like before. This makes FGBG immune to the mutiplexing. It also shows how you can mix modes on the same screen!

Note that BP4, BP5, and BP6 will be zero unless I specifically ask them to be set to 1 in the Bitplane Complement register. So if they are zero, I do not need to program the rest of the palette. But I can program the other parts of the palette, and use the bitplane complements for BP4, BP5, and BP6 to switch between sub-palettes!

VIC-II modes, enhanced VIC-II modes, and VIC-III modes.

The VIC-III supports, what are called, "VIC-II" video modes. It also supports enhancements to the basic VIC-II modes. There are, also a variety of all-new VIC-III modes. In order to utilize any enhanced VIC-II mode, or any VIC-III mode, a special keying sequence is required.

VIC-II modes

Standard Character Mode
Multi-Color Character Mode
Extended Color Mode
Bit Map Mode
Sprites

Enhancements available to VIC-II modes

80 column character modes (vs standard 40 columns)
640 x 200 pixel bit maps (vs standard 320 x 200)
Programmable colors
Character attributes -- Underline, Blink, Reverse, Hilight
Alternate character set
Interlace

VIC-III video modes

Bitplane modes
1280 pixel ultra-high resolution
400 line operation

Location of VIC-II video data in memory (Video Bank selection)

The VIC-II modes can only access a maximum of 16K bytes of memory, out of a total of 64K of potentially available display memory. To select which fourth of the 64K memory will be available for VIC-II video accesses, the user must specify which Video Bank to use. This is done by setting bits 0 and 1 in the Bank Select register (location DD02 hex) as shown.

Bit		Video	Address
1	0	Bank	Range
0	0	3	C000-FFFF
0	1	2	8000-BFFF
1	0	1	4000-7FFF
1	1	0	0-3FFF

e same two bits must be set to a 1 in an enable register (location DD00 ex) in order for a 0 data bit to be recognized. Both of these registers, though write only, may have bits shared, elsewhere in the application system. If this is the case, care must be taken to preserve the other port bits not shown, here.

The Video Matrix

The Video Matrix is a block of memory used to store character-organized display data. Depending on whether the chip is in 40 column or 80 column display mode, it is 1024 or 2048 bytes long. Since the VIC-II modes can only access 16K bytes of memory, this means there are 16 or 8 places that the video matrix can appear within the 16K Video Bank, depending on whether 40 or 80 column mode is selected. The location of the Video matrix is chosen by bits 4 through 7 of the Memory Pointers register (address D018 hex). Bit 4 has no effect in 80 column mode.

The Character Memory Block

The Character Memory is a 2048 byte block of memory that contains character image data. Each character definition requires 8 bytes in order to display a 8 x 8 bit character image. And there are 256 possible values for each character code, so 8 x 256, or 2048 locations are required. For each character definition stored in the character memory, the lowest of the eight memory addresses used by the character represents the top one of eight scan lines of the character. The leftmost pixel of each character is the most significant bit (bit 7) of the respective character memory byte.

Since the VIC-II modes can only access 16K bytes of memory, there are only eight choices where the Character Memory Block can be located. That location is selected by bits 1-3 of the Memory Pointers register (address D018 hex). Special combinations of Character Memory Block and Video Bank selections determine whether the character image data is fetched from RAM or from ROM, as shown below.

CB bit			VB bit		Image source	hex address
3	2	1	1	0		
0	0	0	x	x	RAM	(0-7FF)+VB
0	0	1	x	x	RAM	(800-FFF)+VB
0	1	0	x	0	ROM	D000-D7FF (C000-C7FF if CROM@C000)
0	1	0	x	1	RAM	(1000-17FF)+VB
0	1	1	x	0	ROM	D000-D7FF (C000-C7FF if CROM@C000)
0	1	1	x	1	RAM	(1800-1FFF)+VB
1	0	0	x	x	RAM	(2000-27FF)+VB
1	0	1	x	x	RAM	(2800-2FFF)+VB
1	1	0	x	x	RAM	(3000-37FF)+VB
1	1	1	x	x	RAM	(3800-3FFF)+VB

Color/Attribute Memory

The VIC-II modes have a 1024 or 2048 byte color and attribute memory, depending on whether 40 columns or 80 columns are selected. This memory is used to determine what color and what attributes are to be applied to each character in the video matrix. Color/Attribute RAM is immovable. Physically, it is located at RAM locations 1F800-1FFFF. The CPU, however can access the 1024 byte portion at addresses D800-DBFF. It can access the entire 2048 byte block from D800-DFFF if the COL@DC00 bit is set in control register A. The CPU can also access Color/Attribute RAM directly at addresses 1F800-1FFFF.

Standard Character Mode

Standard Character Mode is selected by writing 0 to the ECM and BMM bits in Mode Register A (location D011 hex), writing 0 to the MCM bit in Mode Register B (location D016 hex), and by writing 0 to Control Register B (location D031 hex).

2.5 CSG F011x -- C65 Disk Controller Chip gate array (preliminary)

2.5.1 Description

CSG4171-F011 Revision C

The CSG4171-F011 is a low cost MFM disk interface. It requires the use of an external 512 byte RAM as a data cache buffer. This interface can perform reads from and writes to MFM formatted diskettes, as well as free-format full track reads and writes. It can also format diskettes. Logic is also provided for timed head stepping and for motor spin-up. The F011 provides for expansion drive interconnect using a serial protocol for control and status signals. It also incorporates an index pulse simulator for drives that do not have an index sensor.

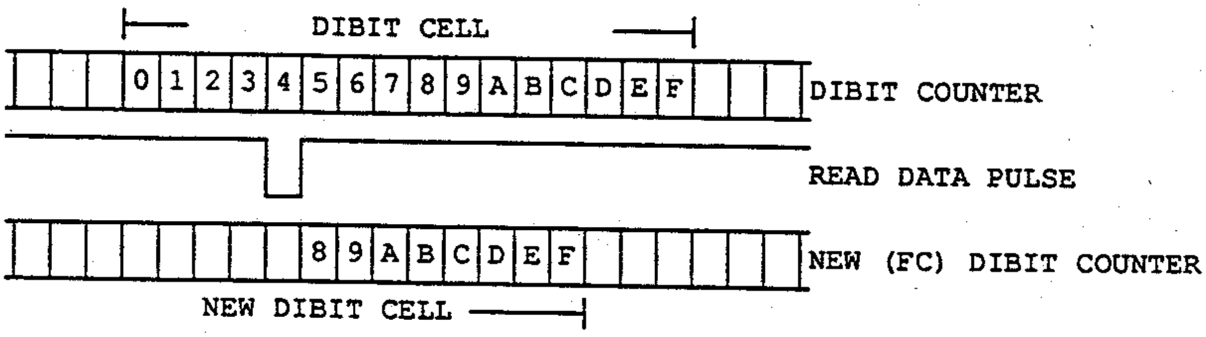
Unlike its predecessors, the "C" revision provides

a. Active high local LED output.
b. Correct remote DSKCHG status.
c. Protection of control bits when changing drive selects.
d. IRQ cleared on reset.
e. Blinking of the local LED.
f. Swapping of buffer halves for CPU access.
g. Two new Digital Phase Locked Loop (DPLL) read recovery methods in addition to the original Full Correction (FC) algorithm.
h. Improved capture range in Full Correction.
i. Decoding for external disk registers.
j. A one line to two line active low decoder for external hardware.

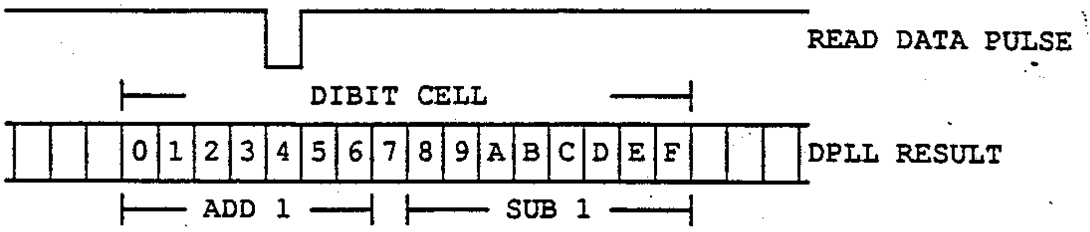
Read recovery options

The F011 now provides 3 methods for recovering MFM formatted disk data. Each method has its own advantages and tradeoffs. This is how they work...

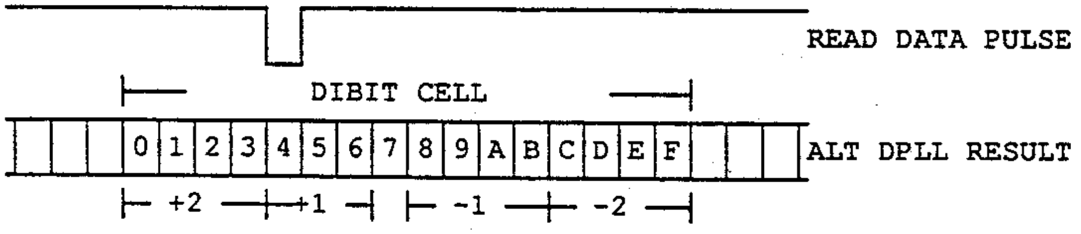
The read-recovery, or dibit counter divides the dibit period into sixteen partitions or counts assuming no read data pulses occur or correctly positioned read pulses occur. When a read data pulse with less-than-ideal positioning occurs, the dibit counter will modify its count depending on whether Full Correction (FC), Digital Phase Locked Loop (DPLL) or Alternate Phase Locked Loop (ALT) recovery methods are selected.



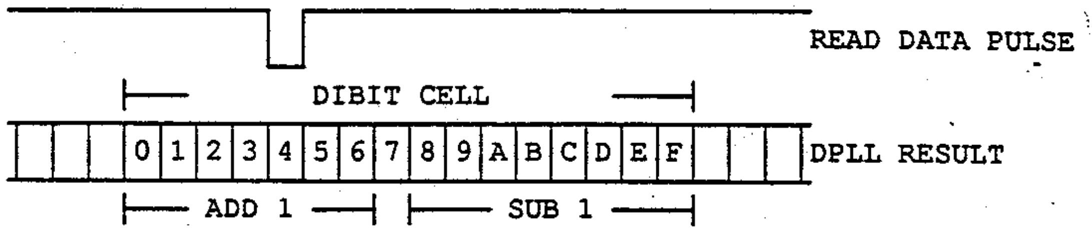
In Full Correction (FC) the dibit counter is forced to count eight after a read pulse is received. This is the equivalent of forcing the read pulse to the center of the bit cell. This method fully compensates for phase and frequency variation. It will tolerate a considerable range of bit frequency error at the cost of permitting a limited range of bit phase error.



In Digital Phase Locked Loop (DPLL) recovery, the dibit counter is incremented if a read pulse occurs early (before a dibit cell center), decremented if a read pulse is late (after a dibit cell center), or counts normally if no read pulse occurs, or if a pulse occurs within a dibit cell center. This method has the ability to track a large range of bit phase ror, but, unfortunately can only handle a very narrow frequency error ange.



In Alternate Digital Phase Locked Loop (ALT) recovery, the dibit counter behaves exactly as it does in standard DPLL mode, except that if a read pulse occurs more than 3 counts early, or 4 counts late,the counter is incremented or decremented by 2. Like DPLL, this method can tolerate a large range of bit phase error, but can also compensate for a larger frequency error range.



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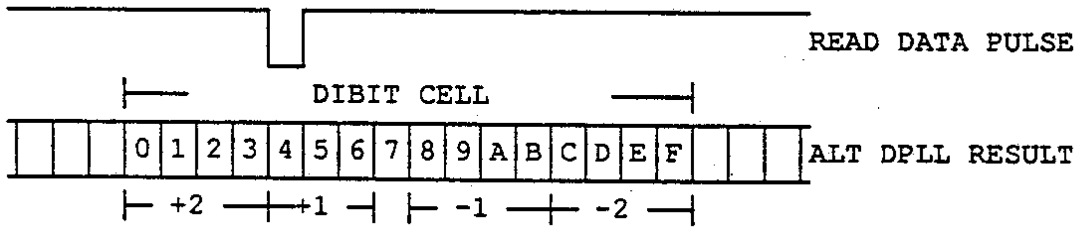


In Alternate Digital Phase Locked Loop (ALT) recovery, the dibit counter behaves exactly as it does in standard DPLL mode, except that if a read pulse occurs more than 3 counts early, or 4 counts late,the counter is incremented or decremented by 2. Like DPLL, this method can tolerate a large range of bit phase error, but can also compensate for a larger requency error range.

46	SERIO	low	I/O	exp	serial control/status
47	LD	low	output	exp	direction of serio
48	CLK	low	output	exp	shift clock
49	LOCAL	low	input	disk	local drive available
50	TSTCLK		input	test	test clock
51	EXTREG	low	output		to external registers
52	A4		input	cpu	address
53	DR0	low	output	disk	drive select 0
54	CS1	low	input	cpu	chip select external logic
55	LED	high	output	disk	panel LED
56	DIR		output	disk	stepping direction
57	STEP	low	output	disk	stepping command
58	PH0		input	cpu	clock
59	DSKIN	low	input	disk	disk inserted
60	RES	low	input	cpu	reset
61	XTAL1		input		crystal
62	XTAL2		output		crystal
63	VENDOR	low	input		vendor
64	VCC				
65	CSLO	low	output		to external logic
66	CSHI	low	output		to external logic
67	GND				
68	GND				

2.5.2.2 Signal Descriptions

Processor Interface Lines

A0-A4	These five address inputs select which internal or external register is to be read or written by the processor.
RW	The RW input determines whether a register will be written (RW=low) or read (RW=high) by the processor.
D0-D7	Eight bi-directional lines which transfer data to and from the processor during register reads and writes. These are normally inputs, but become driven outputs when CS and PH0 are true.
CS	The Chip Select is a low-true input that determines that a register read or write will occur when PH0 becomes true.
CS1	External hardware chip select input. This low-true signal, when asserted, will cause CSLO to go true (low) if A4 is low, or CSHI to go true (low) if A4 is high.
PH0	A high-true input that must be driven high by the processor to indicate that A0-A4, RW, and CS are valid.
IRQ	The Interrupt Request is an open-drain output that will sink current when an interrupt is requested by the F011. IRQ will go low (true) when the BUSY status bit changes from true to false if IRQ is enabled.
RES	The Reset is a low-true input used to reset internal events. When RES goes low (true) any command in progress will be terminated. RES will not, however, affect any control register bits.

Buffer RAM Interface Lines

RA0-RA8	These nine RAM Address outputs must be connected directly to nine of the external buffer RAM chip address inputs. These may be scrambled for PCB simplification.
RD0-RD7	These eight bi-directional lines must be connected to the eight bi-directional data lines of the external buffer RAM. These may be scrambled for PCB simplification. RD0-RD7 are inputs except when RRW and RCS are low. Then they become driven outputs.
RRW	The RAM Read/Write output must be connected to the R/W input of the external buffer RAM to control reading and writing.
RCS	The RAM Chip Select is a 1.0 Mhz clock of 50% duty cycle, and is low at a time when RA0-RA8, RRW, and RCS are valid. It must be connected to the CS input of the external buffer RAM.

Disk Drive Interface Lines
(All disk signals are low-true)

RD	The Read Data input expects a series of low-going pulses from the currently selected disk drive.
WD	The Write Data output provides a series of low-going pulses at all times to all drives. It represents the MFM encoded data stream used for disk writes.
WGATE	The Write Gate output, when true, causes the Write Data to be written to the diskette in the currently selected drive.
WPROT	The Write Protect input must indicate, when true, that the present diskette in the local drive must not be written to. The F011 will not assert WGATE if WPROT is true, and will not execute any write related commands.
LOCAL	The Local Drive Available input must be grouded in systems that have a resident local drive 0, and must be tied to Vcc in systems that are diskless. This will permit drive 0 to be configured externally.
DR0	This output, when low, indicates that the local drive (Drive 0) is the currently selected drive.
DISKIN	The Disk In Input must indicate when a diskette is physically in the local drive, and the drive is available for use.
MOT	The Motor On output, when true, turns on the motor of the local disk drive only. (Also turns on local LED).
LED	The LED output, when true turns on the panel Light-emitting-diode of the local disk drive only. (Causes LED to BLINK).
SIDE	The Side select output determines which side of the media is to be read or written. It is high (false) for side 0, and low (true) for side 1. This output reflects the status of the SIDE control bit regardless of which drive is selected.
STEP	The Step output provides a low-going pulse when a head stepping command is executed, regardless of which drive is selected.
DIR	The Direction output indicates to the drives whether the read/write head is to step toward track 0 (DIR=high) or away from track 0 (DIR=low) when a step pulse is received. This output reflects the status of the DIR command register bit regardless of which drive is selected.
TK0	The Track Zero input must determine when the read/write head of the local drive is positioned over track zero. This input will not suppress stepping pulses.
INDEX	The Index pulse input must provide a low going pulse for each spindle rotation of the local drive, if the local drive has an index sensor. This input must be tied low if the local drive has no index sensor.

Expansion Drive Interface Lines
(all expansion lines are low-true)

SERIO	The Serial I/O line is a bi-directional signal that is used to pass control to all external disk drives, and to receive status information from them. It is a driven output when LD is high, and an input, otherwise.
LD	The Load Data output tells the external expansion drives when to update control information shifted off of the serio line, when to load status information for shifting, and when to drive the SERIO line. (This is discussed later.)
CLK	The Clock output provides a 50% duty cycle clock at 250Khz to be used by the external expansion drives for shifting control and status information in and out.

Other Signals

XTAL1 XTAL2	These two lines form two poles of a series-resonant crystal oscillator circuit. XTAL1 is an input, and XTAL2 is an output. An 8.0000Mhz crystal should be used.
VENDOR	The software Vendor identifier input determines whether the F011 will be capable of generating protect marks within the sector headers. Production units will not have this signal bonded, except those shipped to software vendors. This pin should be grounded at all times.
TSTCLK	The Test Clock input is used to reduce F011 test times. This pin should be grounded at all times.
CSLO	External hardware active-low chip select output. Goes low when CS1 and A4 are both low.
CSHI	External hardware active-low chip select output. Goes low when CS1 is low and A4 is high.
EXTREG	External register active-low chip select output. Goes low when CS is low and A4 is high.

2.5.3 <u>Registers</u>

C4171-F011C Registers

	7	6	5	4	3	2	1	0	
CONTROL	IRQ	LED	MOTOR	SWAP	SIDE	DS2	DS1	DS0	0 RW
COMMAND	WRITE	READ	FREE	STEP	DIR	ALGO	ALT	NOBUF	1 RW
STAT A	BUSY	DRQ	EQ	RNF	CRC	LOST	PROT	TK0	2 R
STAT B	RDREQ	WTREQ	RUN	WGATE	DSKIN	INDEX	IRQ	DSKCHG	3 R
TRACK	T7	T6	T5	T4	T3	T2	T1	T0	4 RW
SECTOR	S7	S6	S5	S4	S3	S2	S1	S0	5 RW
SIDE	S7	S6	S5	S4	S3	S2	S1	S0	6 RW
DATA	D7	D6	D5	D4	D3	D2	D1	D0	7 RW
CLOCK	C7	C6	C5	C4	C3	C2	C1	C0	8 RW
STEP	S7	S6	S5	S4	S3	S2	S1	S0	9 RW
P CODE	P7	P6	P5	P4	P3	P2	P1	P0	A R

Control Register

Data from the control register is sent to both the local drive (DR0) and all of the serially connected expansion drives (DR1-DR7). The MOTOR and LED signals will be held for the local drive while other drives are selected.

IRQ	When set, enables interrupts to occur. when reset clears and disables interrupts.
LED MOTOR	These two bits control the state of the MOTOR and LED outputs. When both are clear, both MOTOR and LED outputs will be off. When MOTOR is set, both MOTOR and LED outputs will be on. When LED is set, the LED will "blink".
SWAP	swaps upper and lower halves of the data buffer as seen by the CPU.
SIDE	when set, sets the SIDE output to 0, otherwise 1.
DS2-DS0	these three bits select a drive (drive 0 thru drive 7). When DS0-DS2 are low and the LOCAL input is true (low) the DR0 output will go true (low).

Command Register

WRITE	must be set to perform write operations.
READ	must be set for all read operations.
FREE	allows free-format read or write vs formatted
STEP	write to 1 to cause a head stepping pulse.
DIR	sets head stepping direction
ALGO	selects read and write algorithm. 0=FC read, 1=DPLL read, 0=normal write, 1=precompensated write.
ALT	selects alternate DPLL read recovery method. The ALGO bit must be set for ALT to work.
NOBUF	clears the buffer read/write pointers

Status Registers

The appropriate status bits are sampled from the local status inputs if the local drive (DR0) is selected. Otherwise, those bits are sampled from the serially connected expansion drive (DR1-DR7).

BUSY	command is being executed
DRQ	disk interface has transferred a byte
EQ	buffer CPU/Disk pointers are equal
RNF	sector not found during formatted write or read
CRC	CRC check failed
LOST	data was lost during transfer
PROT	disk is write protected
TK0	head is positioned over track zero

RDREQ	sector found during formatted read
WTREQ	sector found during formatted write
RUN	indicates successive matches during find operation
WGATE	write gate is on
DSKIN	indicates that a disk is inserted in the drive
INDEX	disk index is currently over sensor
IRQ	an interrupt has occurred
DSKCHG	the DSKIN line has changed this is cleared by deselecting drive

Track Register
Sector Register
Side Register

The Track, Side and Sector registers are used in FIND operations to locate a given sector on a given track on a given side.

Data Register

The data register is the CPU gateway to the data buffer for both read and write operations.

lock Register

The clock register is used to define the clock pattern to be used to write address and data marks. This register should normally be written to FF (hex).

Step Register

The step register is used to time head stepping. This register is compared to a counter, which is clocked at 16Khz, giving a time of 62.5 microseconds per count, allowing a maximum of 16 milliseconds of step time per step operation.

Protect Code Register

The Protection Code register is a read-only register that contains the protect code of the last sector read. If the last sector read does not contain a Protect Mark in its header, then this register will contain zero.

Legal commands are...

hexcode	notes	macro	function
40	1,4,5	RDS	Read Sector
80	1,2	WTS	Write Sector
60	1,4,5	RDT	Read Track
A0	1,2	WTT	Write Track (format)
10	3	STOUT	Head Step Out
14	3	TIME	Time 1 head step interval (no pulse)
18	3	STIN	Head Step In
20	3	SPIN	Wait for motor spin-up
00	3	CAN	Cancel any command in progress
01		CLB	Clear the buffer pointers

Notes:

1. Add 1 for nonbuffered operation.
2. Add 4 for write precompensation
3. Add 1 to clear buffer pointers
4. Add 4 for DPLL recovery instead of FC recovery.
5. Add 6 for Alternate DPLL recovery.

2.5.4 Command Descriptions

Execution of any legal command will cause the BUSY status to be set, and the IRQ, RNF, CRC, and LOST flags to be cleared. Execution of the CANcel or CLearBuffer commands, or any write operation command with the WPROT status set, or any illegal command, will not cause a normal BUSY condition. However, any write to either the Command Register or the Control register will automatically cause BUSY to be set for at least one round trip delay of transmission and reception of the serialized control and status signals. When BUSY gets reset, either by successful command completion, error termination, round trip completion, or by user cancellation, the IRQ flag will be set, and an interrupt generated, unless interrupts are disabled.

The user may CANcel any operation in progress at any time using the CAN command to can it. Use of this command during write operations is not advised.

Unbuffered operations

If the buffer pointers are held clear by setting bit 0 in the command register while issuing a command, unbuffered operations will result. These are most useful for formatting a diskette. The DRQ flag in status register A indicates when a transfer has occurred to or from the disk.

For read operations, DRQ set, indicates that a byte of data has been read from disk, and must be read by the CPU. Reading the data with the CPU will clear the DRQ flag. If the data is not read by the time another byte is read from the disk, the old data will be overwritten and the LOST status flag will be set. The LOST flag will remain set until the next command is written.

For write operations, the user should supply the first byte of data either before, or shortly after issuing a write command. The DRQ flag set indicates that the byte has been written to disk, and the CPU must supply the next byte. When the CPU supplies a byte the DRQ flag will be cleared. If the CPU does not supply a new byte in the time that it is required by the disk interface, the previous byte data will be written, and the LOST flag will be set. The LOST flag will remain set until the next command is written.

Buffered operations

Buffered operations can be monitored by reading status register A. The DRQ and EQ bits indicate the immediate status of the buffer pointers. During any operation, the EQ bit, when set, indicates that both the disk and CPU buffer pointers are pointing to the same location. This can mean that the buffer is full or empty, depending on what operation is, or will be performed. The DRQ bit set indicates that the disk was last to access the buffer, and clear indicates that CPU was last to access the buffer.

For read operations, the disk interface will read bytes from disk into the buffer. This will set DRQ and clear EQ. The CPU may read data from the buffer at any time after this occurs, and can continue to read data until EQ goes high, indicating that the buffer is empty. CPU reads from the data buffer will clear DRQ. If data is read from disk, setting DRQ, and EQ also gets set, this indicates that the buffer is now full. One more byte read from disk will set the LOST flag. The LOST flag will remain set until the next command is written. This condition will not usually occur when performing sectored reads of 512 bytes or less, since that is the buffer size.

For write operations, CPU data may be written to the buffer before executing a write command, but may also be supplied during the transfer. If the EQ flag is set after the CPU writes to the buffer, clearing DRQ, this indicates that the buffer is now full, and that the CPU should wait before stuffing more data. The the EQ flag goes high with DRQ high, this indicates that the disk interface has used all of the available data in the buffer. If one more byte is written to the disk, the LOST flag will be set, indicating old buffer data has been written to disk. The LOST flag will remain set until the next command is written.

Data Transfer Commands

Execution of any of the Data Transfer Commands must be performed assuming that the correct drive has been selected, the proper side has been selected, and the drive's motor is on and has had time to spin up. The read/write head(s) must be positioned over the track that data is to be transferred to or from. If the status of the buffer pointers is not as expected or required, a buffer pointer clear should be performed before writing data or issuing commands.

All write commands should be performed with all bits in the clock register set to a "1" (FF hex). This register is used only for formatting diskettes. For all write operations, the WGATE status flag indicates when data is actually being written to the diskette.

Sectored or formatted operations

These operations differ from free-format commands in that the use of sectors is expected. Sectors are of fixed length, and are located and read or written automatically. The disk control logic will verify that the track/sector/side read from the address marks on the disk match the track/sector/side register contents before transferring any data. If the address marks do not match the address information supplied by the user within 6 index pulses, the command will terminate, BUSY will be reset, and the RNF (record not found) flag will be set. The RNF flag will remain set until the next command is issued. The RUN flag, when set, indicates that so far, the sector being accessed appears to be correct. This flag will reset when any part of the address mark does not match the expected data, or a successful completion occurs. Therefore, RUN can change states several times over a single track.

RDS Read a Sector

Writing a 40 (hex) to the command register will cause the controller to execute a buffered RDS (read sector) command. Writing a 41 (hex) will execute an unbuffered RDS command. Add 4 to either command to select DPLL data recovery instead of the normal FC method. Add 6 to either command to select Alternate DPLL recovery instead of the FC method.

The RDREQ flag, when set, indicates that the requested sector has been found, and is now being read into the buffer. RDREQ will reset after the last byte of the sector is read.

WTS Write a Sector

Writing a 80 (hex) to the command register will execute a buffered WTS (write a sector) command. Add 1 to this command for unbuffered operation, and add 4 if write precompensation is desired.

The WTREQ flag, when set, indicates that the requested sector has been found, and is now being written from the buffer. WTREQ will reset after the last byte of the sector is written.

RDT Read a track

Writing a 60 (hex) to the command register will initiate an unformatted buffered disk read. Add 1 to the command for unbuffered operation. Reading will begin immediately, and will continue until user cancellation. The data recovery logic will use address and data marks to align data to byte boundaries. Add 4 to either command to select DPLL data recovery instead of the normal FC method. Add 6 to either command to select Alternate DPLL recovery instead of the FC method.

WTT Write a track

Writing an A0 (hex) to the command register will initiate a buffered write track operation. Add 1 to this command for unbuffered operation, and add 4 to enable write precompensation.

The Write Track feature is usually only used for formatting diskettes, and will most likely be used in the unbuffered mode, since both data and clock must be supplied on a byte by byte basis. Write normal data with the clock register set to FF hex. Write special marks with missing clocks by writing an FB hex to the clock register.

Writing actually begins with the first index pulse after the command is issued, and continues until the next index pulse.

STIN, STOUT Step In and Step Out

Writing a 10 (hex) or 18 (hex) to the command register will initiate a Step-In or Step-Out operation, respectively. The stepping pulse will be generated immediately, and BUSY will remain set for the duration of the stepping time specified in the STEP register..

TIME General purpose timer

Writing a 14 (hex) to the command register will initiate a TIME operation. BUSY will remain set for the duration of the time specified n the STEP register. No stepping pulse will be generated.

SPIN Wait for motor spin-up

Writing a 20 (hex) to the command register will cause BUSY to be set, and stay set for six index pulses. The RNF flag will be set at the end of this operation.

CAN Cancel or "Can" the current operation

Writing a 0 to the command register will force cancellation of any command in progress, and force BUSY to be reset after at least one round-trip serial control and status transmission and reception.

CLB Clear buffer pointers

Writing a 1 to the command register will unconditionally reset the buffer pointers. This should be considered a buffer clear operation, although the contents of the buffer are not affected. The BUSY flag will be set for at least one round-trip serial control and status transmission and reception.

Full Track Writing and Formatting Diskettes

Writing full-track data and formatting are very similar. Both will require that you generate the appropriate SYNC bytes, so that the read data recovery logic can align the serial bitstream to byte boundaries. Both descriptions, below, will assume that the spindle motor is on, and up to speed, and that the read/write head is positioned over the track and side to be written.

Track Writes

Full-track writes can be done, either buffered or unbuffered, however, the CLOCK pattern register has no buffer, and writes to this register must be done "one on one".

Write track Buffered

```
issue "clear buffer" command
write FF hex to clock register
issue "write track buffered" command
write FF hex to data register
wait for first DRQ flag
write A1 hex to data register
write FB hex to clock register
wait for next DRQ flag
write A1 hex to data register
wait for next DRQ flag
write A1 hex to data register
wait for next DRQ flag
write FF hex to clock register
write your first data byte to the data register
  you may now use fully buffered operation.
```

Write Track Unbuffered

```
      write FF hex to clock register
      issue "write track unbuffered" command
      write FF hex to data register
      wait for first DRQ flag
      write A1 hex to data register
      write FB hex to clock register
      wait for next DRQ flag
      write A1 hex to data register
      wait for next DRQ flag
      write A1 hex to data register
      wait for next DRQ flag
      write FF hex to clock register
loop: write data byte to the data register
      check BUSY flag for completion
      wait for next DRQ flag
      go to loop
```

Formatting a track

In order to be able to read or write sectored data on a diskette, the diskette MUST be properly formatted. If, for any reason, marks are missing or have improper clocks, track, sector, side, or length information are incorrect, or the CRC bytes are in error, any attempt to perform a sectored read or write operation will terminate with a RNF error.

Formatting a track is simply writing a track with a strictly specified series of bytes. A given track must be divided into an integer number of sectors, which are 128, 256, 512, or 1024 bytes long. Each sector must consist of the following information. All clocks are FF hex, where not specified. Data and clock values are in hexadecimal notation. Fill any left-over bytes in the track with 4E data.

quan	data/clock	description
12	00	gap 3*
3	A1/FB	Marks
	FE	Header mark
	(track)	Track number
	(side)	Side number
	(sector)	Sector number
	(length)	sector Length (0=128,1=256,2=512,3=1024)
2	(crc)	CRC bytes
23	4E	gap 2
12	00	gap 2
3	A1/FB	Marks
	FB	Data mark
128, 256, 512, or 1024	00	Data bytes (consistent with length)
2	(crc)	CRC bytes
24	4E	gap 3*

* you may reduce the size of gap 3 to increase diskette capacity, however the sizes shown are suggested.

Generating the CRC

The CRC is a sixteen bit value that must be generated serially, one bit at a time. Think of it as a 16 bit shift register that is broken in two places. To CRC a byte of data, you must do the following eight times, (once for each bit) beginning with the MSB or bit 7 of the input byte.

1. Take the exclusive OR of the MSB of the input byte and CRC bit 15. Call this INBIT.
2. Shift the entire 16 bit CRC left (toward MSB) 1 bit position, shifting a 0 into CRC bit 0.
3. If INBIT is a 1, toggle CRC bits 0, 5, and 12.

To Generate a CRC value for a header, or for a data field, you must first initialize the CRC to all 1's (FFFF hex). Be sure to CRC all bytes of the header or data field, beginning with the first of the three A1 marks, and ending with the before the two CRC bytes. Then output the most significant CRC byte (bits 8-15) and then the least significant CRC byte (bits 7-0). You may also CRC the two CRC bytes. If you do, the final CRC value should be 0.

Shown below is an example of code required to CRC bytes of data.

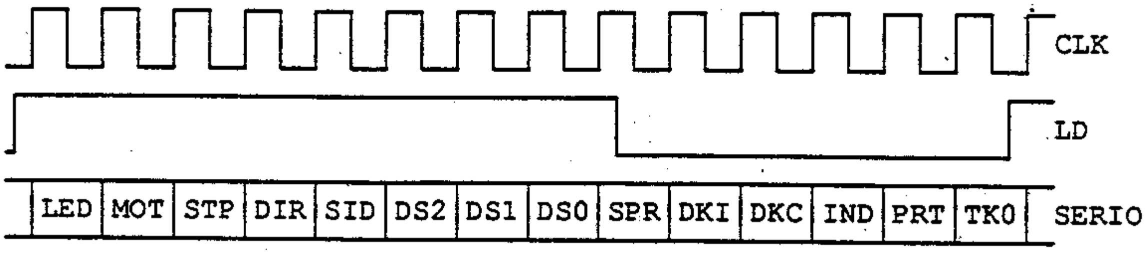
```
;
; CRC a byte. Assuming byte to CRC in accumulator and cumulative
;             CRC value in CRC (lsb) and CRC+1 (msb).

    CRCBYTE LDX #8          ; CRC eight bits
            STA TEMP
    CRCLOOP ASL TEMP        ; shift bit into carry
            JSR CRCBIT      ; CRC it
            DEX
            BNE CRCLOOP
            RTS

;
; CRC a bit. Assuming bit to CRC in carry, and cumulative CRC
;            value in CRC (lsb) and CRC+1 (msb).

    CRCBIT  ROR
            EOR CRC+1       ; MSB contains INBIT
            PHP
            ASL CRC
            ROL CRC+1       ; shift CRC word
            PLP
            BPL RTS
            LDA CRC         ; toggle bits 0, 5, and 12 if INBIT is 1.
            EOR #$21
            STA CRC
            LDA CRC+1
            EOR #$10
            STA CRC+1
    RTS     RTS
```

2.5.5 F011 Disk Expansion Port Serial Protocol



Legend:

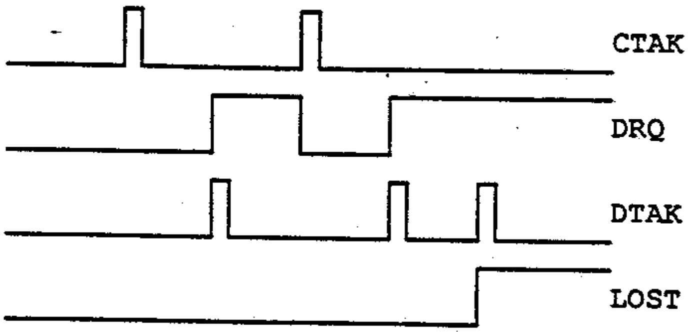
Outputs...		Inputs...	
LED	Panel LED On	TK0	Track Zero
MOT	Spindle Motor On	DKI	Disk Inserted
STP	Step Pulse	DKC	Disk Changed
DIR	Step Direction	IND	Index
SID	Side Select	PRT	Write Protect
DS2-DS0	Drive Unit Select	SPR	Spare input

The SERIO pin is bi-directional, and is used for both transmission of drive control signals, and reception of drive status signals. The F011 will drive SERIO when LD is high. The selected remote unit must drive SERIO when LD is low. All SERIO bits are low-true. SERIO will float high for non-existant drives, making all inputs look false.

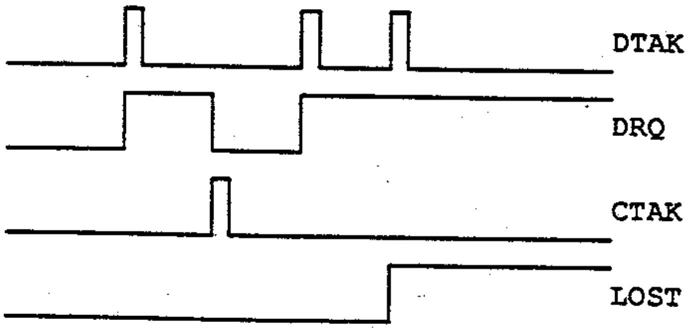
All remote units must clock in serial data on the falling edge of CLK. The remote units must update their control information on LD falling if the DS bits match the given unit. All remote units may load their status inputs when LD is high. Remote units shift out serial status on the rising edge of CLK. The F011 will not change LD coincident with CLK, nor will it drive SERIO when LD is changing.

2.5.6 F011 Disk Timing

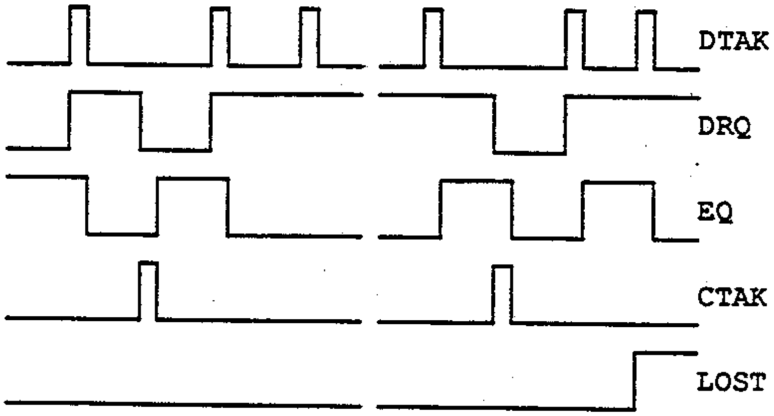
UNBUFFERED WRITE



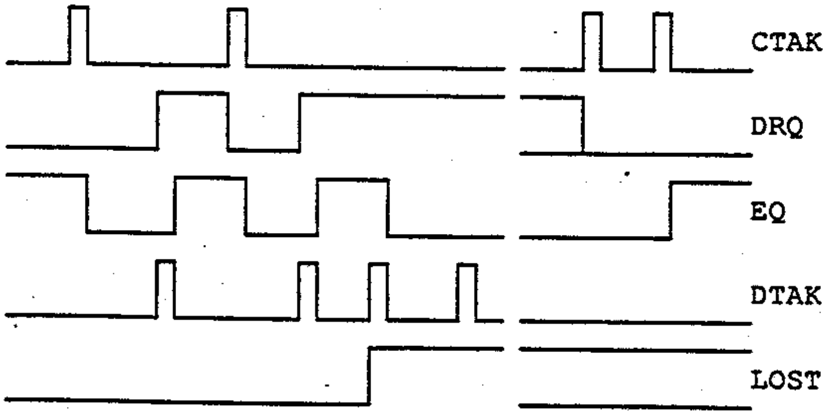
UNBUFFERED READ



BUFFERED READ



BUFFERED WRITE



2.6 F016 Expansion Drive Controller

2.6.1 Description

The CSG4101-F016 is a disk expansion interface that is compatible with the CSG4181-F011B disk controller. With the use of the F016, up to seven external drives can be added to a base F011B system. Drive 0 is the main unit and is controlled entirely by the F011B. Drives 1 thru 7 are external drives, an each must be connected to the F011B with a separate F016.

*** NOTE THAT THE C65 DOS SUPPORTS ONLY ONE EXTERNAL F016 EXPANSION DRIVE ***

CSG4101-F016 Pinout:

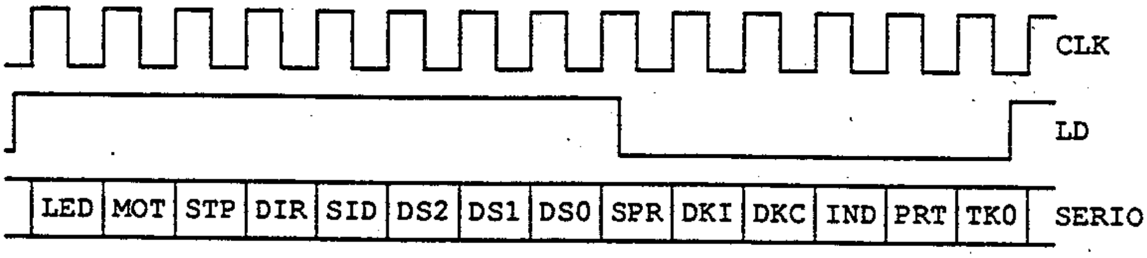
Pin	Name	Active	Dir	Type	Description
1	DS	low	output		drive selected
2	MOT	low	output		motor on
3	SIDE	low	output		side select
4	WPROT	low	input		write protect
5	TK0	low	input		track 0
6	INDEX	low	input		index
7	DR2	low	input	pullup	drive assign dipswitch
8	DR1	low	input	pullup	drive assign dipswitch
9	DR0	low	input	pullup	drive assign dipswitch
10	GND			power	
11	RES	low	input		master reset
12	LED	low	output		panel LED
13	DIR		output		stepping direction
14	STEP	low	output		stepping command
15	SPARE		input		
16	DSKIN	low	input		disk inserted
17	SERIO	low	I/O	bidir	serial data
18	CLK		input		serial data clock
19	LD		input		shift/load command
20	VCC			power	

Signal descriptions:

RES	The Reset is a low-true input used to reset internal flip-flops. The DS (drive selected) output will go false (high) when RES is asserted (low).
WPROT	The Write Protect input must indicate, when true, that the diskette in the attached drive must not be written to (the drive itself will inhibit writing, as well).
DR	This output, when low, indicates that the attached drive is the currently selected drive. This signal will become false (high) upon RESet and when another drive is selected.
DSKIN	The Disk In Input must indicate when a diskette is physically in the attached drive, and the drive is available for use.
MOT	The Motor On output, when true, turns on the motor of the attached disk drive.
LED	The LED output, when true turns on the panel Light-emitting-diode of the attached disk drive.
SIDE	The Side select output determines which side of the media is to be read or written. It is high (false) for side 0, and low (true) for side 1.
STEP	The Step output provides a low-going pulse when a head step operation is required, assuming DS is true (low).
DIR	The Direction output indicates to the drives whether the read/write head is to step toward track 0 (DIR=high) or away from track 0 (DIR=low) when a step pulse is received, assuming DS is true (low).
TK0	The Track Zero input must determine when the read/write head of the attached drive is positioned over track zero.
INDEX	The Index pulse input must provide a low going pulse for each spindle rotation of the attached drive, if it has an index sensor. The F016 will latch index pulses until they are sent out via the SERIO line. This input must be tied low if the attached drive has no index sensor.
SERIO	The Serial I/O line is a bi-directional signal that is used to receive control information from the main disk controller, and return status information to the main controller, assuming the DS output is true (low). It is a driven output when LD and DS are low, and an input, otherwise.
LD	The Load Data input tells when to update control information shifted over the SERIO line, when to load status information for shifting, and when to drive the SERIO line.
CLK	The Clock input is used for shifting control and status information.

2.6.2 <u>Expansion Port Timing</u>

(used by all F016 chips)



Legend:

Outputs...		Inputs...	
LED	Panel LED On	TK0	Track Zero
MOT	Spindle Motor On	DKI	Disk Inserted
STP	Step Pulse	DKC	Disk Changed
DIR	Step Direction	IND	Index
SID	Side Select	PRT	Write Protect
DS2-DS0	Drive Unit Select	SPR	Spare Input

The SERIO pin is bi-directional, and is used for both transmission of drive control signals, and reception of drive status signals. The F011B will drive SERIO when LD is high. Any selected F016 will drive SERIO when LD is low. All SERIO bits are low-true. SERIO will float high for nonexistant drives, making all inputs look false.

All F016 chips clock in serial data on the falling edge of CLK. They update their control information on LD falling if the DS bits match the DS0-DS2 switch settings. All F016 chips load their status inputs when LD is high, and shift out serial status on the rising edge of CLK.

2.7 DMAgic DMA CONTROLLER F018 (Preliminary)

2.7.1 F018 DESCRIPTION

DMAGIC is a custom DMA Gate array IC used in the C65. It functions as a DMA controller with a few tricks up its sleeve. Specifically, DMAgic provides the following commands:

- * COPY - Copy a block of memory to another area in memory.
- * MIX - Perform a boolean Minterm mix of a source block of memory with a destination block of memory.
- * SWAP - Exchange the contents of two blocks of memory.
- * FILL - Fill a block of memory with a source byte.

Special features include:

- * List-based fetching of DMA command sequences.
- * Ability to CHAIN multiple DMA command sequences.
- * Absolute Address access to entire System Memory (8MB).
- * Blocks can be up to 64K bytes long.
- * Windowed Block capability using MODulus function.
- * DMAgic operations yield to VIC video and external DMA accesses.
- * DMAgic operations can optionally yield to system interrupts.
- * Interrupted DMAgic operations can be continued/resumed, or cancelled.
- * Data ReQuest handshaking support for IO devices.
- * Independent memory/mapped IO selection for source and destination.
- * Independent memory tranfer DIRection for source and destination.
- * Independent MODulus enable for source and destination.
- * Independent HOLD (fixed pointer) for source and destination.

The DMA controller has 4 registers:

0	DMA List address low,	Triggers DMA	(write only)
1	DMA List address high		(write only)
2	DMA List address bank		(write only)
3	DMA Status (b7=busy, b0=chained) (a read will restart an INTerupted DMA operation)		(read only)

Note: Minterns & SubCommand will not be implemented until F018A, at which time the register map will be reorganized & support for the REC added.

```
dma_ctlr        = $D700         ;DMA Controller
```

2.7.2 F018 REGISTERS

F018 DMA CONTROLLER

REG NAME	R #	B7	B6	B5	B4	B3	B2	B1	B0
COMMAND	0	SADA	SA$\overline{DA}$	$\overline{SA}$DA	$\overline{SADA}$	$\overline{INT}$	CHAIN	OPERATION	
CNT LO (COL)	1	C7	C6	C5	C4	C3	C2	C1	C0
CNT HI (ROW)	2	C15	C14	C13	C12	C11	C10	C9	C8
SRC LO (FILL)	3	SA7	SA6	SA5	SA4	SA3	SA2	SA1	SA0
SRC HI	4	SA15	SA14	SA13	SA12	SA11	SA10	SA9	SA8
SRC BANK	5	I/$\overline{O}$	DIR	MOD	HOLD	SA19	SA18	SA17	SA16
DEST LO	6	DA7	DA6	DA5	DA4	DA3	DA2	DA1	DA0
DEST HI	7	DA15	DA14	DA13	DA12	DA11	DA10	DA9	DA8
DEST BANK	8	I/$\overline{O}$	DIR	MOD	HOLD	DA19	DA18	DA17	DA16
MOD LO	9	M7	M6	M5	M4	M3	M2	M1	M0
MOD HI	10	M15	M14	M13	M12	M11	M10	M9	M8

OPERATIONS:

0 0	COPY	
0 1	MIX	(MINTERMS ACTIVE)
1 0	SWAP	
1 1	FILL	(SRC LO = FILL BYTE)

PARAMETERS:

$\overline{\text{INT}}$	0	NO INTERRUPTION
	1	IRQ/NMI INTERRUPTION
CHAIN	0	LAST COMMAND IN LIST
	1	PERFORM NEXT COMMAND

BOOLEAN MINTERMS:

		DA	
		0	1
SA	0	$\overline{SADA}$ 0	$\overline{SA}DA$ 1
	1	$SA\overline{DA}$ 2	$SADA$ 3

THE ABOVE COMMANDS ARE NOT YET IMPLEMENTED, AND SOME OF THE REGISTER BITS DEFINED ARE DIFFERENT IN THE PILOT VERSIONS.

2.8 RAM Expansion Controller

2.8.1 Functional Specification

C65 RAM EXPANSION FUNCTIONAL SPECIFICATION

*** THIS IS PRELIMINARY AND WILL BE CHANGING ***

The C65 RAM Expansion Card (REC) provides 1 megabyte of expansion RAM for the C65 computer. The C65 4510/VIC-III provides 1MB of address space, but rudimentary banking capability is provided by the REC to allow several different memory configurations for both the CPU and the VIC-III via available chip selects.

The REC presumes the following system memory map:

$00000-$1FFFF	128K internal RAM
$20000-$3FFFF	128K for internel System ROM
$40000-$7FFFF	256K reserved for cartridge expansion
$80000-$FFFFF	512K reserved for RAM expansion

The REC contains a four-bit write-only register. Data is read from the four low-order bits of the data bus. Reset forces all of these bits into the reset (low) state. The four bits are defined as:

```
       _____CPU bank select
      /_____VIC access enable
     //_____VIC address range
    ///_____VIC Bank select
   ////
```

3210	VIC sees:	
x0xx	Internal RAM	$00000-$1FFFF
x100	Expansion RAM bank 0, physical address	$C0000-$DFFFF
x110	Expansion RAM bank 0, physical address	$E0000-$FFFFF
x101	Expansion RAM bank 1, physical address	$C0000-$DFFFF
x111	Expansion RAM bank 1, physical address	$E0000-$EFFFF

	CPU sees (note that DMA and VIC-DAT access see this too):
0xxx	Expansion RAM bank 0
1xxx	Expansion RAM bank 1

```
/* Inputs */

PIN 1   = MEMCLK ;      /* System memory clock          */
PIN 2   = !CAS ;        /* Correct timing for CAS signal */
PIN 3   = AEC ;         /* The VIC is in town           */
PIN 4   = B3 ;          /* bit to control CPU accesses */
PIN 5   = A19 ;         /* high order address lines */
PIN 6   = A18 ;
PIN 7   = A17 ;
PIN 8   = A16 ;
PIN 9   = A7 ;
PIN 10  = RW ;
PIN 11  = !SID  ;       /* Chip select for SID. Used as a decode */
PIN 13  = B2 ;          /* bits to control VIC accesses */
PIN 14  = B1 ;
PIN 23  = B0 ;

 * Outputs */

PIN 15  = !CAS0B ;      /* Cases for the DRAMS */
PIN 16  = !CAS0A ;
PIN 17  = !CAS1B ;
PIN 18  = !CAS1A ;
PIN 19  = !EXPAND ;     /* Signal to system to allow internal ram out */
PIN 20  = MA8 ;         /* High order Memory address line DRAMS */
PIN 21  = !BRDGOE ;     /* Enable for the Gardei Bridge */
PIN 22  =  EX_LATCH ;   /* Strobe for user write to control latch */

VIC      = !AEC ;
RAST     = !MEMCLK ;
CAST     =  MEMCLK ;

EXVIC    = B0 ;
VICSEL0 = B1 ;
VICSEL1 = B2 ;
CPUBANK = B3 ;

EX_LATCH = CAS & SID & A7 & !RW ;       /* location of control register */
        /* latch data on cas fall to avoid the phi-2 hold time problem */

BRDGOE   = EXPAND & A16 & !VIC ;        /* CPU accessing E bank side. */

EXPAND   = !VIC & A19                   /* ram area */
         #  VIC & EXVIC ;               /* external vic accesses allowed*/

MA8      = VIC  & RAST & !A16           /* Ras time, keep upper*/
         # VIC  & CAST & VICSEL0        /* Cas time, programable. */
         # !VIC & RAST &  A18           /* ras time */
         # !VIC & CAST &  A17 ;         /* cas time */

/* bank 0 drams */
CAS0A    = CAS  & EXPAND & ( !VIC & !CPUBANK & !A16 # VIC & !VICSEL1 );
CAS0B    = CAS  & EXPAND & ( !VIC & !CPUBANK &  A16 # VIC & !VICSEL1 );

/* bank 1 drams */
CAS1A    = CAS  & EXPAND & ( !VIC &  CPUBANK & !A16 # VIC &  VICSEL1 );
CAS1B    = CAS  & EXPAND & ( !VIC &  CPUBANK &  A16 # VIC &  VICSEL1 );
```

2.9 8580 SID REGISTER MAP

	7	6	5	4	3	2	1	0		
0	F7	F6	F5	F4	F3	F2	F1	F0	FREQUENCY LO	VOICE-1
1	F15	F14	F13	F12	F11	F10	F9	F8	FREQUENCY HI	
2	PW7	PW6	PW5	PW4	PW3	PW2	PW1	PW0	PULSE WIDTH LO	
3					PW11	PW10	PW9	PW8	PULSE WIDTH HI	
4	NOISE	PULSE	SAW	TRI	TEST	RING	SYNC	GATE	CONTROL REGISTER	
5	ATK3	ATK2	ATK1	ATK0	DCY3	DCY2	DCY1	DCY0	ATTACK / DECAY	
6	STN3	STN2	STN1	STN0	RLS3	RLS2	RLS1	RLS0	SUSTAIN / RELEASE	
7	F7	F6	F5	F4	F3	F2	F1	F0	FREQUENCY LO	VOICE-2
8	F15	F14	F13	F12	F11	F10	F9	F8	FREQUENCY HI	
9	PW7	PW6	PW5	PW4	PW3	PW2	PW1	PW0	PULSE WIDTH LO	
10					PW11	PW10	PW9	PW8	PULSE WIDTH HI	
11	NOISE	PULSE	SAW	TRI	TEST	RING	SYNC	GATE	CONTROL REGISTER	
12	ATK3	ATK2	ATK1	ATK0	DCY3	DCY2	DCY1	DCY0	ATTACK / DECAY	
13	STN3	STN2	STN1	STN0	RLS3	RLS2	RLS1	RLS0	SUSTAIN / RELEASE	
14	F7	F6	F5	F4	F3	F2	F1	F0	FREQUENCY LO	VOICE-3
15	F15	F14	F13	F12	F11	F10	F9	F8	FREQUENCY HI	
16	PW7	PW6	PW5	PW4	PW3	PW2	PW1	PW0	PULSE WIDTH LO	
17					PW11	PW10	PW9	PW8	PULSE WIDTH HI	
18	NOISE	PULSE	SAW	TRI	TEST	RING	SYNC	GATE	CONTROL REGISTER	
19	ATK3	ATK2	ATK1	ATK0	DCY3	DCY2	DCY1	DCY0	ATTACK / DECAY	
20	STN3	STN2	STN1	STN0	RLS3	RLS2	RLS1	RLS0	SUSTAIN / RELEASE	
21						FC2	FC1	FC0	FREQUENCY LO	FILTER
22	FC10	FC9	FC8	FC7	FC6	FC5	FC4	FC3	FREQUENCY HI	
23	RES3	RES2	RES1	RES0	FILTEX	FILT3	FILT2	FILT0	RESONANCE / FILTER	
24	3 OFF	HP	BP	LP	VOL3	VOL2	VOL1	VOL0	MODE / VOLUME	
25	PX7	PX6	PX5	PX4	PX3	PX2	PX1	PX0	POT X	MISC.
26	PY7	PY6	PY5	PY4	PY3	PY2	PY1	PY0	POT Y	
27	O7	O6	O5	O4	O3	O2	O1	O0	OSCILLATOR 3	
28	E7	E6	E5	E4	E3	E2	E1	E0	ENVELOPE 3	

Notes:

1. CIA#1 ports PRA6 and PRA7 select which control port POT line is routed to SID.

2. While there are 2 SIDs in the C65, the POT lines are still routed to SID#1 for C64 compatibility reasons.

3.0 System Software

3.1 BASIC 10.0

C64DX BASIC 10.0

3.1.1 INTRODUCTION

This section lists BASIC 10.0 commands, statements, and functions in alphabetical order. It gives a complete list of the rules (syntax) of BASIC 10.0, along with a concise description of each.

3.1.1.1 COMMAND AND STATEMENT FORMAT

The commands and statements presented in this section are governed by consistant format conventions designed to make them as clear as possible. In most cases, there are several actual examples to illustrate what the actual command looks like. The following example shows some of the format conventions that are used in the BASIC commands:

```
   EXAMPLE :     DLOAD <"program name"|(file_name_var)> [,U#] [,D#]
                   |             |                       |     |
                   |             |                       |     |
                keyword    -  argument (if any)      optional arguments
```

The parts of the command or statement that the user must type in exactly as they appear are in capital letters. Words that don't have to be typed exactly, such as the name of the program, are not capitalized. When quote marks (" ") appear (usually around a program or file name), the user should include them in the appropriate place according, to the format example.

KEYWORDS, also called RESERVED WORDS, appear in uppercase letters. THESE KEYWORDS MUST BE ENTERED EXACTLY AS THEY APPEAR. However, many keywords have abbreviations that can also be used.

Keywords are words that are part of the BASIC language that the computer understands. Keywords are the central part of a command or statement. They tell the computer what kind of action to take. These words cannot be used as variable names.

ARGUMENTS (also called parameters) appear in lower case. Arguments are the parts of a command or statement; they complement keywords by providing specific information about the command or statement. For example, a keyword tells the computer to load a program, while the argument tells the computer which specific program to load and a second argument specifies which drive the disk containing the program is in. Arguments include filenames, variables, line numbers, etc.

SQUARE BRACKETS [] show OPTIONAL arguments. The user selects any or none of the arguments listed, depending on the requirements.

ANGLE BRACKETS <> indicates that the user MUST choose one of the arguments listed.

VERTICAL BAR | separates items in a list of arguments when the choices are limited to those arguments listed, and no other arguments can be used. When the vertical bar appears in a list enclosed in SQUARE BRACKETS, the choices are limited to the items in the list, but still have the option not to use any arguments.

ELLIPSIS ..., a sequence of three dots, means that an option or argument can be repeated more than once.

QUOTATION MARKS " " enclose character strings, filenames, and other expressions. When arguments are enclosed in quotation marks in a format, the quotation marks must be included in a command file or statement. Quotation marks are not conventions used to describe formats; they are required parts of a command or statement.

PARENTHESES () When arguments are enclosed in parentheses in a format, they must be included in a command or statement. Parentheses are not conventions used to describe formats; they are required parts of a command or statement.

VARIABLE refers to any valid BASIC variable name such as X, A$, or T%.

EXPRESSION means any valid BASIC expression, such as A+B+2 or .5*(X+3).

3.1.2 ALPHABETICAL LIST OF COMMANDS, FUNCTIONS, and OPERATORS

*	Token = AC	multiplication
+	Token = AA	addition
-	Token = AB	subtraction
/	Token = AD	division
<	Token = B3	less-than
=	Token = B2	equal
>	Token = B1	greater-than
^	Token = AE	exponentiation
(PI)	Token = FF	return value of PI
ABS	Token = B6	absolute function
AND	Token = AF	logical AND operator
APPEND	Token = FE,0E	append file
SC	Token = C6	string to PETSCII function
ATN	Token = C1	trigometric arctangent function
AUTO	Token = DC	auto line numbering
BACKGROUND	Token = FE,3B	background color
BACKUP	Token = F6	backup diskette
BANK	Token = FE,02	memory bank selection
BEGIN	Token = FE,18	start logical program block
BEND	Token = FE,19	end logical program block
BLOAD	Token = FE,11	binary load file from diskette
BOOT	Token = FE,1B	load & run ML, or BASIC autoboot
BORDER	Token = FE,3C	border color
BOX	Token = E1	draw graphic box
BSAVE	Token = FE,10	binary save to disk file
BUMP	Token = CE,03	sprite collision function
BVERIFY	Token = FE,28	verify memory to binary file
CATALOG	Token = FE,0C	disk directory
CHANGE	Token = FE,2C	edit program
CHAR	Token = E0	display characters on screen
CHR$	Token = C7	PETSCII to string finction
CIRCLE	Token = E2	draw graphic circle
CLOSE	Token = A0	close channel or file
CLR	Token = 9C	clear BASIC variables, etc.
CMD	Token = 9D	set output channel
COLLECT	Token = F3	validate diskette (chkdsk)
COLLISION	Token = FE,17	enable BASIC event
COLOR	Token = E7	set screen colors
CONCAT	Token = FE,13	concatenate two disk files
CONT	Token = 9A	continue BASIC program execution
COPY	Token = F4	copy a disk file
COS	Token = BE	trigometric cosine function
CUT	Token = E4	cut graphic area
DATA	Token = 83	pre-define BASIC program data
DCLEAR	Token = FE,15	mild reset of disk drive
DCLOSE	Token = FE,0F	close disk channel or file
DEC	Token = D1	decimal function
DEF	Token = 96	define user function
DELETE	Token = F7	delete BASIC lines or disk file
DIM	Token = 86	dimension BASIC array
DIR	Token = EE	disk directory
DISK	Token = FE,40	send disk special command

DLOAD	Token = F0	load BASIC program from disk
DMA	Token = FE,1F	define & execute DMA command
DMA	Token = FE,21	"
DMA	Token = FE,23	"
DMODE	Token = FE,35	set graphic draw mode
DO	Token = EB	start BASIC loop
DOPEN	Token = FE,0D	open channel to disk file
DPAT	Token = FE,36	set graphic draw pattern
DSAVE	Token = EF	save BASIC program to disk
DVERIFY	Token = FE,14	verify BASIC memory to file
ELLIPSE	Token = FE,30	draw graphic ellipse
ELSE	Token = D5	if/then/else clause
END	Token = 80	end of BASIC program
ENVELOPE	Token = FE,0A	define musical instrument
ERASE	Token = FE,2A	delete disk file
ERR$	Token = D3	BASIC error function
EXIT	Token = ED	exit BASIC loop
EXP	Token = BD	exponentiation function
FAST	Token = FE,25	set system speed to maximum
FILTER	Token = FE,03	set audio filter parameters
FIND	Token = FE,2B	hunt for string in BASIC program
FN	Token = A5	define user function
FOR	Token = 81	start BASIC for/next loop
FOREGROUND	Token = FE,39	set foreground color
FRE	Token = B8	available memory function
GCOPY	Token = FE,32	graphic copy
GENLOCK	Token = FE,38	set video sync mode
GET	Token = A1	receive a byte of input
GO	Token = CB	program branch
GOSUB	Token = 8D	program subroutine call
GOTO	Token = 89	program branch
GRAPHIC	Token = DE	set graphic mode
HEADER	Token = F1	format a diskette
HELP	Token = EA	display BASIC line causing error
HEX$	Token = D2	return hexidecimal string function
HIGHLIGHT	Token = FE,3D	set highlight color
IF	Token = 8B	if/then/else conditional
INPUT	Token = 85	recieve input data from keyboard
INPUT#	Token = 84	recieve input data from channel (file)
INSTR	Token = D4	locate a string within a string
INT	Token = B5	integer function
JOY	Token = CF	joystick position function
KEY	Token = F9	define or display function key
LEFT$	Token = C8	leftmost substring function
LEN	Token = C3	length of string function
LET	Token = 88	variable assignment
LINE	Token = E5	draw graphic line, input line
LIST	Token = 9B	list BASIC program
LOAD	Token = 93	load program from disk
LOCATE	Token = E6	(currently unimplemented)
LOG	Token = BC	natural log function
LOOP	Token = EC	end of do/loop
LPEN	Token = CE,04	lightpen position function
MID$	Token = CA	substring function
MONITOR	Token = FA	enter ML Monitor mode
MOUSE	Token = FE,3E	set mouse parameters
MOVSPR	Token = FE,06	set sprite position and speed
NEW	Token = A2	clear BASIC program area

NEXT	Token = 82	end of for-next loop
NOT	Token = A8	logical complement function
OFF	Token = FE,24	(subcommand)
ON	Token = 91	multiple branch or subcommand
OPEN	Token = 9F	open I/O channel
OR	Token = B0	logical or function
PAINT	Token = DF	graphic flood-fill
PALETTE	Token = FE,34	set palette color
PASTE	Token = E3	draw graphic area from cut buffer
PEEK	Token = C2	return memory byte function
PEN	Token = FE,33	set graphic pen color
PIC	Token = FE,37	graphic subcommand
PLAY	Token = FE,04	play musical notes from string
POINTER	Token = CE,0a	address of string var function
POKE	Token = 97	change memory byte
POLYGON	Token = FE,2F	draw graphic pologon
POS	Token = B9	text cursor position function
POT	Token = CE,02	return paddle position
PRINT	Token = 99	display data on text screen
PRINT#	Token = 98	send data to channel (file)
PUDEF	Token = DD	define print-using symbols
QUIT	Token = FE,1E	(currently unimplemented)
RCLR	Token = CD	(currently unimplemented)
RDOT	Token = D0	(currently unimplemented)
READ	Token = 87	read program pre-defined program data
RECORD	Token = FE,12	set Relative disk file record pointer
REM	Token = 8F	BASIC program comment
RENAME	Token = F5	rename disk file
RENUMBER	Token = F8	renumber BASIC program lines
RESTORE	Token = 8C	set DATA pointer, subcommand
RESUME	Token = D6	resume BASIC program after trap
RETURN	Token = 8E	end of subroutine call
RGR	Token = CC	(currently unimplemented)
RIGHT$	Token = C9	rightmost substring function
RMOUSE	Token = FE,3F	read mouse position
RND	Token = BB	pseudo random number function
RREG	Token = FE,09	return processor registers after SYS
RSPCOLOR	Token = CE,07	return sprite color function
RSPPOS	Token = CE,05	return sprite position function
RSPRITE	Token = CE,06	return sprite parameter function
RUN	Token = 8A	run BASIC program from memory or disk
RWINDOW	Token = CE,09	return text window parameter function
SAVE	Token = 94	save BASIC program to disk
SCALE	Token = E9	(currently unimplemented)
SCNCLR	Token = E8	erase text or graphic display
SCRATCH	Token = F2	delete disk file
SCREEN	Token = FE,2E	set parameters or open graphic screen
SET	Token = FE,2D	set system parameter, subcommand
SGN	Token = B4	return sign of number function
SIN	Token = BF	trigometric sine function
SLEEP	Token = FE,0B	pause BASIC program for time period
SLOW	Token = FE,26	set system speed to minimum
SOUND	Token = DA	perform sound effects
SPC	Token = A6	skip spaces in printed output
SPRCOLOR	Token = FE,08	set multicolor sprite colors
SPRDEF	Token = FE,1D	(currently unimplemented)
SPRITE	Token = FE,07	set sprite parameters
SPRSAV	Token = FE,16	set or copy sprite definition

SQR	Token = BA	square root function
STEP	Token = A9	for-next step increment
STOP	Token = 90	halt BASIC program
STR$	Token = C4	string representation of number function
SYS	Token = 9E	call ML routine
TAB(	Token = A3	tab position in printed output
TAN	Token = C0	trigometric tangent function
TEMPO	Token = FE,05	set tempo (speed) of music play
THEN	Token = A7	if/then/else clause
TO	Token = A4	(subcommand)
TRAP	Token = D7	define BASIC error handler
TROFF	Token = D9	BASIC trace mode disable
TRON	Token = D8	BASIC trace mode enable
TYPE	Token = FE,27	display sequential disk file
UNTIL	Token = FC	do/loop conditional
USING	Token = FB	define print output format
USR	Token = B7	call user ML function
VAL	Token = C5	numeric value of a string function
VERIFY	Token = 95	compare memory to disk file
VIEWPORT	Token = FE,31	(currently unimplemented)
VOL	Token = DB	set audio volume
WAIT	Token = 92	pause program pending memory condition
WHILE	Token = FD	do/loop contitional
WIDTH	Token = FE,1C	(currently unimplemented)
WINDOW	Token = FE,1A	set text screen display window
XOR	Token = CE,08	logical xor function

3.1.3 BASIC 10.0 COMMAND AND FUNCTION DESCRIPTION

ABS - Absolute value function

```
ABS (expression)
```

The ABSolute value function returns the unsigned value of the numeric expression.

```
X = ABS(1)              Result is X = 1
X = ABS(-1)             Result is X = 1
```

AND - Boolean operator

```
expression AND expression
```

The AND operator returns a numeric value equal to the logical AND of two numeric expressions, operating on the binary value of signed 16-bit integers in the range (-32768 to 32767). Numbers outside this range result in an 'ILLEGAL QUANTITY' error.

```
X = 4 AND 12            Result is X=4
X = 8 AND 12            Result is X=8
X = 2 AND 12            Result is X=0
```

In the case of logical comparisons, the numeric value of a true situation is -1 (equivalent to 65535 or $FFFF hex) and the numeric value of a false situation is zero.

```
X = ("ABC"="ABC") AND ("DEF"="DEF")    Result is X=-1 (true)
X = ("ABC"="ABC") AND ("DEF"="XYZ")    Result is X= 0 (false)
```

APPEND - Open a disk file and prepare to append data to it

```
APPEND# logical_file_number, "filename" [,Ddrive] [<ON|,>Udevice]
```

Opens filename for writing, and positions the file pointer at the end of the file. Subsequent PRINT# statements to the logical_file_number will cause data to be appended to the end of this file. If the file does not exist, it will be created.

```
APPEND#1, "filename"
APPEND#1, (file$), ON U(unit)
```

ASC - PETSCII value function

```
ASC (string)
```

This function returns the PETSCII numeric value of the first character of a string. The PETSCII value of an empty (null) string is zero. This function is the opposite of the CHR$ function. Refer to the Table of PETSCII Character Codes.

```
X = ASC("ABC")          Result is X=65
X = ASC("")             Result is X=0
```

ATN - Arc tangent function

```
ATN (expression)
```

This function returns the angle whose tangent is the value of the numeric expression, measured in radians. The result is in the range of -PI/2 to PI/2 radians.

X = ATN(45)	Result is X=1.54050257

To get the arc tangent of an angle measured in degrees, multiply the numeric expression by pi/180.

AUTO - Enable or disable automatic line numbering

```
AUTO [increment]
```

Turns on the automatic line numbering feature which eases the job of entering programs by typing the line numbers for the user. As each program line is entered by pressing RETURN the next line number is printed on the screen, with the cursor in position to begin typing that line. The increment parameter refers to the increment between line numbers. AUTO with no increment given turns off auto line numbering. AUTO mode is also turned off automatically when a program is RUN. This statement is executable only in direct mode.

AUTO 10	automatically numbers line in increments of ten.
AUTO 50	automatically numbers line in increments of fifty.
AUTO	turns off automatic line numbering.

BACKGROUND - Set the background color of the display

```
BACKGROUND color
```

Sets the screen background color to the given color. The color given must be in the range (0-15). See the Color Table.

BACKUP - Backup an entire disk from one drive to another

```
BACKUP Dsource_drive TO Ddestination_drive [<ON|,>Udevice]
```

This command copies all the files on a diskette to another on a dual drive system only. It cannot backup diskettes using CBM serial bus type drives, for example. If the destination diskette is unformatted, BACKUP will automatically format it. BACKUP copies every sector, so any data already on the destination diskette will be overwritten. To copy specific files from one drive to another, use the COPY command.

NOTE: This command can only be used with a dual disk drive, such as the built-in C64DX drive and optional F016-type expansion drive. To backup diskettes using different drives, such as the built-in drive and a 1581-type serial bus drive, use a utility program.

BACKUP D0 to D1	Copies all files from the disk in drive 0 to the disk in drive 1.
BACKUP D0 TO D1, ON U9	Copies all files from drive 0 to drive 1 in disk drive unit 9.

BANK - Set the memory bank number for PEEK,POKE,SYS,WAIT,LOAD,SAVE

```
BANK memory_bank
```

[*** THIS COMMAND MIGHT CHANGE ***]

This command should be used before and BASIC command that has an address parameter. The address parameters are limited to the range (0-65535, $0000-$FFFF hex). The BANK command tells the computer which 64K byte memory bank the location you want is in.

The memory_bank parameter is number from 0-255. Refer to the System memory map to see what is in each bank. A BANK number greater than 127 (i.e., has its most significant bit set) means "use the current system configuration", and must be used to access an I/O location. BASIC defaults to BANK 128.

For examples, see PEEK, POKE, etc.

BEGIN/BEND - Extend an IF clause over more than one line

BEGIN/BEND are used to define a block of code which is considered by the IF statement to be one statement.

The normal usage of IF/THEN/ELSE would be along the following lines:

```
        IF boolean THEN statement(s) : ELSE statement(s)
```

The main restriction is that the entire body of the IF/THEN/ELSE construct can only occupy one line. BEGIN/BEND allows either the 'THEN' or the 'ELSE' clause to run on for more than one line.

```
        IF boolean THEN BEGIN : statements....
                                statements...
                                statements...  BEND : ELSE BEGIN
                                statements...
                                statements...  BEND
```

Remember, however, that this is only a way to extend the body for more than one line: all other 'IF/THEN' rules apply. For example:

```
                100 IF x=1 THEN BEGIN : a=5
                110 :  b=6
                120 :  c=7
                130 BEND : print "ah-ha!"
```

In the above example, "ah-ha!" would be printed ONLY if the expression expression 'x=1' is TRUE, because the print statement is on the same logical line as the THEN clause.

It is bad practice to GOTO a line in the middle of a BEGIN-BEND block. If BEGIN or BEND is encountered outside of an active IF statement, it is ignored.

BLOAD - loads a binary disk file into memory

```
        BLOAD "filename" [,Bbank] [,Paddress] [<ON|,>Udevice]
```

Used to load a machine language program or other binary data (such as display pictures or sprite data) into memory. If a load address is not given, the load address given in the disk file will be used. If a bank number is not given, the bank given in the last BANK statement will be used. If a load overflows a bank (that is, the load address exceeds 65535 ($FFFF), an 'OUT OF MEMORY' error is reported. Also see the LOAD command.

```
                BLOAD "sprites", P(dec("600")), B0
```

BOOT - Load and execute a program

```
BOOT
BOOT SYS
BOOT filename [,Bbank] [,Paddress] [,Ddrive] [<ON|,>Udevice]
```

BOOT without a filename given causes the computer to look for a BASIC program called AUTOBOOT.C65* on the indicated diskette, LOAD it and RUN it (just like RUN "AUTOBOOT.C65*").

BOOT with a filename given will cause the executable binary file to be BLOADed and executed beginning at the load address. If a load address is not given, the file will be loaded and execution begun at the address stored on disk.

BOOT SYS is a special command that copies the "home" sector (the very track and sector) of the C64DX built-in drive into memory at address $400 to $5FF (one physical sector, 512 bytes) and perform a machine language JSR (Jump SubRoutine) to it. It has the same function as turning on your C64DX while holding down the ALT key. It is used to boot an alternate operating system from either a CBM 3.5" diskette or an MSDOS (720K) diskette. If used in a BASIC program, and it fails, the system can be corrupted. BOOT SYS does *not* use the normal DOS to access the disk.

BOOT	Loads & runs BASIC program called AUTOBOOT.C65* on system disk.
BOOT U9	Loads & runs BASIC program called AUTOBOOT.C65* on disk unit 9.
BOOT "ml"	Load & executes machine language program called ML, starting at address stored on disk.

BORDER - Set the exterior border color of the display

```
BORDER color
```

Sets the screen border color to given color. The color must be in the range (0-15). See the Color Table.

BOX - Draw a 4-sided graphical shape

```
BOX x0,y0, x1,y0, x0,y1, x1,y1 [,solid]
```

Requires two line segments to be specified, the order of which determines the shape drawn. The shape is drawn in the currently specified PEN color, on the currently specified SCREEN. The above command will draw the following shape:

But if the order of the coordinates were given as:

```
BOX x0,y0, x1,y0, x1,y1, x0,y1
```

a "bowtie" shape would be drawn. See the sample program at SCREEN.

BSAVE - Save an area of memory in binary disk file

```
BSAVE "[@]filename", Pstart_adr TO Pend_adr [,Bbank] [,Ddrive] [<ON|,>Udevice]
```

BSAVE copies an area of memory into a binary disk file called "filename", starting at start_adr and ending at end_adr-1 (i.e., end_adr must be one more than actual last address saved). If a bank number is not given, the bank given in the last BANK statement will be used. End_adr must be greater than start_adr, and area to be saved must be limited to the indicated memory bank. You cannot save data from more than one bank at a time. Start_adr is saved on disk as the load address. If filename already exists on the designated diskette, memory is NOT saved and a 'FILE EXITS' error is reported. Preceding the filename with an '@'-sign will allow you to overwrite an existing file, but see the cautions at DSAVE.

```
BSAVE "sprites", P(dec("600")) TO P(dec("800")), B0
```

BUMP - Sprite collision function

```
BUMP (type)
```

This function return a numeric summary of sprite collisions accumulated since the last time the BUMP function was used.

You can use the COLLISION command to set up a special routine in your program to receive control whenever a sprite BUMPs into something, but a particular COLLISION does not have to be enabled to use BUMP. See the COLLISION command.

To evaluate sprite collisions, where a BIT position (0-7) in the numeric result corresponds to a sprite number (0-7):

```
BIT position:             7 6 5 4 3 2 1 0
                          | | | | | | | |
BUMP value in binary:     0 0 0 0 0 1 0 1      = 5 decimal
```

BUMP(1) returns a value representing sprite-to-sprite collisions.
BUMP(2) returns a value representing sprite-to-data collisions.

```
X = BUMP(1)       Result is X=3 if sprites 0 & 1 collided,
                  as shown above. (binary 101 = 5 decimal).
```

Note that more than one collision can be recorded, in which case you should evaluate a sprite's position using the RSPPOS function to figure out which sprite collided with what. BUMP is reset to zero after each use.

BVERIFY - Compare a binary disk file to an area of memory

```
BVERIFY "filename" [,Paddress] [,Bbank] [,Ddrive ] [<ON|,>Udevice]
```

BVERIFY compares a binary disk file called "filename" to an area of memory. In direct mode, if the areas contain the same data the message "OK" is displayed, and if the data differs the message 'VERIFY ERROR' is displayed.

In program mode, an error is generated if a mismatch is found, otherwise the program continues normally. The comparison starts with the address given, else it starts at the address stored on disk. The comparison ends when the last byte is read from the disk file.

If a bank number is not given, the bank given in the last BANK statement will be used. The ending address is determined by the length of the disk file. The comparison halts on the first mismatch or at the end of the file. The area to be compared must be confined to the indicated memory bank.

```
BVERIFY "sprites", P(dec("600")), B0
```

CATALOG - see DIR (DIRECTORY) command

CHANGE - Find text in a BASIC program and change it.

```
CHANGE :string1: TO :string2: [,line_range]
CHANGE "string1" TO "string2" [,line_range]
```

This is a direct (edit) mode command. CHANGE looks for all occurances of string1 in the program, displays each line containing string1 with the target string highlighted, and prompts the user for one of the following:

Y<return>	Yes, change it and look for more
N<return>	No, don't change it, but look for more
*<return>	Yes, change all occurances from here on
<return>	Exit command now, don't change anything

Any character can be used for the string delimiter, but there are side effects: see comments at FIND command. If the line number range is not given (see LIST for description of range parameter), the entire program is searched.

CHAR - Draw a character string on a graphic screen

```
CHAR column, row, height, width, direction, "string" [,charsetadr]
```

[*** THIS IS SUBJECT TO CHANGE ***]

CHAR displays text on a graphic screen at a given location. The character height, width, and direction are programmable. The parameters are defined as:

column:	Character position: For 320 wide screens, 0-39 For 640 wide screens, 0-79
row:	Pixel line: For 200 line screens, 0-199 For 400 line screens, 0-399
height:	Multiple of 8-bit character height: 1= 8 pixels high, 2= 16 pixels, etc.
width:	Multiple of 8-bit character width: 1= 8 pixels high, 2= 16 pixels, etc.
direction:	Bit mask: B0= up B1= right B2= down B3= left

The string can consist of any printable character, as defined by the VIC character set. Non-text characters are ignored. If the address if the character set is not given, the upper/lower ROM character set is used ($29800).

```
CHAR 18,96, 1,1,2, "C64D", DEC("9000")
```

The above example will draw the characters "C65D" in the center of a 320x200 pixel screen using the system's uppercase/graphic character set.

CHR$ - Character string function

```
CHR$ (value)
```

This function returns a string of one character having the PETSCII value specified. This function is the opposite of the ASC function. It's often used in PRINT strings to output data that is not visible, such as control codes and escape sequences. Refer to the Table of PETSCII Character Codes.

`PRINT CHR$(27)"Q";`	CHR$(27) is the escape character. This statement performs the clear-to-end-of-line escape function.

CIRCLE - Draw a circle on a graphic screen

```
CIRCLE  x_center, y_center, radius [,solid]
```

The CIRCLE command will draw a circle with the given radius centered at (x_center,y_center) on the current graphic screen. The circle will be filled (i.e., a disc) if SOLID is non-zero.

```
CIRCLE 160,100,50
```

The above example will draw a circle in the center of a 320x200 pixel screen (160,100) having a radius of 50 pixels. The aspect ratio of the screen may cause it to appear as an ellipse, however. See also the ELLIPSE command.

CLOSE - Close a logical I/O channel

```
CLOSE logical_channel_number
```

This command closes the input/output channel associated with the given logical_channel_number, established by an OPEN statement. In the case of buffered output (such as the serial bus or RS232) any data in the device's buffer will be transmitted before the channel is closed. Refer to specific I/O operations for details.

The logical_channel_number is required; to close all channels on a given device, use the DCLOSE command. Note that RUN, NEW, and CLR commands will initialize the logical channel tables but will not actually close any channels.

CLR - Clear program variables

```
CLR
```

This statement initializes BASIC's variable list, setting all numeric variables to zero and string variables to null. It also initializes the DATA pointer, BASIC runtime stack pointer (i.e., clears all GOSUBs, DO/LOOPs, FOR/NEXT loops, etc.), and clears any user functions (DEF FNx). Any OPEN channels are forgotten (but a CLOSE is not performed- don't use if there are any open disk output files). A CLeaR is automatically performed by a RUN or a NEW command.

CMD - Set default output channel

```
CMD logical_channel_number [,string]
```

CMD changes the default output device, normally the screen, to that specified. The logical_channel_number can be any previously OPENed write channel, such as one to a disk file, printer, or RS232.

When redirected via CMD, all output which normally would go to the screen (such as PRINT commands, LIST output, DIRECTORY lists, etc.) is sent to another device or file.

The redirection is terminated by CLOSE-ing the CMD channel or executing a PRINT# to the CMD channel. Some output devices require a PRINT# to be performed before the CMD channel is closed, such as printers, to cause the device's buffer to be flushed (i.e., displayed).

Any system error will redirect output back to the system default, normally the screen, but will not flush nor close the output channel.

If the optional string is given, it is output immediately after the CMD device is established. This feature is normally used to set up printers (eg., set printer modes via escape codes) or to identify the output (eg., title printouts).

```
OPEN 4,4        OPENS device #4, which is the printer.
CMD 4           All normal output now goes to the printer.
LIST            The LISTing goes to the printer.
PRINT#4         Set output back to the screen.
CLOSE 4         Close the printer channel.
```

COLLECT - Check (validate) disk, delete bad files and free lost sectors

COLLECT [Ddrive] [<ON|,>Udevice]

Refer to the DOS 'V'alidate command. This command will cause the DOS to recalculate the Block Availability Bam (BAM) of the diskette in the indicated drive, allocating only those sectors being used by valid, properly closed files. All other sectors are marked as "free" and improper files are automatically deleted.

Note: COLLECT should be used with extreme care, and MUST NOT be used on diskettes with special boot sectors or direct access (eg., random) files. In any case, be sure the diskette has been BACKUP-ed first.

COLLISION - Setup subroutine to handle special events

COLLISION type [,linenumber]

[*** THIS MIGHT CHANGE ***]

COLLISION is used to handle "interrupt" situations in BASIC, such as sprites bumping into things or lightpen triggers. When the specified situation occurs, BASIC will finish processing the currently executing instruction and perform an automatic GOSUB to the linenumber given.

When the subroutine terminates (it must end with a RETURN) BASIC will resume processing where it left off. Interrupt handling continues until a COLLISION of the same type but without any linenumber is specified. More than one type interrupt may be enabled at the same time, but only one interrupt can be handled at a time (i.e., no recursion and no nesting of interrupts). The type interrupt can be:

1 = Sprite to sprite collision
2 = Sprite to display data collision
3 = Light pen

Note that what caused an interrupt may continue causing interrupts for some time unless the situation is altered or the interrupt is disabled. This is especially true for BASIC, which is slow to respond to interrupts. Use the BUMP and RSPPOS functions to evaluate the results of sprite collisions, and the LPEN function to evaluate the position of a light pen.

```
10 COLLISION 1,90
20 SPRITE1,1:MOVSPR1,100,100:MOVSPR1,0#5
30 SPRITE2,1:MOVSPR2,100,150:MOVSPR2,180#5
40 DO:PRINT:LOOP
50 END
90 PRINT"BUMP! ";:RETURN
```

In this example, sprite-to-sprite collisions are enabled (line 10), and two sprites are turned on, positioned, and made to move (lines 20 & 30). One sprite moves up and the other moves down while the program does nothing other than print blank lines to the screen (line 40). When the sprite collide, the subroutine at line 90 is called, it prints "BUMP!", and the computer goes back to printing blank lines.

COLOR - Enable or disable screen color (character attribute) control

```
COLOR <ON|OFF>
```

COLOR turns on or turns off the screen editor's attribute handler. When colors are turned off, whatever character attributes are being currently displayed (text color, underline, flash, etc.) are "stuck". The main purpose for doing this is to speed up screen handling (writing to the screen or scrolling the screen) about two times, since the screen editor no longer has to manipulate the attibutes. Note that only FOREGROUND colors (and special VIC attributes) are affected.

To change screen colors, use the following commands:

FOREGROUND	color#	Set Foreground color (text)
HIGHLIGHT	color#	Set Highlight color (text)
BACKGROUND	color#	Set VIC Background color
BORDER	color#	Set VIC Border color

CONCAT - Concatenate (merge) two sequential disk files

```
CONCAT "file1"[,Ddrive1] TO "file2"[,Ddrive2] [<ON|,>Udevice]
```

CONCAT merges two SEQuential files, appending the contents of "file1" to "file2". Upon completion, "file2" contains the data of both files, and "file1" is unchanged. Both files must exist on drives of the the same unit, and pattern matching is not allowed.

Some disk drives handle CONCAT differently; refer to the DOS manual for specific details.

CONT - Continue program execution

```
CONT
```

CONTinue is used to re-start a BASIC program that was halted by a STOP or END statement, or interrupted by the STOP key. The program will resume at the statement following the STOP or END instruction, or at the statement after the one that was interrupted by the STOP key. CONT is typically used during program debugging. You can look at and alter variables while the program is halted.

Programs halted as a result of an untrapped error condition cannot be CONTinued. Programs that have been edited in any way cannot be restarted. Any error condition that occurs since the program was halted will prevent it from being restarted. Programs that cannot be restarted via CONT can be restarted with a GOTO, as long as you don't need to resume execution in the middle of a line of commands and you recall where the halt occurred.

Note that the STOP key can interrupt some commands in mid-execution, such as file I/O, drawing commands, etc. In such cases, programs may not run correctly after a CONTinue.

COPY - Copy disk files

```
COPY ["file1"][,Dd1] TO ["file2"][,Dd2] [<ON|,>Udevice]
```

COPYs a disk file to another disk file. On single drive units, the filenames must be different. On dual drive units, copying can be done between two drives on the same unit, and the filenames can be the same or different. Pattern matching an be used.. Copying files from one unit to a different unit cannot be done; use a copy utility program in such cases. Only legal type files can be copied; direct access data, boot sectors, and partitions cannot be copied.

Refer to the DOS manual for your disk drive for specific details.

`COPY "file1" TO (f2$)`	Copies "file1" to another file whose name is in F2$ on the same drive. Names must differ.
`COPY "file1",D0 TO D1,U9`	Copies "file1" from unit 9 drive-0 to unit 9 drive-1.
`COPY D0 TO D1`	Copies all files from drive-0 to drive-1 on the same unit.
`COPY "???.src",D0 TO "*",D1`	Copies all files on drive-0 matching the pattern to a file of the same name on drive-1.

COS - Cosine function

```
COS (expression)
```

This function returns the cosine of X, where X is an angle measured in radians. The result is in the range -1 to 1.

`X = COS(pi)`	Result is X=-1

To get the cosine of an angle measured in degrees, multiply the numeric expression by pi/180.

CUT - Cut a graphic area into a temporary structure

```
CUT x,y,dx,dy
```

[*** NOT YET IMPLEMENTED ***]

DATA - Define program constant data to be accessed by READ command

```
DATA [list of constants]
```

DATA statements store lists of data that will be accessed during program execution by a READ statement. The DATA statement can appear anywhere in the program, and it is never executed. BASIC keeps a pointer to the earliest un-READ DATA statement, and data is read sequentially from first item in a DATA statement to the last item, from the earliest DATA statement in the program to the last DATA statement in the program.

The list of constants can contain both numeric data (integer or floating point) and string data, but cannot contain expressions which must be evaluated (such as 1+2, DEC("1234"), or CHR$(13)). Items are separated by commas. String data need not be enclosed in quotes unless it contains certain characters, such as spaces, commas, colons, graphic characters, or control codes. If two commands have nothing between them, the data will be READ as 0 if numeric or a null string.

The RESTORE command allows you to position BASIC's data pointer to a specific line number. If the program tries to read more DATA than exists in the program, an 'OUT OF DATA' error results. If a READ statement's variable type does not agree with the DATA being read, a 'TYPE MISMATCH' error results.

```
DATA 100, 200, FRED, "HELLO, MOM", , 3.14, ABC123, -1.7E-9
```

DCLEAR - Clear all open channels on disk drive

```
DCLEAR  [Ddrive] [<ON|,>Udevice}
```

DCLEAR sends the indicated disk drive an 'I'nitialize command. This clears all open channels, closes all open files, and causes the DOS to re-read the diskette's Block Allocation MAP (BAM). Note that DCLEAR DOES NOT close open channels on the computer's side (see the DCLOSE command). There are some other side affects caused by this command with different types of drives- refer the DOS manual for your disk drive for specific details.

DCLOSE - Close a disk file, or close all channels on a device

```
DCLOSE [#logical_file_number] [<ON|,>Udevice]
```

DCLOSE is intended to close a file opened with the DOPEN command. Specific files can be closed by specifying a logical_file number, or all files on a particular drive can be closed by not specifying a particular logical_file number.

It is possible to close channels on non-disk devices with this command by specifying only the device number.

DCLOSE#1	Closes the file associated with logical logical file number 1.
DCLOSE	Closes all files currently open on the default system drive.
DCLOSE U(U2)	Closes all channels open to device U2.

DEC - Decimal value function

```
DEC (hex_string)
```

This function return the decimal value of a string representing a hexadecimal number in the range "0000" to "FFFF". The result is in the range 0-65535. If the string contains a non-hexadecimal digit or is more than four (4) characters in length an 'ILLEGAL QUANTITY' error is reported.

VIC = DEC("D000")	Result is VIC=53248, the address of the VIC chip

DEF FN - Define function

```
DEF FNname (numeric_variable) = numeric_expression
```

Define a user-written numeric function. The DEF FNx statement must be executed before the function can be used. Once a function has been defined, it can be used like any other numeric variable. The function name is the letters FN followed by any legal floating point (non-integer) variable name. A function can be defined only in a program.

The numeric_variable is a "dummy" variable. It names the variable in the numeric_expression which will be replaced when the function is used. It's not required to be used in the numeric_expression, and its value won't be changed by the function call.

The numeric_expression performs the calculations of the function. It is any legal numeric expression that fits on one line. Variables used in the expression have their value at the time the function is used.

Functions can be used only by the program which defines them. If one program chains to another program, the first program's functions cannot be used (usually a 'SYNTAX ERROR' results). Similarly, if the program is moved in any way after the function is defined, the function cannot be used.

```
10 DEF FNR(MAX) = INT(RND(0)*MAX)+1
20 INPUT "MAXIMUM"; MAX
30 PRINT FNR(MAX)
```

In this example, we've defined a function which will return a pseudo random number between 1 and whatever MAX is. Instead of using the expression INT(RND(0)*MAX)+1 every time a random number is needed, we can now use FNR(MAX). When we use FNR(x), the value of 'x' will be be substituted everywhere MAX is used in the function definition.

```
10 DEF FNI(X) = X+1
20 DEF FNL(Z) = LEN(A$)
30 DEF FNAVG(N) = (TOT*CNT+N)/(CNT+1)
```

DELETE - Delete lines of BASIC program, or Delete disk files

```
DELETE [startline] [-[endline]]
DELETE "filespec" [,Ddrive] [<ON|,>Udevice] [,R]
```

There are two forms of DELETE. The first form is used in direct mode to remove lines from a BASIC program:

DELETE 75	Deletes line 75.
DELETE 10 - 50	Deletes line 10 through 50 inclusive.
DELETE - 50	Deletes all lines from the beginning of the program up to and including line 50.
DELETE 75-	Deletes all lines from 75 to the end of the program.

The second form is used in program or direct mode to delete a disk file. See the SCRATCH command.

DELETE "myfile"	Deletes the file MYFILE on the system drive.

DIM - Declare array dimensions

```
DIM variable(subscripts) [,variable(subscripts)]...
```

Before arrays of variables can be used, the program must first execute a DIM statement to establish DIMensions of that array (unless there are 11 or fewer elements in the array). The statement DIM is followed by the name of the array, which may be any legal variable name. Then, enclosed in parentheses, put the number (or numeric variable) of elements in each dimension. An array with more than one dimension is called a matrix. Any number of dimensions may be used, but keep in mind that the whole list of variables being created takes up space in memory, and it is easy to run out of memory if too many are used. To figure the number of variables created with each DIM, multiply the total number of elements in each dimension of the array. Note: each array starts with element 0, and integer arrays take up 2/5ths of the space of floating point arrays.

More than one array can be dimensioned in a DIM statement by separating the arrays by commas. If the program executes a DIM statement for any array more than once, the message 'REDIM'D ARRAY' is reported. It is good programming practice to place DIM statements near the beginning of the program.

```
10 DIM A$(40),B7(15),CC%(4,4,4)
          |       |         |
41 elements   16 elements  125 elements
```

DIR - List the files of a diskette
DIRECTORY

```
DIRECTORY ["filespec"] [,R] [,Ddrive] [<ON|,>Udevice]
```

A directory is a list of the names of the files that are on a diskette. The directory listing consists of the name of the diskette, the names, sizes, and filetypes of all the files on a diskette, and the remaining free space on the diskette. The filespec is used to specify a pattern match string to view selected files. Not all disk drives support the same options or filespecs; refer to your DOS manual for details. The C64DX allows you to print DIR listings without having to 'load' the directory; see example below.

The commands DIR, DIRECTORY, and CATALOG have the exact same function. They can be used in direct or program mode.

DIRECTORY	List all files on the diskette in the default system drive.
DIR "*.src", U9	Lists the all the files ending with ".src" on unit 9.
DIR "*,=p",R	List all the deleted but recoverable PRG-type files on the system drive.
OPEN4,4:CMD4:DIR:CLOSE4	Print DIR listing to printer unit 4.

The following program can be used to load the directory into variables for use within a program. In this case, the filename is simply printed to the screen:

```
10 OPEN 1,8,0,"$0:*,P,R"                open dir as a file
20 : IF DS THEN PRINT DS$: GOTO100      abort if error
30 GET#1,X$,X$                          trash load address
40 DO                                   read each line
50 : GET#1,X$,X$: IF ST THEN EXIT       trash links, check eof
60 : GET#1,BL$,BH$                      get file size
70 : LINE INPUT#1, F$                   get filename & type
80 : PRINT LEFT$(F$,18)                 print filename
90 : LOOP                               loop until eof
```

```
        100 CLOSE 1                                   close dir
```

DISK - Send a disk command

```
DISK "command_string"  [<ON|,>Udevice]
```

The DISK command is used to send special commands to the DOS via the disk drive's command channel. The DISK command is analogous to the following BASIC code:

```
OPEN 1,n,15: PRINT#1,"command_string": CLOSE 1
```

Not all disk drives understand the same commands. Refer to your DOS manual for commands and command syntax for your drive. Note that the drive number, if any, must be included in the command_string.

DISK "U0>10"	Renumber system drive to 10.
DISK "U0>V"+chr$(0)	Turn off write verify
DISK "S0:file" ,U(n)	Scratch "file" on unit n

DLOAD - Load a BASIC program file from disk

```
DLOAD "filename" [,Ddrive] [<ON|,>Udevice]
```

This command copies a BASIC program from disk into the BASIC program area of the computer. It can then be edited, DSAVEd, or RUN.

Used in program mode, it overlays the current program in memory and begin execution automatically at the first line of the new program. Variable definitions will be left intact, but any open data files and the disk command channel will be automatically closed. This is called CHAINING.

See also RUN. Use BLOAD to load binary or machine language data.

DLOAD "myprogram"	Searches the default system disk drive for the BASIC program "myprogram", loads it, and relinks it.
DLOAD (F$),U9	LOADs a program whose name is in F$ from disk unit 9.

DMA - Perform a DMA operation

```
DMA command [,length,source(l/h/b),dest(l/h/b),subcmd,mod(l/h) [,...]]
```

[*** THIS COMMAND IS SUBJECT TO CHANGE ***]

The DMA command defines and executes a Direct Memory Access operation. The parameters are used to construct a DMA list, which is then passed to the DMA processor for execution. Refer to the DMA chip specification for details. Chained DMA commands are not allowed, but multiple DMA commands can be given and the DMA handler will set up and execute each one, one at a time. Refer to the system memory map to find out where things are.

Because this command directly accesses system memory, extreme care should be taken in its use. Changing the wrong memory locations can crash the computer (press the reset button to reboot).

DMA 3, 2000, ASC("+"),0, DEC("800"),0	Fill screen with '+'
DMA 0, 2000, DEC("800"),0, DEC("8000"),1	Copy screen to $18000

DMODE – Set graphic display mode

```
DMODE  jam, comp, inverse, stencil, style, thickness
```

[*** THIS COMMAND IS SUBJECT TO CHANGE ***]

jam	0-1
complement	0-1
inverse	0-1
stencil	0-1
style	0-3
thickness	1-8

DO/LOOP/WHILE/UNTIL/EXIT – Program loop definition and control

```
DO   [UNTIL boolean_expression | WHILE boolean_expression]
                .
                .       statements [EXIT]
                .
LOOP [UNTIL boolean_expression | WHILE boolean_expression]
```

Performs the statements between the DO statement and the LOOP statement. If no UNTIL or WHILE modifies either the DO or the LOOP statement, execution of the intervening statements continues indefinitely. If an EXIT statement is encountered in the body of a DO loop, execution is transferred to the first statement following the nearest LOOP statement. Do loops may be nested, following the rules defined for FOR-NEXT loops. If the UNTIL parameter is used, the program continues looping until the boolean argument is satisfied (becomes true). The WHILE parameter is basically the opposite of the UNTIL parameter: the program continues looping as long as the boolean argument is TRUE. An example of a boolean argument is A=1, or G>65.

```
DO UNTIL X=0 or X=1
      : statements
LOOP
```

This loop will continue until X=0 or X=1. If X=0 or 1 at beginning, the loop won't execute.

```
10  A$="": DO GETKEY A$: LOOP UNTIL A$="Q"
```

This will loop until the user types 'Q'

```
10  DOPEN#1,"FILE"
20  C=0
30  DO: LINEINPUT#1,A$: C=C+1: LOOP UNTIL ST
40  DCLOSE#1
50  PRINT"FILE CONTAINS";C;" LINES."
```

This program will count the number of lines in FILE

DOPEN – Open a disk file

```
DOPEN#lf, "filename[,<S|P>]" [,L[reclen]] [,W] [,Ddrive] [<ON|,>Udevice]
```

This command OPENs a file on disk for reading or writing. Lf is the logical file number, which you will use in PRINT#, INPUT#, GET#, RECORD#, and DCLOSE# commands to reference the channel to your file. The filename is required. The defaults are to OPEN a SEQuential file for Reading, in which case the file must exist or a 'FILE NOT FOUND' error results. To create an file and write to it, use the 'W'rite option. 'FILE EXISTS' error is report if an output file already exists. To read or write a RELative file, use the 'L'ength option. The 'reclen' record length is required only when creating a relative file. For more information regarding Relative files, see the RECORD command and refer to your DOS manual. See also APPEND.

See the OPEN command for a discussion about channel and device numbers.

DOPEN#1, "readfile"	Opens sequential READFILE for reading.
DOPEN#1; "writefile",W	Creates & opens seq WRITEFILE for writing.
DOPEN#1, "file,P",U(u)	Opens a PRoGram type file for reading on unit U
DOPEN#1, (rf$),L	Open existing relative file whose name's in RF$
DOPEN#a, "rel",L80	Create a relative file with record length of 80

DPAT - Set graphic draw pattern

```
DPAT  type [, # bytes, byte1, byte2, byte3, byte4]
```

[*** THIS COMMAND IS SUBJECT TO CHANGE ***]

type	0-63
# bytes	1-4
byte1	0-255
byte2	0-255
byte3	0-255
byte4	0-255

DSAVE - Save a BASIC program into a disk file

```
DSAVE "[@]filename" [,Ddrive] [<ON|,>Udevice]
```

This command copies a BASIC program in the computer's BASIC memory area into a PRoGram-type disk file. If the file already exists, the program is NOT stored and the error message 'FILE EXISTS' is reported. If the filename is preceded with an '@', then if the file exists it will be replaced by the program in memory. Because of some problems with the 'save-with-replace' option on older disk drives, using this option is not recommended if you do not know what disk drive is being used. Use the DVERIFY to compare the program in memory with a program on disk.

To save a binary program, use the BSAVE command.

DSAVE "myprogram"	Creates the PRG-type file MYPROGRAM on the default system disk and copies the BASIC program in memory into it.
DSAVE "@myprogram"	Replaces the PRG-type file MYPROGRAM with a new version of MYPROGRAM. If MYPROGRAM doesn't exist, it's created.
DSAVE (F$),U9	Saves a program whose name is in F$ on disk unit 9.

DVERIFY - Compare a program in memory with one on disk

```
DVERIFY "filename" [,Ddrive] [<ON|,>Udevice]
```

This command is just like a DLOAD, but instead of LOADing the BASIC program file into computer memory the data is read from disk and compared to computer memory. If there's any difference at all a 'VERIFY ERROR' is reported.

Note: If the BASIC program in memory is not located at the same address as the version on disk was SAVEd from, the files will not match even if the program is otherwise identical. The comparison ends when the last byte is read from the disk file.

Use the BVERIFY command to compare memory with binary files.

```
DVERIFY "myprogram"
```

```
Good:   SEARCHING FOR 0:myprogram        Bad:  SEARCHING FOR 0:myprogram
        VERIFYING                              VERIFYING
        OK                                     ?VERIFY ERROR
```

ELLIPSE - Draw an ellipse on a graphic screen

```
ELLIPSE x_center, y_center, x_radius, y_radius [,solid]
```

The ELLIPSE command will draw an ellipse with the given radii centered at (x_center,y_center) on the current graphic screen. The ellipse will be filled (i.e., a disc) if SOLID is non-zero.

```
ELLIPSE 160,100,65,50
```

The above example will draw an ellipse in the center of a 320x200 pixel screen (160,100) having radii of (65,50) pixels. The aspect ratio of the screen may cause it to appear as an circle, however. See also the CIRCLE command.

ELSE - See IF/THEN/ELSE

END - Define the end of program execution

```
END
```

The END statement terminates program execution. It does not close channels or files, and it does not clear any variables or reset any pointers. An END statement does not need to be put at the last line of a program.

The CONTinue command can be used to resume execution with the next statement following the END statement. See also the STOP command.

ENVELOPE - Define musical instrument envelopes

```
ENVELOPE n, [,[atk] [,[dec] [,[sus] [,[rel] [,[wf] [,pw] ]]]]]
```

n..............	Envelope number	(0-9)
atk	Attack rate	(0-15)
dec	Decay rate	(0-15)
sus	Sustain rate	(0-15)
rel	Release rate	(0-15)
wf	Waveform:	0 = triangle 1 = sawtooth 2 = pulse (square) 3 = noise 4 = ring modulation
pw	Pulse width	(0-4095)

[*** THIS COMMAND IS SUBJECT TO CHANGE ***]

A parameter that is not specified will retain its current value. Pulse width applies to pulse waves (wf=2) only and is determined by the formula (pwout = pw/40.95 %), so that pw = 2048 produces a square wave and values of 0 or 4095 produce constant DC output. The C64DX initializes the ten (10) tune envelopes to:

```
                 n  A  D  S  R  wf  pw          instrument
                 ------------------------       -------------
    ENVELOPE     0, 0, 9, 0, 0, 2, 1536          piano
    ENVELOPE     1,12, 0,12, 0, 1                accordion
    ENVELOPE     2, 0, 0,15, 0, 0                calliope
    ENVELOPE     3, 0, 5, 5, 0, 3                drum
```

ENVELOPE	4, 9, 4, 4, 0, 0	flute
ENVELOPE	5, 0, 9, 2, 1, 1	guitar
ENVELOPE	6, 0, 9, 0, 0, 2, 512	harpsichord
ENVELOPE	7, 0, 9, 9, 0, 2, 2048	organ
ENVELOPE	8, 8, 9, 4, 1, 2, 512	trumpet
ENVELOPE	9, 0, 9, 0, 0, 0	xylophone

ERASE - Delete disk files

```
ERASE "filespec" [,Ddrive] [<ON|,>Udevice] [,R]
```

This command is identical to DELETE and SCRATCH. See the SCRATCH command for details.

```
ERASE "myfile"     Deletes the file MYFILE on the system drive.
```

ERR$ - Error message function

```
ERR$ (error_number)
```

This function returns a string which is the BASIC error message corresponding to the given error_message. If the given number is too small (less than 1) or too large (greater than 41) an 'ILLEGAL QUANTITY' error is reported.

This function is usually used to display a BASIC error condition in a TRAP routine, using the BASIC error word ER as the error_number. Note that when ER=-1, no BASIC error has occurred and ER$(-1) results in an illegal quantity error.

See the example at TRAP.

EXIT - See DO/LOOP/WHILE/UNTIL/EXIT

EXP - Function to return e^x

```
EXP (number)
```

This function returns the numeric value of e (2.71828183), the base of natural logarithms) raised to the power of given number. If the number is greater than 88.0296919 an 'OVERFLOW' error is reported.

```
X = EXP(4)                 Result is X=54.5981501
```

FAST - Set system speed to 3.58MHz

FAST is the default state of the system. FAST is used to restore this state following direct access of "slow" I/O devices such as the SID sound chips.

FETCH - (see the DMA command)

FILTER - Define sound filter parameters

```
FILTER [freq] [,[lp] [,[bp] [,[hp] [,res] ]]]
```

freq ..... Filter cut-off frequency (0-2047)
lp .... Low pass filter on (1), off (0)
bp .... Band pass filter on (1), off(0)

```
hp ....... High pass filter on (1), off(0)
res ...... Resonance (0-15)
```

[*** THIS COMMAND IS SUBJECT TO CHANGE ***]

Unspecified parameters result in no change to the current value. The filter output modes are additive. For example, both low pass and high pass filters can be selected to produce a notch (or band reject) filter response. For the filter to have an audible effect at least one filter output mode must be selected and at least one voice must be routed through the filter.

FIND - Find text in a BASIC program.

```
FIND :string: [,line_range]
FIND "string" [,line_range]
```

This is a direct (edit) mode command. FIND looks for all occurances of string in the program and displays each line containing string, with string highlighted. Use the C= key to slow the display, or the NO-SCROLL key to pause the display. Press STOP to cancel.

Any character can be used for the string delimiter, but there are side effects. Using a non-quote delimiter will cause the string to be tokenized, and FIND will find only tokenized strings in the program that match. Using a quote character as the delimiter will cause the string to be interpreted as plain PETSCII, and any matches found will therefore be plain PETSCII. Searching for some tokens such as DATA statements may require the use of colons as delimiters due to the special affect these commands have upon the interpreter.

If the line number range is not given (see LIST for description of range parameter), the entire program is searched.

FNxx - User defined function

```
FNxx (expression)
```

The result of this numeric function is determined by the BASIC program in a DEF FN statement. See the example at DEF FN.

FOR/TO/STEP/NEXT - Program loop definition and control

```
FOR index = start TO end [STEP increment]
 |
NEXT index [,index]
```

This command group performs a series of instructions a given number of times. The loop index is a floating point (non-integer) variable which will initially be set to the start value and be incremented by the STEP increment when the NEXT statement is encountered. The loop continues until the index exceeds the end value at the NEXT statement.

The start, end, and increment values can be numeric variables or expressions. If the STEP increment is not specified, it is assumed to be one (1). The STEP increment can be any value, positive, negative, or non-integer. If the STEP increment is negative, the loop continues until the index is less than the end value at the NEXT statement.

Note that, regardless of the start, end, or increment values, the loop will alway execute at least once. The index can be modified within the loop, but it is bad practice to do so. It is also bad practice to GOTO a line inside a loop structure, or to similarly jump out of a loop structure (which can cause an out of memory error).

Loops may be nested. If too many are nested, an 'OUT OF MEMORY' error is reported (depends upon stack size, room for about 28 nested loops).

The index variable can be omitted from the NEXT statement, in which case the NEXT will apply to the most recent FOR statement. If a NEXT statement is encountered and there is no preceeding FOR statement, the error 'NEXT WITHOUT FOR' is reported.

```
10 FOR L = 1 TO 10
20 PRINT L
30 NEXT L
40 PRINT "I'M DONE! L = "L
```

This program prints the numbers from one to ten, followed by the message I'M DONE! L = 11.

```
10 FOR L = 1 TO 100
20 FOR A = 5 TO 11 STEP .5
30 NEXT A
40 NEXT L
```

This program illustrates a nested loop.

FOREGROUND - Set the text color of the display

```
FOREGROUND color
```

Sets the text color to the given color index. Color must be in the range (0-15). See the Color Table. COLOR must be ON (see the COLOR command).

FRE - Free byte function

```
FRE (x)
```

This function returns the number of available ("free") bytes in a specified area.

PRINT FRE(0)	Shows the amount of memory left in the program area, C64DX bank 0
X = FRE(1)	X= the amount of avaliable memory in variable area, C64DX bank 1. This causes a "garbage collect" to occur, a process which compacts the string area.
X = FRE(2)	X= the number of expansion RAM banks present.

GCOPY - Copy a graphic area

```
GCOPY x,y,dx,dy
```

[*** NOT YET IMPLEMENTED ***]

GENLOCK - Enable or disable video sync mode & colors

```
GENLOCK ON  [,color#]...
GENLOCK OFF [,color#,R,G,B]...
```

To enable video sync mode and specify which colors are affected, use the GENLOCK ON command, and list the palette color indices (0-255) which will display external video.

To disable video sync mode and restore the associated palette colors, use the GENLOCK OFF command, and list the color index and its RGB values to restore them (see the SET PALETTE command for details). Also see the PALETTE RESTORE command.

GET - Get input data from the keyboard

```
GET  variable_list
```

The GET statement is a way to get data from the keyboard one character at a time. When the GET is executed, the character that was typed is received. If no character was typed, then a null (empty) character is returned, and the program continues without waiting for a key. There is no need to hit the RETURN key, and in fact the RETURN key can be received with a GET. The word GET is followed by a variable name, usually a string variable. If a numeric were used and any key other than a number was hit, the program would stop with an error message. The GET statement may also be put into a loop, checking for an empty result, that waits for a key to be struck to continue. The GETKEY statement could also be used in this case. This statement can only be executed within a program.

```
10 DO: GET A$: LOOP UNTIL A$ ="A"
```

This line waits for the A key to be pressed to continue.

GETKEY - Get input character from keyboard (wait for key)

```
GETKEY  variable_list
```

The GETKEY statement is very similar to the GET statement. Unlike the GET statement, GETKEY waits for the user to type a character on the keyboard. This lets it be used easily to wait for a single character to be typed. This statement can only be executed within a program.

```
10 GETKEY A$
```

This line waits for a key to be struck. Typing any key will continue the program.

GET# - Get input data from a channel (file)

```
GET# logical_channel_number, variable_list
```

Used with a previously OPENed device or file to input one character at a time. Otherwise, it works like the GET statement. This statement can only executed within a program.

```
10 GET#1,A$
```

GO64 - Exit C64DX mode and switch to C64 mode

```
GO64
```

This statement switches from C64DX mode to C64 mode. The question 'ARE YOU SURE?' (in direct mode only) is posted for the user to respond to. If Y and return is typed then the currently loaded program is lost and control is given to C64 mode. This statement can be used in direct mode or within a program.

GOSUB - Call a BASIC subroutine

```
GOSUB line
```

This statement is like the GOTO statement, except that the computer remembers from where it came. When a line with a RETURN statement is encountered, the program jumps back to the statement immediately following the GOSUB. The target of a GOSUB statement is called a subroutine. A subroutine is useful if there is a section of the program that can be used by several different parts of the program. Instead of duplicating the section over and over, it can be set up as a subroutine and called with a GOSUB statement from different parts of the program. This also make the main part of your program much more readable. See also the RETURN statement.

Variables are shared with the main program and all subroutines. You can pass information to, and get information back from, subroutines by using variables as messengers.

GOSUB statements can be nested. That is, one subroutine can call another subroutine, and the computer automatically keeps track of all the calls. It's important not to jump into or out of subroutines, since this can confuse the computer. If too many GOSUBs are nested (usually cause by jumping out of them) an 'OUT OF MEMORY' error is reported because the computer ran out of room to keep track of all the calls.

```
 10 DIR            : GOSUB 100   show directory, check status
 20 GOSUB 200                    print gap
 30 LIST "PROGRAM": GOSUB 100    show listing, check status
 40 GOSUB 200                    print gap
 50  etc...
 90 END
 99:
100 REM SUBROUTINE TO CHECK DISK STATUS
110 IF DS THEN GOSUB 200: PRINT "DISK ERROR: ";DS$
120 RETURN
199:
200 REM SUBROUTINE TO PRINT A SPACER ON THE SCREEN
210 PRINT
220 FORI=1TO39:PRINT"-";:NEXT
230 PRINT
240 RETURN
```

GOTO - Transfer program execution to specified line number

```
GOTO   line_number
GO TO  line_number
```

After a GOTO statement is executed, the next line to be executed will be the one with the line number following the word GOTO. When used in direct mode, GOTO line number allows starting of execution of the program at the given line number without clearing the variables.

```
10 PRINT"COMMODORE"
20 GOTO 10
```

The GOTO in line 20 makes line 10 repeat continuously until STOP is pressed.

GRAPHIC - select graphic mode

```
GRAPHIC CLR
GRAPHIC command#, [,args]
```

Basically this is a modified C64-type SYS command, minus the address. In the C64DX system, this will represent the ML interface, not the BASIC 10.0 interface which is implemented in the development system.

[*** THIS COMMAND IS SUBJECT TO CHANGE ***]

GRAPHIC CLR initializes (warm-starts) the BASIC graphic system. It clears any existing graphic modes, screens, etc. and allows a program to commence graphic operations from scratch.

HEADER - Format a diskette

```
HEADER "diskname" [,Iid] [,Ddrive] [<ON|,>Udevice]
```

The HEADER command prepares a new diskette for use, sometimes called FORMATing a diskette. There are two types of "newing" a diskette- a long form and a quick (or short) form. You must use the long form when preparing a new diskette for its first use. Thereafter you can use the quick form.

WARNING: Formatting a diskette (long or short) will destroy all existing data on the diskette! In direct mode, you are asked to confirm what you are doing with 'ARE YOU SURE?'. Type 'Y' and press return to proceed, or TYPE ANY OTHER CHARACTER AND PRESS RETURN TO CANCEL the command. In program mode there is no confirmation prompt.

The long HEADER form requires a diskname and an ID. The diskette will be completely (re)sectored, zeros written to all blocks, and a new system track (directory, BAM, etc.) will be created.

```
HEADER "newdisk",I01          prepares a new diskette
```

The short HEADER form is performed when the ID option is omitted. The diskette is assumed to have been previously formatted, and only a new system track (directory, BAM, etc.) is installed. This is roughly equivalent to deleteing all the files, but much quicker.

```
HEADER "makelikenew"          re-news an working diskette
```

The diskname is limited to 16 characters and the ID string to two characters. The same rules apply for the diskname as for a filename. Some Disk Systems use the ID string to tell if you have swapped a diskette in a drive, so it's recommended that the ID string be unique for each of your diskettes. Some more examples:

```
HEADER "QUICK"
HEADER "MYDISK", I23
HEADER "RECS", I"FB", U9
HEADER (FILE$), I(ID$), U(UNIT)
```

HELP - Show the BASIC line that cause the last error

The HELP command is used after an error has been reported in a program. When HELP is typed, the line where the error occurred listed, with the portion containing the error highlighted. Print ERR$(ER) for the error message, and print EN or EL for the error number and error line, respectively. HELP can be used in direct mode or in program mode. Note that, in the case of many I/O errors, there is no associated BASIC error. Check ST or DS$ errors in these cases.

HEX$ - Hexadecimal value function

```
HEX$ (decimal_expression)
```

This function returns a 4-character string that represents the hexadecimal value of the numeric decimal expression. The expression must be in the range (0-65535, $0000-$FFFF hex) or an 'ILLEGAL QUANTITY' error is reported.

```
   PRINT HEX$(10)                The string "000A" is printed.
   PRINT RIGHT$(HEX$(10),2)      The string   "0A" is printed.
```

HIGHLIGHT - Set the text highlight color of the display

```
HIGHLIGHT color
```

Sets the highlight color to the given color index. The color value must be in the range (0-15). See the Color Table. COLOR must be ON (see the COLOR command). The highlight color is used in HELP messages and FIND/CHANGE strings.

IF/THEN/GOTO/ELSE - Conditional program execution

```
IF expression <GOTO line | THEN then_clause> [:ELSE else_clause]
```

IF...THEN lets the computer analyze a BASIC expression preceded by IF and take one of two possible courses of action. If the expression is true, the statement following THEN is executed. This expression can be any BASIC statement. If the expression is false, the program goes directly to the next line, unless an ELSE clause is present. The ELSE clause, if present, must be in the same line as the IF-THEN part. When an ELSE clause is present, it is executed when the THEN clause isn't executed. In other words, the ELSE clause executes when the expression is FALSE. See BEGIN/BEND to spread the IF statement out over several lines. An ELSE statement is matched to the closest THEN statement in the case of nested IF/THEN statements.

The expression being evaluated may be a variable or formula, in which case it is considered true if nonzero, and false if zero. Usually expressions involve relational operators =, <, >, <=, >=, <>.

```
50 IF X>0 THEN PRINT "X>0": ELSE PRINT "X<=0"
```

If X is greater than 0, the THEN clause is executed, and the ELSE clause isn't. If X is less than or equal to 0, the ELSE clause is executed and the THEN clause isn't.

INPUT - Get input from the keyboard

```
[LINE] INPUT ["prompt"<,|;>] variable_list
```

The INPUT statement pauses the BASIC program, prints the prompt string if present, prints a question mark and a space, and waits for data to be typed by the user, terminated by a return character. If the prompt string ends with a comma instead of a semicolon, a question mark and space is not printed.

Input is gathered and assigned to variables in the variable_list. The type of variable must match the type of input typed or a 'TYPE

MISMATCH' error is reported. Separate data items typed by the user must be separated with commas. String data with imbedded spaces or commas must be surrounded with quotes. If insuffecent data to satisfy the variable-list is typed, two question marks are displayed by the computer to prompt for additional data to be input. If the computer does not understand the input (such as the user typing cursor up or down keys) the computer responds with the message 'REDO FROM START?' and waits for acceptable data to be entered. Input is limited to 160 characters (two screen lines in 80-column mode), which is the size of the input buffer.

The INPUT statement can only be executed from within a program.

LINE INPUT allows the program to input a string which includes any PETSCII character (including colons, commas, imbedded spaces, etc.) up to but not including a null or return character. There should be only one string-type variable name in the variable_list in this case, but if there are more the computer prompts as usual with two question marks for more data to assign to the additional variables.

```
    10 INPUT "WHAT'S YOUR FIRST NAME AND AGE"; NA$,A
    20 PRINT "YOUR NAME IS ";NA$;" AND YOU ARE";A;" YEARS OLD"
```

The above INPUT is the traditional BASIC form.

```
    10 LINE INPUT "WHAT'S YOUR ADDRESS"; AD$
    20 PRINT "YOUR ADDRESS IS: ";AD$
```

The above INPUT allows an entire line of data to be assigned to a string variable, including commas and other common punctuation marks.

```
    10 INPUT "ENTER YOUR NAME HERE: ", NA$
```

The above INPUT suppresses the traditional '? ' prompt by using a comma instead of a semicolon after the prompt string. To suppress the '? ' without a prompt string, make the prompt string null.

INPUT# - Input data from an I/O channel (file)

```
        [LINE] INPUT#logical_channel_number, variable_list
```

The INPUT# command works like the INPUT command, except no prompt string is allowed and input is gathered from a previously OPENed channel or file. This command can only be used in a program.

The logical_channel_number is the number assigned to the device (file) in an OPEN (or DOPEN) statement. Items in the variable_list must agree with the type of data input, or a 'FILE DATA ERROR' will result.

On the C64DX, an End Of File (EOF) condition or bad I/O status will terminate input, as if a return character was received. It's good practice to examine the I/O status byte (and the DS disk status for file I/O) after every I/O instruction to check for problems or errors.

```
10  DOPEN#1,"FILE"
20  C=0
30  DO: LINEINPUT#1,A$: C=C+1: LOOP UNTIL ST
40  DCLOSE#1
50  PRINT"FILE CONTAINS";C;" LINES."
```

This program will count the number of lines in FILE

INSTR - Get the location of one string inside another string

```
        INSTR (string_1, string_2 [,starting_position])
```

This function searches for the first occurrence of string_2 in string_1 and returns its location. A value of zero (0) is returned if no match is found, if either string is null (empty), or if string_2 is longer than string_1.

If the starting_position is given, the search begins at that location, otherwise the search begins at the first character of string_1.

The strings can be literals, variables, or string expressions.

```
X = INSTR("123456","4")          Result is X=4
X = INSTR("123456","X")          Result is X=0
X = INSTR("123123","2")          Result is X=2
X = INSTR("123123","2",3)        Result is X=5
```

INT - Greatest integer function

INT (expression)

This function returns the greatest integer less than or equal to the numeric expression.

```
X = INT( .123)          Result is X=  0
X = INT(-.123)          Result is X= -1
X = INT( 123.456)       Result is X= 123
X = INT(-123.456)       Result is X=-124
```

JOY - Joystick function

JOY (port)

This function returns the state of a joystick controller in the specified port.

When port=1 returns position of joystick 1
When port=2 returns position of joystick 2

The value returned is encoded as follows:

```
Fire = 128 +               1

                      8         2

                 7         0         3

                      6         4

                           5
```

A value of zero (0) means that the joystick is not being manipulated. A value of 128 or more means that the fire button is being pressed. The possible vales returned are:

0	No activity	128	fire
1	up	129	fire + up
2	up + right	130	fire + up + right
3	right	131	fire + right
4	right + down	132	fire + right + down
5	down	133	fire + down
6	down + left	134	fire + down + left
7	left	135	fire + left
8	left + up	136	fire + left + up

KEY - Enable, disable, display, or define function keys

```
KEY ON
KEY OFF
KEY [key#, string]
```

There are 14 function keys available on the C64DX (seven unshifted and seven shifted). The user can assign a string consisting of BASIC commands, control codes, escape functions, or a combination of each to function key. The data assigned to a key is typed out when that key is pressed, just as if the characters were typed one by one on the keyboard. The user can enable ("turn on") or disable ("turn off") the function keys. When they are disabled, pressing a function key return that key's normal character code instead of the string assigned to it. This includes the HELP and (shifted)RUN keys. It is also possible to redefine the HELP and (shifted)RUN keys, as function keys 15 and 16, respectively. The system has default assignments for all function keys. KEY with no parameters displays a listing of the current assignments for all the function keys.

The maximum length for all the definitions together is 240 characters. If an assignment would be too big to fit, an 'OUT OF MEMORY' error is reported and the assignment is not made.

```
KEY 2, "DIR U9"+CHR$(13)
```

This causes the computer to display the directory from disk unit #9 when function key 2 is pressed. This is equivalent to typing 'DIR U9' and pressing the RETURN key directly. The CHR$(13) is the character for RETURN. Other often used control codes are CHR$(141) for 'shifted RETURN', CHR$(27) for 'ESCape', and CHR$(34) to incorporate a double quote into a KEY string.

```
KEY 2, "DIR"+CHR$(34)+"*=P"+CHR$(34)+CHR$(13)
```

This is equivalent to typing DIR"*=P" and pressing return at the keyboard. Note the way quotes can be incorporated into an assignment. When function key 2 is pressed, a directory of all program files on the default system disk will be displayed.

```
KEY OFF
```

This turns off function key strings. Pressing a function key now would return the character codes associated with F-keys as on the VIC-20 and C64 computers. KEY ON would re-enable function key strings, unchanged from their previous assignments. To restore the system default assignments, reset the computer.

LEFT$ - Get the leftmost characters of a string

```
LEFT$ (string,count)
```

This function returns a string containing the leftmost 'count' number of characters of the string expression. Count is an numeric expression in the range (0-255). If count is greater than the length of the string, the entire string will be returned. If count is zero, a null (empty) string will be returned.

```
A$ = LEFT$("123ABC",3)          Result is A$="123"
```

LEN - Get the length of a string

```
LEN (string)
```

This function returns the number of characters in a string expression. Nonprinting characters and blanks are counted.

```
        A = LEN("ABC")                          Result is A=3
```

LET - Assign a value to a variable

```
[LET] variable = expression
```

The LET command is optional, since the equal sign by itself is understood by the computer to mean assignment. Multiple assignments on LET statements are not allowed.

```
          10 LET A=1: LET B=A+1: LET C$=" THREE"
          20 :    D=1:     E=D+1:      F$=" THREE"
          30 PRINT A;B;C$
          40 PRINT D;E;F$

        Output:        1 2 THREE
                       1 2 THREE
```

LINE - Draw a line on a graphic screen

```
LINE  x0, y0, x1, y1
```

LINE draws a line on the currently defined graphic screen with the currently defined draw modes. The line is draw from (x0,y0) to (x1,y1).

LIST - List a BASIC program from memory or disk

```
LIST [ startline ]  [ - [ endline ] ]

LIST "filename" [,Ddrive] [<,|ON>Udevice]
```

LIST is used to view part or all of a BASIC program in memory or all of a BASIC program on disk (without affecting the program that is currently in memory).

The display can be slowed down by holding down the C= key or it can be paused by pressing the NO-SCROLL key or CONTROL-S. A listing that is paused can be restarted by pressing NO-SCROLL again or by pressing CONTROL-Q. The display can be stopped by pressing STOP.

If the word LIST is followed by a line number, the computer shows only that line number. If LIST is typed with two numbers separated by a dash, the computer shows all lines from the first to the second line number. If LIST is typed followed by a number and just a dash, it shows all lines from that number to the end of the program. And if LIST is typed, a dash, and then a number, all lines from the beginning of the program to that line number are LISTed. By using these variations, any portion of a program can be examined or easily brought to the screen for modification. LIST can be used in direct mode or in a BASIC program.

LIST	Shows entire program.
LIST 100-	Shows from line 100 until the end of the program.
LIST 10	Shows only line 10.
LIST -100	Shows lines from the beginning until line 100.
LIST 10-200	Shows lines from 10 to 200, inclusive.

LOAD - Load a program or data into memory from disk

```
LOAD "filename" [,device_number [,relocate_flag]]
```

This command loads a file into the computer's memory. The filename must be given, and pattern matching may be used. In the case of dual drive systems, the drive number must be part of the filename. If a device number is given, the file is sought on that unit, which must be a disk drive. If a device number is not given, the default system drive is used. See also DLOAD and RUN commands.

The relocate_flag is used to LOAD binary files. If the relocate_flag is present and non-zero, the file will be copied into memory starting at the address stored on disk when the file was SAVEd. See BLOAD. Do not use the relocate_flag to load BASIC programs; they will be automatically relocated to the start of the BASIC program area and relinked.

To compare a program in memory to a disk file, use the VERIFY or DVERIFY command. To compare a binary file, use BVERIFY.

See the discussion at DLOAD regarding CHAINING programs.

LOAD "PROG"	Loads BASIC program PROG from the system drive.
LOAD FILE$,DRV	Loads a program whose name is in the variable called F$ from the unit whose number is in DRV.
LOAD "0:PROG",8	Loads BASIC program PROG from unit 8, drive-0.
LOAD "BIN",8,1	Loads a binary file into memory.

LOCATE - [*** NOT YET IMPLEMENTED ***]

LOG - Get the natural logarithm of a number

```
LOG (number)
```

This function returns the natural logarithm of a numeric expression. A natural log is a log to the base e (2.71828183). See the EXP function. To convert to log base 10, divide by LOG(10).

A = LOG(123)	Result is A=4.81218436
A = LOG(123) / LOG(10)	Result is A=2.08990511

LOOP - See DO/LOOP/WHILE/UNTIL/EXIT

LPEN - Get the position of a lightpen

```
PEN (position)
```

This function returns the current position of a lightpen on the screen. When position=0, the X position is returned, and when position=1 the Y position is returned. Note that lightpen coordinates, like sprite coordinates, are offset from the normal graphic coordinate map. This means you have to calculate where the lightpen is with respect to the screen display. The electronics of each lightpen also introduces a skew which must be factored into your calculations.

The X resolution is limited to every 2 pixels, and will always be an even number in the approximate range (60-320). The Y position is in the approximate range (50-250). If either the X or the Y position is zero, the lightpen is off-screen.

Note that a lightpen COLLISION need not be enabled to use LPEN. A bright background color, such as white, is usually required to stimulate the light pen. Lightpens only work in game port 1.

```
 10 TRAP 40                       We're done if STOP key
 15 BACKGROUND 1                  Make backgound color white
 16 FOREGROUND 0                  Make text color black
 20 COLLISION 3,100               Enable lightpen interrupt
 30 DO:LOOP                       Hang here until done
 40 END                           Done
100 COLLISION 3                   Got one, don't want more
110 PRINT LPEN(0),LPEN(1)         Display lightpen position
120 COLLISION 3,100               Re-enable interrupt
130 RETURN
```

MID$ - Substring function

MID$ (string, position [,length])

This function can appear on the left or the right side of an assignment statement:

Case 1:   string_var = MID$ (string_expression, position [,length])

This form returns a piece of another string. The function returns a string of the specified length taken from the string_expression beginning at the indicated position. The position must be in the range (1-255), one (1) being the first character. The length can be any number in the range (0-255), or it can be omitted. If the position specified is greater than the number of characters in the string_expression, a null (empty) string is returned. If the length is greater than the number of characters from the given position to the end of the string_expression, or the lenght is omitted, then all the rightmost characters beginning at the position are returned.

```
A$ = MID$("TICTACTOE",4,3)      Result is A$="TAC"
A$ = MID$("TICTACTOE",4)        Result is A$="TACTOE"
A$ = MID$("TICTACTOE",10,1)     Result is A$="" (empty)
```

Case 2:   MID$ (string_var, position [,length]) = string_expression

This form replaces a portion of the string contained in string_var with data from another string_expression, beginning at the specified position in the string_var. If the length is given only, that many characters from the string_expression are taken, otherwise all the characters in the string_expression will replace characters in the string_var beginning at the position specified. The there are too many characters to fit in the string_var, an 'ILLEGAL QUANTITY' error is reported. If the length given is zero, no characters will be replaced.

```
A$="TICTACTOE": MID$(A$,4,3)="123456"  Result is A$="TIC123TOE"
A$="TICTACTOE": MID$(A$,4)  ="123456"  Result is A$="TIC123456"
A$="TICTACTOE": MID$(A$,5)  ="123456"  Result is 'ILLEGAL QUANTITY'
```

MONITOR - Enter the built-in machine language monitor

SEE SECTION ?.? ON THE C64DX MONITOR.

MOUSE - Enable or disable the mouse driver

MOUSE ON [,port [,sprite [,position]]]

MOUSE OFF

port = joyport 1, 2, or either (both) (1-3)
sprite = sprite pointer (0-7)
position = initial pointer location (x,y)
normal, relative, or angluar coordinate

defaults to sprite 0, port 2
???? add min/max x/y positions

[*** THIS COMMAND IS SUBJECT TO CHANGE ***]

Mouse ON enables the built-in mouse driver. The user must load a pointer into the proper sprite area ($600-$7FF). The driver assumes the "hot point" is the top left corner of the sprite, and does not allow this point to leave the screen.

Mouse OFF will turn off the driver and the currently associated sprite.

Use the RMOUSE function to get the current pointer position and button status. See the sample program at RMOUSE.

MOVSPR - Position sprite or set sprite in motion

MOVSPR sprite <,x,y>

Use the SPRITE command to turn on a sprite, and MOVSPR to position it. Sprites are numbered 0-7. The sprite's position can be specified using one of the following coordinate types:

[+/-]x,[+/-]y = [relative] position
x#y = angle and speed
x;y = distance and angle

Angles are specified as 0-360 degrees, with 0 being straight up. Speeds are specified as a number of pixels per frame, 0-255. Sprites are moved through each pixel so that collisions are accurately detected.

NEW - Delete program in memory and clear all variables

NEW [RESTORE]

This command erases the entire program in memory and clears all variables and open channels (but it does NOT properly close open disk write files- used DCLOSE or DCLEAR beforehand). NEW also resets the runtime stack pointer (clears GOSUB & FOR/NEXT stacks), the DATA pointer, and the PRINTUSING characters.

The BASIC program in memory is lost unless it was previously SAVEd to disk. If you have not entered or loaded any BASIC programs since typing NEW, the RESTORE option will recover the BASIC program in memory. But if the BASIC environment has been changed in any way, the program may not be restored correctly. If BASIC can tell something's wrong, it will report 'PROGRAM MANGLED'.

NEW can be used in direct (edit) mode or in a program. When it's encountered in a program, the program terminates.

NEXT - See FOR/NEXT/STEP and RESUME

NOT - Get the complement of a number

```
NOT (expression)
```

The NOT function returns the complement of an integer in the range (-32768 to 32767). The function operates on the binary value of signed 16-bit integers. An expression outside of this range will cause an 'ILLEGAL QUANTITY' error.

```
X = NOT(5)                          Result is X=-6
X = NOT(-6)                         Result is X=5
```

NOT is often used in logical comparisons (such as an IF statement) to invert the result, since -1 (true) is the result of NOT(0) (false), and 0 (false) is the result of NOT(-1) (true).

```
X = NOT("ABC"="ABC") AND ("DEF"="DEF")      Result is X= 0 (false)
X = NOT("ABC"="ABC") AND ("DEF"="XYZ")      Result is X=-1 (true)
```

OFF - Subcommand used with various BASIC commands.

ON - Computed GOTO/GOSUB

```
ON expression <GOTO|GOSUB> line_number_list
```

This is a variation of the IF<expression>GOTO statement that branches to one of several line numbers based upon the value of an expression. The integer value of the evaluated expression determines which line number in the line_number_list gets control.

If the expression evaluates to one, the first line number in the list gets control, if it's two the second line number gets control, and so on. Fractional parts of the value are truncated (for example, 2.9 becomes 2). If the value is zero or greater than the number of items in the list the computer takes none of the branches and continues on with the next statement. If the value is negative, an 'ILLEGAL QUANTITY ERROR' is reported.

The ON/GOSUB statement must call the first line number of a subroutine, and the subroutine must end with a RETURN statement. After executing the subroutine, control is returned to the statement following the ON/GOSUB statement.

```
 10 INPUT"ENTER A NUMBER 1-3: ",X
 20 ON X GOTO 100,200,300
 30 PRINT"TOO LOW OR TOO HIGH": RUN
100 PRINT"ONE":   RUN
200 PRINT"TWO":   RUN
300 PRINT"THREE": RUN
```

OPEN - Open a channel to a device or disk file

```
OPEN logical_chnl_num, device_number [,secondary_adr [,<filespec|command>]]
```

Before a program can access a device or a file, an I/O channel must be opened to it to communicate through. When something is opened, you associate a logical_channel_number with it, and it is with this number that all other I/O statements access the device or file. The OPEN command can be used in direct (edit) mode or in a program.

The channel number, device number, and optional secondary address are integers from 0-255. Refer to the device's manual for more information about what (if any) secondary addresses it uses.

channel:	0-127	return = output return character only
	128-255	return = output return + linefeed

device:	0	Keyboard
	1	Default system drive whatever its number is (see SET DEF)
	2	RS232
	3	Screen
	4-7	Serial bus (usually reserved for printers)
	8-31	Serial bus (usually reserved for disk drives)

The filespec is the file name in the case of disk files (refer to your DOS manual for details). Typically, the filename ia a string having the the following form:

`[[@|$]drive:] filename [,type] [,mode]`

An example would be `0:MYFILE,SEQ,READ` to open the sequential file MYFILE for reading on drive 0. Disk drives usually support some kind of filename pattern matching. Most disk drives support the following file types and modes (can be abbreviated to first character):

types:	'S'equential
	'P'rogram
	'R'elative
	'U'ser
modes:	'R'ead
	'W'rite
	'L'ength (for relative type files)

Some channels or devices accept a command string instead of a filename when they are opened. An example would be the disk command channel or the RS232 open/setup command. Refer to the device's documentation.

OPEN 1,8,15,"I"	Open CBM disk command channel & send it the 'I'nitialize command.
OPEN 4,4,7	Open CBM printer channel in upper/lower case mode.
OPEN 128,2,2,CHR$(14)	Open a 9600 8N1 RS232 channel and translate CR into CRLF on output.

See also DOPEN, DCLOSE, CLOSE, CMD, GET#, INPUT#, and PRINT# statements and I/O status variables ST, DS, and DS$.

OR - Boolean operator

expression OR expression

The OR operator returns a numeric value equal to the logical OR of two numeric expressions, operating on the binary value of signed 16-bit integers in the range (-32768 to 32767). Numbers outside this range result in an 'ILLEGAL QUANTITY' error.

X = 4 OR 8	Result is X=12

In the case of logical comparisons, the numeric value of a true situation is -1 (equivalent to 65535 or $FFFF hex) and the numeric value of a false situation is zero.

X = ("ABC"="ABC") OR ("DEF"="DEF")	Result is X=-1 (true)
X = ("ABC"="ABC") OR ("DEF"="XYZ")	Result is X=-1 (true)
X = ("ABC"="XYZ") OR ("DEF"="XYZ")	Result is X= 0 (false)

PAINT - Fill a graphics area with color

```
                PAINT x,y, mode [,color]

        x,y     coordinate to begin fill at
        mode    0: fill area to edge = color
                1: fill area to edge=same as color at x,y
```

PAINT fills an enclosed graphic area starting at the given coordinate with the color of the currently defined PEN. The mode parameter identifies the region to be filled.

[*** THIS COMMAND IS NOT YET IMPLEMENTED ***]

PALETTE - Define a color

```
        PALETTE [screen#|COLOR], color#, red, green, blue
        PALETTE RESTORE
```

screen#	0-1
color#	0-255
red	0-15
green	0-15
blue	0-15

The PALETTE command can be used to define a color for a logical graphic screen, set an absolute color, or restore the C64DX VIC-III default colors. PALETTE can be used in direct mode or in a program.

The VIC-III pre-defines the first 16 colors to the usual C64-type colors, but you can change them with the PALETTE COLOR command or restore them all with the PALETTE RESTORE command.

See the sample program after the SCREEN command.

PASTE - Put a CUT graphic area on the screen

```
                PASTE x,y
```

[*** NOT YET IMPLEMENTED ***]

PEEK - Function returning the contents of a memory location

```
                PEEK (address)
```

This function returns the contents of a memory location. The address must be an integer in the range of 0-65535 ($0-$FFFF) and the value returned will be an integer in the range of 0-255 ($0-$FF).

Use the BANK command to specify which 64K memory bank the address is in. Note that a BANK number greater than 127 (i.e., a bank number with the most significant bit set) must be used to address an I/O location, such as the VIC chip or color memory. Refer to the system memory map for details. PEEK uses the DMA device to access memory.

Use the POKE command to change the contents of a memory location.

```
    BANK 0:   X = PEEK (208)   Reads the keyboard buffer index.  If
                               it's empty, X will be zero, otherwise X
                               will be the number of characters in it.
```

PEN - Specify a pen color for drawing on graphic screen

```
PEN  pen, color
```

pen	0-2
color	0-255

Before you can draw anything on a graphic screen, you have to tell BASIC what color your PENs are. You should first define what your colors are using the PALETTE command, then use PEN to associate those colors with a PEN. Whatever graphic commands you use after a PEN command will use the PEN you specified.

```
PEN 0,1          Put color 1 "ink" into draw pen 0
```

See the sample program after the SCREEN command..

PIC - Graphic picture subcommand

PLAY - Play a musical string

```
PLAY "[Vn,On,Tn,Un,Xn,elements]"
```

[*** WILL CHANGE TO ADD 2nd SID SUPPORT ***]

The PLAY command lets you select a voice, octave, instrument, volume, filter, and musical notes. All these parameters are packed into a string (spaces are allowed for readablilty).

On = Octave (n=0-6)
Tn = Tune envelope # (n=0-9)
    0= piano (defaults)
    1= accordion
    2= calliope
    3= drum
    4= flute
    5= guitar
    6= harpsichord
    7= organ
    8= trumpet
    9= xylophone
Un = Volume (n=0-9)
Vn = Voice (n=1-3)
Xn = filter on (n=1), off (n=0)

Elements:

A,B,C,D,E,F,G	... Notes, may be preceeded by:
#	Sharp
$	Flat
.	Dotted
W	Whole note
H	Half note
Q	Quarter note
I	Eighth note
S	Sixteenth note
R	Rest
M	Wait for all voices playing to end (a measure)

Once the music string starts PLAYing, the computer will continue with the next statement. The music will continue to play automatically. Using the 'M'easure command will cause the computer to wait until the music has up to that point has been played out.

Use the TEMPO command to alter the tempo (speed) of PLAY. Note that the VOLume command can change a PLAY string's volume setting.

POINTER - Get the address of a variable descriptor

```
POINTER (variable_name)
```

This function returns the address of an entry in the variable table. If the value returned is zero, the variable is currently undefined. The variable table is normally in the second RAM bank (BANK 1). See the section on variable storage for details.

Note that, while the location of a string descriptor will not change, the location of the actual string in memory changes all the time. Also, when working with an array name you must specify a particular element, to which POINTER will return a pointer to that element's descriptor and not to the array descriptor.

```
10 A$="FRED"                 Define A$
20 DESC=POINTER (A$)         Lookup A$ in variable table
30 BANK1: PRINT PEEK(DESC)   Displays the length of A$
```

POKE - Write a byte to memory location

```
POKE address, byte [,byte ...]
```

POKE is used to write one or more bytes into one or more memory locations. The address must be an integer in the range of 0-65535 ($0-$FFFF) and the value to be written must be an integer in the range of 0-255 ($0-$FF). If more than one byte is given, it will be written into successive memory locations.

Use the BANK command to specify which 64K memory bank the address is in. Note that a BANK number greater than 127 (i.e., a bank number with the most significant bit set) must be used to address an I/O location, such as the VIC chip or color memory. Refer to the system memory map for details. Also note that, unlike previous CBM computers, POKEs to a ROM location will not "bleed through" into a corresponding RAM location. POKE uses the DMA device to access memory.

Use the PEEK function to read a byte from a memory location.

Because this command directly accesses system memory, extreme care should be taken in its use. Altering the wrong memory location can crash the computer (press the reset button to reboot).

```
BANK 0:   POKE 208,0                 Resets location 208 ($000D0), clearing
                                     the keyboard buffer.

BANK 128: POKE DEC("D023"),1,2,3     Sets the VIC extended background
                                     colors to 1, 2, and 3 respectively
```

POLYGON - Draw a regular n-sided figure on a graphic screen

```
POLYGON x,y, xradius,yradius, [solid], angle, drawsides, sides, subtend
```

```
x,y          = center of polygon
x,yradius    = radii of polygon
solid        = solid flag              (0-1)
angle        = starting angle          (0-360)
drawsides    = # of sides to draw      (3-127)
sides        = # sides of polygon      (drawsides<=sides)
```

subtend = subtend flag (0-1)

POS - Get the column number of the cursor

POS (0)

This function returns the current text column the cursor is in, with respect to the currently defined window (see RWINDOW). It's usually used to format text printed to the screen. The argument (0) is not used for anything. POS will not work as expected if text output is redirected to a disk file or the printer.

```
10 MAXCOL = RWINDOW(1)
20 FOR ADR=DEC("600") TO DEC("7FF")
30 PRINT HEX$(PEEK(ADR));" ";
40 IF POS(0) > (MAXCOL-5) THEN PRINT
50 NEXT
```

This example illustrates one way to format output to the screen, keeping the last item on a line from being split between two lines, regardless of the window size (as long as the window size is at least 4 characters wide). It dumps the data for the first sprite in hex.

POT - Paddle function

POT (paddle)

This function returns the state of a game paddle (POTentiometer) controller in one of the two game ports.

paddle=1 ..... Position of paddle #1 (port 1, paddle "A")
paddle=2 ..... Position of paddle #2 (port 1, paddle "B")
paddle=3 ..... Position of paddle #3 (port 2, paddle "A")
paddle=4 ..... Position of paddle #4 (port 2, paddle "B")

The value returned by POT ranges from 0 to 255. Any value greater than 255 means that the file button is also pressed. Paddles are read "backwards" from normal things like volume knobs or faucets. A value of 255 means the paddle has been turned counterclockwise as far as it will go ("off"), and a value of 0 means the paddle has been turned clockwise as far as it will go ("on").

Note that some paddles are "noisy" and their output must be averaged or "damped" to prevent whatever they are controlling from jittering.

```
10 SPRITE 1,1                       Turn on a sprite
20 DO                               Begin a loop
30 X=POT(3)                         Read paddle "A" in port 2
40 MOVSPR 1,300-(X AND 254),200     Move the sprite
50 LOOP UNTIL X>255                 Loop until button pressed
60 SPRITE 1,0                       Turn off sprite
```

This sample program turns on a sprite and lets you move it horizontally with a paddle. If you press the paddle's fire button, it turns off the sprite and the program ends. The calculations in line 40 do several things all at once- they mask the fire button and "damp" the output to reduce jitter by masking the least significant bit (the X AND 254 part) and invert the output so that turning the paddle to the right makes the sprite go right (subtracting result from 300).

PRINT - Display data on text screen

PRINT [expression_list] [<,|;>]

PRINT will evaluate each item in the expression_list and pass the results to the system screen editor to display on the screen. If a screen window is defined, the output will be confined to the window. PRINT can be used to send control codes and escape sequences to the screen editor to do such things as set windows, change TAB stops, change text colors or set reverse field, or choose cursor styles. See the section on Editor modes for details.

PRINT can be followed by any of the following:

Numeric or string expressions	12, "HELLO", 1+1, "$"+STR$(I)
Variable names	A, B, A$, X$
Functions	ABS(33), HEX$(160)
Punctuation marks	; ,
Nothing	

Numeric values are always followed by a space. Positive numbers are preceeded by a space, and negative numbers are preceeded by a minus sign ('-'). Scientific notation is used when a number is less than 0.01 or greater than or equal to 999999999.2.

A semicolon (':') or space between list items causes the next item to be printed immediately following the previous item. A comma (',') causes the next item to be printed at the next comma stop (similar to TAB stops, but every 10 spaces). These rules apply to the next print statement if the expression_list ends with either a semicolon or a comma, otherwise a return is printed. Note that floating point variable names should not be separated from the next variable name with a space, and constants should not be preceeded or followed by a space.

For formatted PRINT output, see the PRINT USING command.

```
PRINT "HELLO"                      HELLO

A$="THERE": PRINT "HELLO ";A$      HELLO THERE

A=4:B=2: PRINT A+B                  6

J=41: PRINT J;: PRINT J-1           41  40

C=A+B:D=B-A: PRINT A;B;C;D          4  2  6 -2
C=A+B:D=B-A: PRINT A,B,C,D          4         2         6         -2

A=1:B=2:AB=3: PRINT A B             3
PRINT 1 2 3, 1 2 3 +1               123       124

PRINT 0.009, 0.01                   9E-03     .01
PRINT 999999999; 999999999.2        999999999  1E+09
```

The CMD command can be used to redirect PRINT output to a device or file. Also see the POS, SPC, TAB functions, CHAR and PRINT USING.

PRINT# - Send data to an I/O channel (file)

```
PRINT#logical_channel_number [,expression_list] [<,|;>]
```

This command is used to send (transmit) data to a device or file. The logical_channel_number is the number assigned to the device (file) in an OPEN (or DOPEN) statement. The output is otherwise identical to that of a PRINT statement, including the comma and semicolon conventions. Note that certain screen-oriented functions, such as TAB and SPC do not have the same effect as they do with screen I/O.

It's good practice to examine the I/O status byte (and the DS disk status for file I/O) after every I/O instruction to check for problems or errors.

For formatted output, use the PRINT# USING command.

```
10 OPEN 1,8,15                  Initialize disk drive
20 PRINT#1,"I"                  (same as DCLEAR)
30 CLOSE 1

10 DOPEN#1,"NEWFILE",W          Create a SEQ file
20 FOR I=1TO10
30 PRINT#1, I,STR$(I)           Write numbers 1-10 to it
40 NEXT
50 DCLOSE#1

10 OPEN 2,2,2,CHR$(12)          Open 1200 baud RS232 channel
20 PRINT#2, "ATDT,5551212"      Send modem a Hayes dial command
```

PRINT USING - Output formatted data to the screen, device, or file

PRINT [#logical_channel_number,] USING format; expression_list [<,|;>]

Read about the PRINT and PRINT# commands first for information regarding the syntax of the expression_list and, for device output, establishing the logical_channel_number.

The items in the expression list must be separated by commas (',').

The format is defined in a string literal or string variable and is described below. See the PUDEF command for specifing special formatting characters. The various formatting characters are:

CHARACTER	SYMBOL	NUMERIC	STRING
Pound sign	#	X	X
Plus sign	+	X	
Minus sign	-	X	
Decimal Point	.	X	
Comma	,	X	
Dollar Sign	$	X	
Four Carets	^^^^	X	
Equal Sign	=		X
Greater Than Sign	>		X

The pound sign ('#') reserves room for a single character in the output field. If the data item contains more characters than the number of pound signs in the format field, the entire field will be filled with asterisks ('*').

```
10 PRINT USING "####";X
```

For these values of X, this format displays:

```
A = 12.34      12
A = 567.89     568
A = 123456     ****
```

For a STRING item, the string data is truncated at the bounds of the field. Only as many characters are printed as there are pound signs in the format item. Truncation occurs on the right.

The plus ('+') and minus ('-') signs can be used in either the first or last position of a format field but not both. The plus sign is printed if the number is positive. The minus sign is printed if the number is negative.

If a minus sign is used and the number is positive, a blank is printed in the character position indicated by the minus sign.

If neither a plus sign nor a minus sign is used in the format field for a numeric data item, a minus sign is printed before the first digit or dollar symbol if the number is negative and no sign is printed if the number is positive. This means that one more character is printed if the number is positive. If there are too many digits to fit into the field specified by the pound sign and +/- signs, then an overflow occurs and the field is filled with asterisks ('*').

A decimal point ('.') symbol designates the position of the decimal point in the number. There can be only one decimal point in any format field. If a decimal point is not specified in the format field, the number is rounded to the nearest integer and printed without any decimal places.

When a decimal point is specified, the number of digits preceding the decimal point (including the minus sign, if the number is negative) must not exceed the number of pound signs before the decimal point. If there are too many digits an overflow occurs and the field is filled with asterisks('*').

A comma (',') allows placing of commas in numeric fields. The position of the comma in the format list indicates where the commas appears in a printed number. Only commas within a number are printed. Unused commas to the left of the first digit appear as the filler character. At least one pound sign must precede the first comma in a field.

If commas are specified in a field and the number is negative, then a minus sign is printed as the first character even if the character position is specified as a comma.

FIELD	EXPRESSION	RESULT	COMMENT
##.#	-.1	-0.1	Leading zero added
##.#	1	1.0	Trailing zero added
####	-100.5	-101	Rounded to no decimal places
###.	10	10.	Decimal point added
#$##	1	$1	Leading dollar sign
####	-1000	****	Overflow because 4 digits and minus sign don't fit in field

A dollar sign ('$') symbol shows that a dollar sign will be printed in the number. If the dollar sign is to float (always be placed before the number), specify at least one pound sign before the dollar sign. If a dollar sign is specified without a leading pound sign, the dollar sign is printed in the position shown in the format field. If commas and/or a plus or minus sign is specified in a format field with a dollar sign, the program prints a comma or sign before the dollar sign. The four up arrows or carets symbol is used to specify that the the number is to be printed in E format (scientific notation). A pound sign must be used in addition to the four up arrows to specify the field width. The arrows can appear either before or after the pound sign in the format field. Four carats must be specified when a number is to be printed in E format. If more than one but fewer than four carats are specified, a syntax error results. If more than four carats are specified only the first four are used. The fifth carat is interpreted as a no text symbol. An equal sign ('=') is used to center a string in a field. The field width is specified by the number of characters (pound sign and =) in the format field. If the string contains fewer characters than the field width, the string is centered in the field. If the string contains more characters that can be fit into the field, then the rightmost characters are truncated and the string fills the entire field. A greater than sign ('>') is used to right justify a string in a field.

```
 5 X=32: Y=100.23: A$="TEST"
10 PRINT USING "$##.## ";13.25,X,Y
20 PRINT USING "###>#";"CBM",A$
```

When this is RUN, the following output appears on the screen:

```
$13.25 $32.00 $*****
  CBM TEST
```

$***** is printed instead of Y because Y has 5 digits, which exceeds the format specification. The second line asks for the strings to be right justified, which they are.

PUDEF - Redefine PRINT USING symbols

```
PUDEF definition_string
```

PUDEF allows redefinition of up to 4 symbols in the PRINT USING statement. Blanks, commas, decimal points, and dollar signs can be changed into some other character by placing the new character in the correct position in the PUDEF definition_string.

Position 1 is the filler character. The default is a space character. Place another character here to be used instead of spaces. Similarly,

Position 2 is the comma character. Default is a comma.
Position 3 is the decimal point.
Position 4 is the dollar sign.

```
10 PUDEF "*"        PRINTs * in the place of blanks.
20 PUDEF " @"       PRINTs @ in place of commas.
```

QUIT - [*** UNIMPLEMENTED ***]

RCLR - Get the current screen color

```
RCLR(source)
```

[*** CURRENTLY UNIMPLEMENTED ***]

This function returns the color assigned to source as an number in the range of 0-15. The color sources are:

0 = background
1 = foreground
2 = multicolor 1
3 = multicolor 2
4 = border
5 = highlight color

RDOT - Get the current position or color of the pixel cursor

```
RDOT(source)
```

[*** CURRENTLY UNIMPLEMENTED ***]

This function returns information about the current pixel location.

0 = current X position
1 = current Y position

2 = color index

READ - Read data from DATA statements

```
READ variable_list
```

READ statements are used along with DATA statements. READ statements read data from DATA statements into variables, just like an INPUT statement reads data typed by the user. READ statements can be used in direct or program mode, but DATA statements must be in a program.

The variable types in the variable_list must match the type of DATA being read, or a 'TYPE MISMATCH' error is reported. If there are insufficent data in the program's DATA statements to satisfy all of the variables in the READ statement, an 'OUT OF DATA' error is reported.

The computer maintains a pointer to the next DATA item to be read by a READ statement. Initially this pointer points to the beginning of the program. As each variable in a READ statement is filled, the computer moves the DATA pointer to the next DATA item. If all of a READ statement's variables are filled before all of the data has been read from a DATA statement, the next READ statement will begin reading data at the point where the previous READ stopped.

The DATA pointer can be changed by the RESTORE command. It can be reset back to the beginning of the program, or pointed to a specific line number. See RESTORE.

```
 10  DATA 100, 200, FRED, "HELLO, MOM", , 3.14, ABC123, -1.7E-9
 20  READ X,Y
 30  READ NAME$, MSG$, NULL$
 40  READ PI, JUNK$, S
 50  RESTORE
```

RECORD - Specify a relative disk file record number

```
RECORD #logical_channel_number, record [,byte]
```

This command allows you to access any part of any record in a RELative type disk file. If the byte parameter is omitted, the access pointer is pointed at the first byte of the specified record number.

Before you can use RECORD, you must OPEN a file. See OPEN and DOPEN for instructions. Also refer to your DOS manual for an explanation of RELative type files.

```
 10 INPUT "ENTER RELATIVE FILENAME: ",F$  get name of existing file
 20 DOPEN#1, (F$),L: PRINT DS$            open it & display disk status
 30 R=1: INPUT "ENTER RECORD NUMBER: ",R  get a record number
 40 B=1: INPUT "ENTER BYTE (RETURN): ",B  get byte number, if any
 50 RECORD#1, R,B                         position file pointer
 60 INPUT#1,REC$                          read the record
 70 PRINT REC$                            display the record
 80 PRINT "CONTINUE? (Y/N)"
 90 GETKEY A$: IF A$="Y" THEN 30
100 DCLOSE#1                              close the file
```

REM - Place an explanatory remark or comment in a program

```
REM plain text message
```

The REMark command is just a way to leave a note to whomever is reading a LISTing of the program. It might explain a section of the program, give information about the author, etc.

REM statements in no way effect the operation of the program, except to add length to it (and therefore slow it down a little). No other executable statement can follow a REMark on the same line.

```
10 REM  THIS PROGRAM WAS WRITTEN ON 2/14/91 BY F.BOWEN
20 REM  SAMPLE PROGRAM
30 :
40 DIR                    :REM  DISPLAY THE DISK DIRECTORY
50 LIST "SAMPLE PROGRAM"  :REM  DISPLAY THIS PROGRAM
60 END
```

RENAME - Rename a disk file

```
RENAME "oldname" TO "newname" [,Ddrive] [<ON|,>Udevice]
```

The RENAME command changes the name of a file in the disk directory. Pattern matching is not allowed, and "newname" must be a valid filename that does not already exist on the disk. The file being renamed does not need to be open.

```
RENAME "TEST" TO "FINALTEST"
RENAME (OLD$) TO (OLD$+".OLD") ON U(DEV)
```

RENUMBER - Renumber the lines of a BASIC program

```
RENUMBER [new_starting_line [,[increment] [,old_starting_line]]]
```

Renumber is used to resequence the line numbers of a BASIC program in memory. All or part of a program can be renumbered. The RENUMBER command first scans the program to make sure all the line numbers referenced in commands (such as GOTO, GOSUB, TRAP, etc.) exist, that new line numbers are in the legal range, and that changing the program would not overflow the available memory. An 'UNRESOLVED REFERENCE', 'LINE NUMBER TOO LARGE', or 'OUT OF MEMORY' error is reported if there's a problem, and RENUMBER is automatically canceled without having changed anything.

If the program passes all the checks, RENUMBER changes the specified line numbers and updates all references to the old numbers throughout the program and relinks the program.

The new_starting_line is the number of the first line in the program after renumbering. It defaults to 10. The increment is the spacing between line numbers (eg., 10, 20, 30 would mean an increment of 10). It also defaults to 10. The old_starting_line is the line number in the program where you want renumbering to begin.

RENUMBER can be used in direct (edit) mode only. Note that line number zero (0) is a valid line number.

RENUMBER	Renumbers the entire program. After renumbering, the first line will be 10, the second 20, etc. through the end of the program
RENUMBER ,1	Renumbers the entire program as above, but in increments of one. The first line will be 10, the second 11, etc.
RENUMBER 100, 5, 80	Starting at line 80, renumbers the program. Line 80 becomes line 100, and lines after that are numbered in

	increments of 5, through the end of the program.
`RENUMBER ,,65`	Starting at line 65, renumbers lines in increments of 10, starting at line 10 through the rest of the program.

RESTORE - Position READ pointer at specific DATA statement

```
RESTORE [line]
```

The computer maintains a pointer to the next DATA item to be read by a READ statement. Initially this pointer points to the beginning of the program. The DATA pointer can be changed by the RESTORE command.

Using RESTORE without specifying a line number will reset the DATA pointer back to the beginning of the program. If a line number is specified, the DATA pointer is pointed to that line. The line does not have to contain a DATA statement. When the computer executes the next READ statement, it will look for the next DATA item starting at the line the DATA pointer is at.

See the READ command an example.

RESUME - Resume program execution after error TRAP

```
RESUME [line|NEXT]
```

Used to return to execution after TRAPping an error. If a line number is given, the computer performs a 'GOTO line' and resumes execution at that line. RESUME NEXT resumes execution at the statement following the one that cause the error. RESUME without any parameters will resume execution at the statement that cause the error.

If the computer encounters a RESUME statement outside of a TRAP routine or if a TRAP was not in effect a 'CAN'T RESUME' error is reported. RESUME can only be used in program mode.

```
10 TRAP 90
20 FOR I=-5 TO 5
30 PRINT 5/I
40 NEXT
50 END
60 :
90 PRINT ERR$(ER): RESUME NEXT
```

RETURN - Return from subroutine or event handler

```
RETURN
```

This statement is associated with the GOSUB (GO SUBroutine) statement. When a subroutine is called by a GOSUB statement, the computer remembers where it's at before it calls the subroutine. When the computer encounters a RETURN statement, it returns to the place it last encountered a GOSUB and continues with the next statement.

If there wasn't a previous GOSUB, then a 'RETURN WITHOUT GOSUB' error is reported.

RETURN is also used by event handlers, set up by the COLLISION command. See COLLISION.

RGR - Get the current graphic mode

```
RGR (0)
```

[*** CURRENTLY UNIMPLEMENTED ***]

This function returns current graphic mode. A result of zero means the display is text, a non-zero result means it's graphic.

RIGHT$ - Get the rightmost characters of a string

```
RIGHT$ (string,count)
```

This function returns a string containing the rightmost 'count' number of characters of the string expression. Count is an numeric expression in the range (0-255). If count is greater than the length of the string, the entire string will be returned. If count is zero, a null (empty) string will be returned.

```
A$ = RIGHT$("123ABC",3)        Result is A$="ABC"
```

RMOUSE - Get the mouse position and button status

```
RMOUSE [Xposition [,Yposition [,button]]]
```

X,Yposition = current position of mouse pointer sprite
Button = current status of mouse buttons
0 = no button
1 = right button
128 = left button
129 = both buttons

RMOUSE is a command which retrieves a mouse's current position and the state of its buttons, and places this information into the specified numeric variables. If a mouse is not installed, "-1" is returned for all variables. If both ports are enabled, buttons from each port are merged. Use the MOUSE command to turn a mouse on or off.

```
10 MOUSE ON, 2, 1             Turn mouse on, port 2, sprite 1
20 DO                         Begin loop
30 RMOUSE X, Y, B             Get mouse position & buttons
40 PRINTUSING"### ";X,Y,B     Show   "        "         "
50 LOOP UNTIL B=129           Loop until user presses both buttons
60 MOUSE OFF                  Turn mouse off
```

RND - Get a pseudo-random number

```
RND (type)
```

The RND function returns a pseudo RaNDom number between 0 and 1. The random sequence returned is determined by the type parameter:

type = 0	Returns a random number based upon the system clock.
type < 0	Negative numbers "seed" the random number generator, defining a new but reproducible random sequence.
type > 0	Positive numbers draw the next random number from the sequence defined by the last "seed" value.

This lets a programmer use a reproducible sequence while debugging (fixing) a program, so that random errors can be easily reproduced. Once the program has been fixed, it can be "seeded" such that a random sequence is used every time the program is run.

```
10 DO
20 INPUT "SEED"; S
30 IF S=0 THEN END
40 FOR I=1 TO 5
50 PRINT INT(RND(1)*6)+1, INT(RND(1)*6)+1
60 NEXT
70 LOOP
```

The above program will demonstrate the results of seeding the random number generator. It lets you specify a positive or negative seed value, and then prints the first 5 random pairs of that sequence. Enter a zero to end the program. The calculations in line 50 make the random numbers be integers from 1 to 6, like dice. Type in a negative number to start a new sequence, and a positive number to "roll" more dice from that sequence. Every time you enter "-1", for example, you will roll the same numbers:

first roll	2 and 6
second	6 and 1
third	1 and 1
fourth	1 and 4
fifth	5 and 5

Games and statistical programs should use RND(0) for true randomness, or seed the generator with a random number, such as RND(-TI).

The general form for getting random integers using RND is:

```
INT( RND(0) * MAX ) + 1
```

where MAX is the highest number you can get. This gives you numbers as low as 1 and as high as MAX. For dice, MAX is 6 (or 12 if you want to simulate rolling two die at once). For cards, MAX is 52.

```
INT( RND(0) * 16)
```

This form will return integers from zero to 15, which is useful for generating random color values, for example.

RREG - Get register data after a SYS call

```
RREG [a_reg] [,[x_reg] [,[y_reg] [,[z_reg] [,status] ]]]
```

Following a SYS call, the RREG command retrieves the contents of the microprocessor's registers and puts them into the specified numeric variables. See the sample program at SYS.

RSPCOLOR - Get multicolor sprite colors

```
RSPCOLOR (multicolor#)
```

Returns the current colors for multicolor sprites. Color values range from 0-15. Use RSPRITE function to get the foreground sprite color.

multicolor# = 1 gets multicolor #1
multicolor# = 2 gets multicolor #2

See SPRITE and SPRCOLOR.

RSPPOS - Get the location and speed of a sprite

```
RSPPOS (sprite,parameter)
```

The RSPPOS function returns the current X or Y position of a sprite and its speed, set by the MOVSPR command. A sprite does not have to be on to use RSPPOS. The sprite number must be in the range of 0-7, and the parameter is:

0	to get current X position
1	to get current Y position
2	to get current speed (0-255)

RSPRITE - Get information about a sprite

```
RSPRITE (sprite,parameter)
```

The RSPRITE function returns the current state of a sprite, set by the SPRITE command. The sprite number must be in the range of 0-7, and the parameter is:

0	to see if it's turned on	(1)=yes	(0)=no
1	to get sprite foreground color	(0-15)	
2	to get priority over background	(1)=yes	(0)=no
3	to get X-expansion factor	(1)=yes	(0)=no
4	to get Y-expansion factor	(1)=yes	(0)=no
5	to get multicolor factor	(1)=yes	(0)=no

RUN - execute BASIC program

```
RUN [line #]
RUN "filename" [,Ddrive] [<ON|,>Udevice]
```

RUN executes the BASIC program that is currently in memory. The program has to be LOADed (DLOAD) or manually typed in before it can be executed. If a line number is specified, execution begins at that line. If a filename is specified, the program is automatically loaded from disk into memory and executed. RUN can be used in a program.

RUN clears all variables and open channels (but it does NOT properly close open disk write files- used DCLOSE or DCLEAR beforehand). RUN also resets the runtime stack pointer (clears GOSUB & FOR/NEXT stacks), the DATA pointer, and the PRINT USING characters. To start a program without initializing everything, use GOTO.

RUN	Starts the program at the first line.
RUN 100	Starts the program at line 100.
RUN "TEST"	Loads the program TEST from the default system disk and starts the program at the first line.

RWINDOW - Get information about the current text window

```
RWINDOW (parameter)
```

This is a function that returns information about the current console text display. The parameter is specified as:

0	to get the maximum line # in the current window
1	to get the maximum column # in the current window
2	to get the screen size, either 40 or 80 columns

SAVE - Save a BASIC program in memory to disk

```
SAVE "[[@]drive:]filename" [,device_number]
```

This command copies a BASIC program in the computer's BASIC memory area into a PRoGram-type disk file. If the file already exists, the program is NOT stored and the error message 'FILE EXISTS' is reported. If the filename is preceded with an '@0:', then if the file exists it will be replaced by the program in memory. Because of some problems with the 'save-with-replace' option on older disk drives, using this option is not recommended if you do not know what disk drive is being used (DELETE the file before SAVEing). Pattern matching is not allowed. In the case of dual drive systems, the drive number must be part of the filename.

Use the VERIFY or DVERIFY command to compare the program in memory with a program on disk. To save a binary program, use the BSAVE command.

SAVE "myprogram"	Creates the PRG-type file MYPROGRAM on the default system disk and copies the BASIC program in memory into it.
SAVE "@0:myprogram"	Replaces the PRG-type file MYPROGRAM with a new version of MYPROGRAM. If MYPROGRAM doesn't exist, it's created.
SAVE F$,9	Saves a program whose name is in F$ on disk unit 9.

SCALE - Set the logical dimension of the graphic screen

[*** NOT YET IMPLEMENTED ***]

SCNCLR - Clear a text or graphic screen

```
SCNCLR [color]
```

This command will clear the current text window if [color] omitted, otherwise it will clear the current graphic screen using the given color value. See also SCREEN CLR.

SCNCLR	Clears the text screen. If a window is defined, it clears only the window area.
SCNCLR 0	Clears the current graphic screen with color 0.

SCRATCH - Delete files from disk directory
Recover accidentally deleted files

```
SCRATCH "filespec" [,Ddrive] [<ON|,>Udevice] [,R]
```

SCRATCH, ERASE, or DELETE are different names of the same command. They are used to delete a file from a disk directory, or optionally to recover if possible an accidentally deleted file. The diskette must not be 'write protected', or a 'WRITE PROTECT ON' error is reported.

WARNING: Deleting a file will destroy all existing data in that file. Be extremely careful if you are using pattern matching, which can delete any or all files. In direct mode, you are asked to confirm what you are doing with 'ARE YOU SURE?'. Type 'Y' and press return to proceed, or TYPE ANY OTHER CHARACTER AND PRESS RETURN TO CANCEL the command. In program mode there is no confirmation prompt.

Upon completion, in direct mode only, the computer will display the number of files deleted.

Refer to your disk manual for other details. Different disk drives implement slightly different pattern matching rules or support features such a specially protected files.

If the 'R'ecover option is present and the DOS supports it, a deleted file can be recovered if nothing else has been written to the diskette since the file was accidentally deleted. You will still be asked to confirm the operation, and upon completion the computer will display the number of files restored.

SCRATCH "oldfile"	Deletes the file OLDFILE from the disk in the default system drive.
SCRATCH "file.*"	Deletes all files beginning with FILE.
SCRATCH (F$), U(DD)	Deletes the file whose name is in F$ from the disk in device DD.
SCRATCH "saveme" ,R	Attempt to recover the program SAVEME.

SCREEN - Graphic command

The SCREEN command is used to initiate a graphic command. It always precedes another command word which identifies the graphic operation to be performed:

SCREEN CLR - Set graphic screen color

```
SCREEN CLR  color#
```

Clears (erases) the currently opened graphic screen using the given color value. Use SCNCLR to clear a text screen. See also SCNCLR.

SCREEN DEF - Define a graphic screen

```
SCREEN DEF  screen#, width, height, depth
```

screen#	0-1
width	0=320, 1=640, 2=1280
height	0=200, 1=400
depth	1-8 bitplanes (2-256 colors)

Defines a logical screen (numbered 0 or 1), specifies its size and how many colors (bitplanes) it has. It does not allow access to the screen and it does not display the screen. The screen must be defined before it is opened for viewing and/or drawing to.

SCREEN SET - Set draw and view screens

```
SCREEN SET  DrawScreen#, ViewScreen#
```

draw screen #	0-1
view screen #	0-1

This command specifies which logical screen is to be viewed and which logical screen is to be accessed by the various draw commands. The screen must be defined and opened first. Both the draw and the view screen can be, and usually are, the same logical screen. For double buffering, they are different.

SCREEN OPEN - Open a screen for access

```
SCREEN OPEN  screen# [,error_variable]
```

screen#	0-1

error_variable [*** NOT YET IMPLEMENTED ***]

This command actually sets up the screen and allocates the necessary memory for it. If it's the view screen it will be displayed. If it's the draw screen, it can now be drawn to. If there is not enough memory for the screen, 'NO GRAPHICS AREA' is reported and the screen is not opened.

SCREEN CLOSE - Close a screen

SCREEN CLOSE screen#

screen# 0-1

This command closes a logical screen, ending access to it by the draw commands if it's the draw screen and restoring the text screen if it's the view screen. SCREEN CLOSE deallocates any memory reserved for the screen.

SAMPLE GRAPHIC PROGRAM:

```
  1 TRAP 170                              in case of error want text screen
 10 GRAPHIC CLR                           initialize graphics
 20 SCREEN DEF  1,0,0,2                   define a 320x200x2 graphic screen
 30 SCREEN OPEN 1                         open it
 40 PALETTE 1,0,  0, 0, 0                 define screen 1, color 0 = black
 50 PALETTE 1,1, 15, 0, 0                 define screen 1, color 1 = red
 55 PALETTE 1,2,  0, 0,15                 define screen 1, color 2 = blue
 60 PALETTE 1,3,  0,15, 0                 define screen 1, color 3 = green
 70 SCREEN SET  1,1                       make it the view screen
 80 SCNCLR 0                              clear screen with palette color 0
 90 BORDER 0                              set border color to color 0
100 PEN 0,1                               make draw pen = color 1 (red)
110 LINE 100,100, 150,150                 draw a diagonal red line
120 PEN 0,2                               make draw pen = color 2 (blue)
130 BOX  50,50, 50,80, 80,50, 80,80       draw a blue box
140 PEN 0,3                               make draw pen = color 3 (green)
150 CHAR 25,50, 1,1,2, "WORDS"            draw green text
160 SLEEP 5                               pause for 5 seconds
170 SCREEN CLOSE 1                        close graphic, get text screen
180 PALETTE RESTORE                       restore normal system colors
190 BORDER 6                              restore normal border color
200 END
```

SET - Set various system parameters

The SET command is used to set a system parameter. It always precedes another command word which identifies the parameter to be changed:

SET DEF - Set default system disk drive

SET DEF device

The BASIC DOS commands default to disk unit 8. Use SET DEF to change which device these commands default to. This command does not renumber a disk device, use SET DISK for that. Commands which specify a device will still access the device they specified. A program can be made more "user friendly" by either not specifying a drive (thus using the user's perferred drive) or by specifying device 1. Device number 1 means "use the system default drive, whatever its number is."

```
10 DIR                  gets directory of device 8
20 DIR U1               gets directory of device 8
```

```
30 DIR U10              gets directory of device 10
40 SET DEF 10           change the default drive to unit 10
50 DIR                  gets directory of device 10
60 DIR U1               gets directory of device 10
70 DIR U8               gets directory of device 8
```

SET DISK - Change a disk device number

```
SET DISK oldnumber TO newnumber
```

Use this command to renumber (change) a disk drive's unit number. Not all drives can be renumbered- refer to your disk drive manual for details. This command sends to the disk's command channel the conventional CBM serial disk drive "M-W" command. See also the DISK command, which lets you send any command to a disk drive.

```
SET DISK 8 TO 10          Change unit 8's number to 10
```

Because the built-in C64DX drives always take precedence over serial bus drives, this is one way to get the built-in drive "out of the way" so that you can access a serial bus drive #8.

SGN - Get the sign of a number

```
SGN (expression)
```

The SiGN function returns the sign of a numeric expression as follows:

```
If the expression is < 0 (negative) .... returns -1
If the expression is = 0 (zero) ........ returns  0
If the expression is > 0 (positive) .... returns  1
```

SIN - Sine function

```
SIN (expression)
```

This function returns the sine of X, where X is an angle measured in radians. The result is in the range -1 to 1.

```
X = SIN(pi/4)            Result is X=0.707106781
```

To get the sine of an angle measured in degrees, multiply the numeric expression by pi/180.

SLEEP - Pause program execution of a specified period of time

```
SLEEP seconds
```

Temporarily suspends execution of your program for 1 to 65535 seconds.

SLOW - Set system speed to 1.02MHz

SLOW is used primarily to directly access "slow mode only" devices such as the SID sound chips. FAST is the default system speed.

SOUND - Produce sound effects

```
SOUND v, f, d [,[dir] [,[m] [,[s] [,[w] [,p] ]]]]
```

v = voice (1-6)
f = frequency (0-65535)

d = duration (0-32767)
dir = step direction (0(up), 1(down), or 2(oscillate)) default=0
m = min frequency (0-65535) default=0
s = sweep (0-65535) default=0
w = waveform (0=triangle,1=saw,2=square,3=noise) default=2
p = pulse width (0-4095) 50% duty cycle=default=2048

The sound command is a fast and easy way to create sound effects and musical tones. The first three parameters are required to select the voice, frequency, and duration of the tone. The duration is specified in "jiffies" (60 jiffies = 1 second).

Optionally, you can specify a waveform and, for square waves, the pulse width. The SOUND command can sweep a voice through a series of equally-spaced frequencies. The direction of the sweep, minimum and maximum frequencies can be programmed. If time expires before the sweep is done, the sound stops. If the minimum or maximum frequency is reached before time expires, the sound repeats.

For programming details, refer to the SID hardware documentation. Use the VOLume command to change the volume of the sound. Note that the TEMPO command affects PLAY strings only, not SOUND effects.

```
FREQout = ( f * 0.0596 ) Hz
PWout   = ( p / 40.95  ) %
```

Each voice can be programmed separately and played simultaneously for a wide variety of sound effects. Once a sound effect is initiated, BASIC execution continues with the next statement while the sound plays out, allowing you to combine and control graphics, animation, and sound from a BASIC program. The examples below include information about how to generate precise tones for exact times, but for most casual users trial and error are perfectly acceptable! (Note that the values used are for 60Hz (NTSC) systems):

Using voice 1, emit a square-wave, 440Hz tone for 1 second. Note that 440Hz = 7382 * 0.0596 using the above formula.

```
SOUND 1, 7382, 60
```

Using voice 2, sweep from 100Hz (m=1638) to 440Hz (f=7382) in increments of 1Hz (s=17). The time required to do this can be calculated as t=(f-m)/s, so t=336 jiffies.

```
SOUND 2, 7382, 336, 0, 1678, 17
```

Using voice 3, make a neat sound using an oscillating sweep (dir=2) and a sawtooth waveform (w=1) for 3 seconds (t=180).

```
SOUND 3, 5000, 180, 2, 3000, 500, 1
```

SPC - Space PRINT output

```
SPC (number)
```

The SPaCe function is used to format PRINTed data to the screen, a printer, or a file. It specifies the number of spaces to be skipped, from 0 to 255. A semicolon (';') is always assumed to follow SPC, even if it appears at the end of a print line.

The SPC function works a little differently on screen, printer, and disk output. On the screen, SPC skips over characters already on the screen, which is not the case with printer and disk output. On printers, if the last character on a line is skipped, the printer will automatically perform a carriage return and linefeed.

```
PRINT "123";SPC(3);"456"        Displays '123   456'

PRINT "X";SPC(5) :PRINT"X"      Displays 'X     X'
```

See also the TAB function. A better way to format PRINT output is with PRINT USING.

SPRCOLOR - Set multicolor sprite colors

```
SPRCOLOR [sprite_mc1] [,sprite_mc2]
```

Use the SPRITE command to set up a multicolor sprite, and used SPRCOLOR to set the additional colors. Note that these colors are common to all multicolor sprites. The color values must be in the range (0-15). Use the RSPCOLOR function to get the current multicolor sprite colors, and RSPRITE to get the current sprite foreground color.

SPRDEF - Define a sprite pattern

[*** NOT EXPECTED TO BE IMPLEMENTED ***]

SPRITE - Turn a sprite on or off, and set its characteristics

```
SPRITE number [,[on] [,[fgnd] [,[priority] [,[x_exp] [,[y_exp] [,mode] ]]]]]
```

The SPRITE command allows you set all of the characteristics of a sprite. Use the MOVSPR command to position it or set it in motion. Use the SPRCOLOR to set the multicolor sprite colors, if you are using multicolor sprites.

All the parameters except the sprite number are optional. If you don't specify a parameter then it won't be changed.

```
number   = sprite number                  (0-7)
on       = enable (1) or disable(0)
color    = sprite foreground color        (0-15)
priority= sprite to display data priority:
               0 means sprite goes over screen data
               1 means sprite goes under screen data
x,y-exp = sprite expansion on (1) or off (0)
mode     = sprite mode:
               0 high resolution
               1 multicolor
```

The SPRITE command does not define a sprite. The sprite definitions must be loaded into the sprite area first ($600-$7FF). Use the BLOAD and BSAVE commands. [*** THIS MAY CHANGE ***] A sprite is 24 pixels wide and 21 pixels high. Each sprite definition requires 63 ($40 hex) bytes:

$600	Sprite 0 definition
$640	Sprite 1 definition
$680	Sprite 2 definition
$6C0	Sprite 3 definition
$700	Sprite 4 definition
$740	Sprite 5 definition
$780	Sprite 6 definition
$7C0	Sprite 7 definition

Use the RSPRITE function to read a sprite's characteristics, or the RSPPOS function to read a sprite's position. The RSPCOLOR function is used to get the current multicolor sprite colors.

```
10 BLOAD"sprite 1 data",P(dec("640")) Load sprite 1's definition
20 SPRITE 1, 1, 2                     Turn it on, make it red
30 MOVSPR 1, 24,50                    Put it at top-leftmost corner
40 SPRSAV 1, 2                        Copy sprite 1 definition to 2
50 SPRITE 2, 1, 7                     Turn on sprite 2 make it yellow
60 MOVSPR 2, 320,229                  Put it at bottom-rightmost corner
70 BSAVE"sprite 2 data"), P(dec("680")) TO P(dec("6c0")) save sprite 2
80 SPRITE 1, 0                        Turn off sprite 1
90 SPRITE 2, 0                        Turn off sprite 2
```

SPRSAV - Copy a sprite definition

```
SPRSAV  source, destination
```

Use this command to copy a sprite's data (shape) to another sprite or into a string variable, or copy a shape from a string variable into a sprite. You can have many different sprite shapes in memory at one time, all stored in strings. This makes it possible to animate sprites from BASIC by quickly "flipping through" shapes, using each shape like a frame from a movie film.

```
SPRSAV 0, A$     copy the data (shape) of sprite 0 into A$

SPRSAV A$, 2     copy the data (shape) in A$ into sprite 2

SPRSAV 1, 2      copy the data (shape) in sprite 1 to sprite 2
```

STASH - (see the DMA command)

SQR - Square root function

```
SQR (number)
```

This function returns the of the SQuare Root of the given numeric expression. The numeric expression must not be negative or an 'ILLEGAL QUANTITY' error is reported.

```
A = SQR(10)      Result is A = 3.16227766
```

STEP - See FOR/NEXT/STEP

STOP - Halt program execution

```
STOP
```

When STOP is executed, the computer immediately stops running the program and reports 'BREAK IN LINE xx'. No variables are cleared and files are not closed.

This command is usually used while debugging (fixing) a BASIC program, since it lets you stop at a specific place, examine variables, change variables, and restart the program where it was halted (see CONTinue command) or some other line (see GOTO). In many cases, you can even change the program and use GOTO to resume execution with variables and open channels intact.

SWAP - (see the DMA command)

STR$ - Get the string representaion of a number

```
STR$ (number)
```

The STRing function returns a string identical to PRINT's output of the given numeric expression. See PRINT for details regarding the format of numeric output. STR$ is the opposite of VAL.

```
A$ = STR$(123)          Result is A$ = " 123"
A$ = STR$(-123)         Result is A$ = "-123"
A$ = STR$(.009)         Result is A$ = " 9E-03"
```

SYS - Call a ROM routine or user machine language routine

```
SYS address [,[a] [,[x] [,[y] [,[z] [,s] ]]]
```

This statement performs a call to a machine language routine at the specified address (range 0-65535, $0000-$FFFF) in a memory bank set up previously by the BANK command.

The microprocessor's registers are loaded with the values specified in the parameters following the address (if given) and a JSR (Jump SubRoutine) instruction is performed. When the called routine ends with an RTS (ReTurn from Subroutine), the microprocessor's registers are saved and control is returned to the BASIC program. The microprocessor's registers can be examined with the RREG command.

Because this command instructs the computer's microprocessor (CPU) to perform something, extreme care should be taken in its use. It can easily crash the computer if you do something wrong (press the reset button to reboot). Also see the BOOT SYS command.

```
BANK 128: SYS DEC("FF5C")       Call the Kernel's PHOENIX routine.

BANK 128: SYS DEC("FF81")       Reset the Screen Editor

10 BANK 128
20 BLOAD"user_routine",P(dec("1800"))   Load a user routine
30 SYS DEC("1800"), areg, xreg          Call it with args in A and X
40 RREG areg, xreg, , , sreg            Get args back in A, X, and S
50 carry = (sreg AND 1)                 Get carry flag from S
60 PRINT "ACCUMULATOR = ";HEX$(areg)    Display registers
60 PRINT "X REGISTER  = ";HEX$(xreg)
60 PRINT "CARRY FLAG  = ";carry
```

See the USR function for another way to call machine language routines.

TAB - Space PRINT output

```
TAB (number)
```

The TAB function is used to format PRINTed data to the screen, a printer, or a file. It's primarily for screen text output, moving the cursor to the specified column (plus one) as long as the current print position is not already beyond that point (for example, if the current print position is the first column, TAB(1) would print subsequent text beginning in column 2). If the current print position is already beyond the column specified by the TAB function, nothing is done. For disk and printer output, TAB works exactly like the SPC function (see SPC).

A semicolon (';') is always assumed to follow TAB, even if it appears at the end of a print line.

```
PRINT "TEXT";TAB(10);"HERE"        Result is 'TEXT      HERE'
PRINT "TEXT";SPC(10);"HERE"        Result is 'TEXT          HERE'
```

The above examples illustrate the difference between TAB and SPC. See also the SPC function. A better way to format PRINT output is with PRINT USING. Don't confuse the TAB function with the TAB character, CHR$(9), which is used to format data using the programmable TAB stops.

TAN - Tangent function

```
TAN (expression)
```

This function returns the tangent of the numeric expression, measured in radians. If the result overflows, TAN(pi/2) for example, an 'OVERFLOW' error is reported.

```
X = TAN(1)                Result is X=1.55740772
```

To get the tangent of an angle measured in degrees, multiply the numeric expression by pi/180.

TEMPO - Set the tempo (speed) of a PLAY string

```
TEMPO rate
```

Use this command to adjust the tempo (speed) of music playback by the PLAY command. The rate determines the duration of a whole note. The default is 12, making a whole in 4/4 time last 2 seconds. The formula is:

```
duration = 24/rate
```

The higher the rate, the faster the note. The range is (1-255).

THEN - See IF/THEN/ELSE

TO - See FOR/NEXT/STEP. Also used as a subcommand.

TRAP - Define an BASIC error handler

```
TRAP [line_number]
```

When turned on, TRAP intercepts all BASIC execution error conditions except 'UNDEF'D STATEMENT ERROR'. Even the STOP key can be TRAPped.

When an error occurs, BASIC saves the error's location, line number, and error number. If TRAP is not set, BASIC returns to direct mode and displays the error message and line number. If TRAP is set, BASIC performs a GOTO to the line number specified in the TRAP statement and continues executing.

Your BASIC error handling routine can examine the error number, message, and the line number where the error occurred and determine the proper course of action. The system error words are:

ER	Error Number
EL	Error Line (line where the error occurred)
ERR$()	Error Message

If ER is -1, then a BASIC error did not occur. The error routine should check the disk status words, in case they were the cause of the error:

DS	Disk Error Number
DS$	Disk Error Message

Refer to the list of BASIC and Disk error messages in the appendix.

Note that an error in your TRAP routine cannot be trapped. The RESUME statement can be used to resume execution- see RESUME.

TRAP with no line number specified turns off error TRAPping.

```
10 TRAP 90                                 enable trapping
20 FOR I=-5 TO 5
30 PRINT 5/I                               error when I=0
40 NEXT
50 TRAP                                    turn trapping off
60 END
70 :
90 PRINT ERR$(ER): RESUME NEXT             error routine
```

TROFF - Turn off trace mode
TRON - Turn on trace mode

```
TROFF
TRON
```

Trace mode is used while debugging (fixing) a BASIC program. TRON enables tracing, and TROFF disables tracing. When the program is run and trace mode os on, the line number of the command that is being executed is displayed on the screen. If there are three commands on the line, the line number will be displayed three times, once each time one of the commands is executed. Trace mode lets you know what the computer is doing.

Trace mode works even when a graphic screen is being displayed, but the line number is still displayed on the text screen so you won't be able to see it until the graphic screen is turned off. If your program is doing alot of PRINT statements, the display can seen a little confusing.

Trace mode can be set in direct mode to trace the entire program, or it can be turned on and off from within your program to let you trace only selected portions of the program.

Trace mode has no effect on commands entered in direct (edit) mode. The NEW command disables trace mode, but RUN and CLR do not.

```
10 FOR I=-5 TO 5
15 TRON
20 PRINT 5/I
25 TROFF
30 NEXT
```

TYPE - Display the contents of a sequential disk file

```
TYPE "filename" [,Ddrive] [<,|ON>Udevice]
```

Use this command to print the contents of a PETSCII data file on the screen. The file must contain lines no longer than 255 characters long and terminated by a return character (CHR$(13)). Lines too long result in a 'STRING TOO LONG' error.

```
TYPE "readme"           display the contents of the README
```

file on the screen

The command sequence below will print the contents of the README file on a CBM serial bus printer in upper/lower case mode.

```
OPEN 4,4,7: CMD4: TYPE"readme": CLOSE4
```

UNTIL - See DO/LOOP/WHILE/UNTIL/EXIT

USR - Call a user defined machine language function

USR (expression)

When this function is used, the program jumps to a machine language subroutine whose starting address must be POKEd into system memory (BANK 128) at address 760 (low byte) and 761 (high byte), or $2F8 hex. The floating point value of the numeric expression is passed to the routine in the Floating point ACCumulator (FACC), and the value to be returned is taken from the FACC when the routine ends.

If the USR vector is not set up prior to making the USR call, an 'UNDEF'D FUNCTION' error is reported. The routine must be located in the system bank. The BANK command does not affect USR.

Using this method of calling a machine language routine requires a fair amount of set up and a good knowledge of the lower level math routines built into BASIC. See the SYS command, which is more commonly used to call a machine language routine.

The following program illustrates the basic steps required for installing a USR routine and calling it:

```
10 BANK 128                                System bank for poke & load
20 UV = DEC("1800")                        Where my routine is
30 BLOAD "my user routine",P(UV)           Load my routine
40 POKE DEC("2F8"), UV AND 255, UV / 256   Set up USR address
50 X = USR(123): PRINT X                   Call my routine with the
                                           the value 123, get back and
                                           print whatever my routine
                                           leaves in FACC
```

The following program actually works. It points the USR vector to the BASIC math jump table entry for the routine which inverts the sign of the number in the FACC. Type in positive & negative numbers:

```
10 BANK 128                                System bank for poke
20 POKE DEC("2F8"), DEC("33"), DEC("7F")   Set up USR address
30 DO: INPUT"SIGNED NUMBER"; N             Get number input
40 :   PRINT USR(N)                        Display USR output
50 :   LOOP UNTIL N=0                      End if user types zero
```

USING - See PRINT USING

VAL - Get the numerical value of a string

VAL (string)

The VALue function converts a string into a number. The conversion starts with the first character and ends at the end of the string or the first character that is not allowed in normal number input. Spaces are ignored. If the first character of the string is not a legal character, a zero is returned.

The VAL function works the same way the INPUT and READ commands do. VAL is the opposite of STR$.

```
        X = VAL(" 123")         Result is X =  123
        X = VAL("-123")         Result is X = -123
        X = VAL(" 9E-02")       Result is X = .09
```

VERIFY - Compare a program or data in memory with a disk file

```
VERIFY "filename" [,device_number [,relocate_flag]]
```

This command is just like a LOAD command, except instead of putting the data read from a file into memory, the computer compares it to what is already in memory. If there's any difference at all a 'VERIFY ERROR' is reported.

The filename must be given, and pattern matching may be used. In the case of dual drive systems, the drive number must be part of the filename. If a device number is given, the file is sought on that unit, which must be a disk drive. If a device number is not given, the default system drive is used. See also DVERIFY.

Note: If the BASIC program in memory is not located at the same address as the version on disk was SAVEd from, the files will not match even if the program is otherwise identical.

The relocate_flag is used to VERIFY binary files. If the relocate_flag is present and non-zero, the file will be compared to memory starting at the address stored on disk when the file was SAVEd. The memory bank used is the bank given in the last BANK statement. The ending address is determined by the length of the disk file. The comparison halts on the first mismatch or at the end of the file. The area to be compared must be confined to the indicated memory bank. Do not use the relocate_flag to verify BASIC programs. See also BVERIFY.

```
                        VERIFY "myprogram"

Good:   SEARCHING FOR 0:myprogram       Bad:   SEARCHING FOR 0:myprogram
        VERIFYING                              VERIFYING
        OK                                     ?VERIFY ERROR
```

VERIFY "PROG"	Compares BASIC program in memory to file PROG on the default system disk.
VERIFY FILE$,DRV	Compares program in memory to a program whose name is in the variable F$ on the unit whose number is in DRV.
VERIFY "0:PROG",8	Compares memory to BASIC program PROG on unit 8, drive-0.
BANK 128 VERIFY "BIN",8,1	Compares a binary file into memory. The address used comes from the disk file, but you must specify the memory bank.

VIEWPORT - [*** CURRENTLY UNIMPLEMENTED ***]

VOL - Set audio volume level

```
VOL volume
```

[*** THIS COMMAND WILL CHANGE ***]

This statement sets the volume level for SOUND and PLAY statements.

VOLUME can be set from 0 to 15, where 15 is the maximum volume. A volume of 0 turns sound output off. VOLume affects all 3 voices. Note that PLAY strings can change the volume, too.

WAIT - Pause BASIC program until a memory state satisfied

```
WAIT address, and_mask [,xor_mask]
```

The WAIT statement causes program execution to be suspended until data at a specified memory location matches a given bit pattern. It's used to pause your program until an event occurs.

The event could be an I/O state (such as a fire button or peripheral port change), a hardware state (such as the raster position or RS232 status), or memory change caused by an interrupt event (such as a keyboard scan).

The WAIT statement tells the computer to read (PEEK) a memory location (0-65535) and AND the value it got with the number in and_mask (0-255). If the result is zero, repeat the operation until the result is not zero. This is like the following BASIC instructions, but much faster:

```
DO: result = PEEK(address): LOOP UNTIL (result AND and_mask) <> 0
```

This works if the state you are WAITing for is non-zero (a one or "high" state). If you want to wait for a zero state (a "low" state), you need to use the xor_mask option to "flip" the bits of the result.

Note that it's possible to "hang" your program indefinitely if the state you are waiting for never happens or you specify the wrong data. Press the STOP and RESTORE keys at the same time to get control back.

Be sure to use the BANK command before you tell the computer to WAIT, to specify which 64K memory bank the address is in. Note that a BANK number greater than 127 (i.e., a bank number with the most significant bit set) must be used to address an I/O location, such as the VIC chip. Refer to the system memory map for details.

```
10 BANK 128                           Wait for the VIC raster to be
20 WAIT DEC("D011"), 128              offscreen (want RC8 = 1)

10 BANK 128
20 WAIT DEC("D011"), 128, 128         Wait for the VIC raster to be
                                      onscreen (want RC8 = 0)
10 BANK 128
20 WAIT DEC("D3"), 1                  Wait for user to press shift
30 WAIT DEC("D3"), 2                  Wait for user to press C= key
40 WAIT DEC("D3"), 4                  Wait for user to press CTRL key
50 WAIT DEC("D3"), 8                  Wait for user to press ALT key
```

WHILE - See DO/LOOP/WHILE/UNTIL/EXIT

WIDTH -

[*** CURRENTLY UNIMPLEMENTED ***]

WINDOW - Set a text window

```
WINDOW  left_column, top_row, right_column, bottom_row [,clear]
```

This command defines a logical text screen window. All text I/O will be confined to this window. The row parameters must be in the range (0-24), and the column parameters must be in the range (0-79) for 80-column screens or (0-39) for 40-column screens. The parameters are always referenced to the physical screen (i.e., you cannot define a window within a window). If the clear flag is given, the new window area will be cleared after it's set up.

Use the RWINDOW function to get the current window size.

You are responsible for saving and restoring screen data in all windows because the WINDOW command simply sets the window margins. The WINDOW command does not draw a border around a window. All color commands and screen modes (such as scroll disable, TAB stops, etc.) are global.

Two consecutive "home" characters will reset the window definition back to the physical screen.

WINDOW 0,0,39,24	Define a window in 80-column mode that is the left half of the screen
WINDOW 40,0,79,24	Define a window in 80-column mode that is the right half of the screen
WINDOW 0,0,79,12	Define a window in 80-column mode that is the top half of the screen
WINDOW 0,13,79,24	Define a window in 80-column mode that is the bottom half of the screen
WINDOW 20,6,59,12,1	Define a window in 80-column mode in the center of the screen and clear it. The window is 12 characters high and 40 characters wide.
PRINT CHR$(19)CHR$(19);	Reset the window back to full screen in either 40 or 80-column mode and put the cursor in top left corner.

XOR - Exclusive-Or function

XOR (number,number)

The XOR function returns a numeric value equal to the logical XOR of two numeric expressions, operating on the binary value of the unsigned 16-bit integers in the range (0 to 65535). Numbers outside this range result in an 'ILLEGAL QUANTITY' error.

X = XOR(4,12)	Result is X= 8
X = XOR(2,12)	Result is X=14

3.1.4 VARIABLES -

The C64DX uses three types of variables in BASIC:

floating point	X
integer	X%
string	X$

Normal NUMERIC VARIABLES, also called floating point variables, can have any from up to nine digits of accuracy. When a number becomes larger than nine digits can show, as in +10 or -10, the computer displays it in scientific notation form, with the number normalized to 1 digit and eight decimal places, followed by the letter E and the power of ten by which the number is multiplied. For example, the number 12345678901 is displayed as 1.23456789E+10.

INTEGER VARIABLES can be used when the number is a signed whole number from +32767 to -32768. Integer data is a number like 5, 10, or -100. Integers take up less space than floating point variables, particularly when used in an array.

STRING VARIABLES are those used for character data, which may contain numbers, letters, and any other character that the computer can make. An example of string data is "Commodore C64DX".

VARIABLE NAMES may consist of a single letter, a letter followed by a number, or two letters. Variable names may be longer than 2 characters, but only the first two are significant. An integer is specified by using the percent (%) sign after the variable name. String variables have a dollar sign ($) after their names.

EXAMPLES:
Numeric Variable Names: A, A5, BZ
Integer Variable Names: A%, A5%, BZ%
String Variable Names: A$, A5$, BZ$

ARRAYS are lists of variables with the same name, using an extra number (or numbers) to specify an element of the array. Arrays are defined using the DIM statement, and may be floating point, integer, or string variable arrays. The array variable name is followed by a set of parentheses () enclosing the number of the variable in the list.

EXAMPLE:
A(7), BZ%(11), A$(87)

Arrays can have more than one dimension. A two dimensional array may be viewed as having rows and columns, with the first number identifying the row and the second number identifying the column (as if specifying a certain grid on the map).

EXAMPLE:
A(7,2), BZ%(2,3,4), Z$(3,2)

RESERVED VARIABLE NAMES are names that are reserved for use by the computer, and may not be used for another purpose. These are the variables DS, DS$, ER, ERR$, EL, ST, TI, and TI$. KEYWORDS such as TO and IF or any other names that contain KEYWORDS, such as RUN, NEW, or LOAD cannot be used.

ST is a status variable for input and output (except normal screen/keyboard operations). The value of ST depends on the results of the last I/O operation. In general, if the value of ST is 0 then the operation was successful.

TI and TI$ are variables that relate to the real-time clock built into the C64DX. The system clock is reset to zero when the system is powered up or reset, and can be changed by the user or a program.

TI$="hh:mm:ss.t"	Allows optional colons to delimit parameters and allows input to be abbrieviated (eg., TI$="h:mm" or even TI$=""), defaulting to "00" for unspecified parameters. 24-hour clock (00:00:00.0 to 23:59:59.9).
TI	24-hour TOD converted into tenths of seconds.

The value of the clock is lost when the computer is turned off. It starts at zero when the computer is turned on, and is reset to zero when the value of the clock exceeds 23:59:59.9 .

The variable DS reads the disk drive command channel, and returns the current status of the drive. To get this information in words, PRINT DS$. These status variables are used after a disk operation, like DLOAD or DSAVE, to find out why the error light on the disk drive s blinking.

ER, EL, and ERR$ are variables used in error trapping routines. They are usually only useful within a program. ER returns the last error encountered since the program was RUN. EL is the line where the error occurred. ERR$ is a function that allows the program to print one of the BASIC error messages. PRINT ERR$(ER) prints out the proper error message.

3.1.5 OPERATORS -

The BASIC OPERATORS include ARITHMETIC, RELATIONAL, and LOGICAL OPERATORS. The ARITHMETIC operators include the following signs:

+	addition
-	subtraction
*	multiplication
/	division
^	raising to a power (exponentiation)

On a line containing more than one operator, there is a set order in which operations always occur. If several operators are used together, the computer assigns priorities as follows: First, exponentiation, then multiplication and division, and last, addition and subtraction. If two operators have the same priority, then calculations are performed in order from left to right. If these operations are to occur in a different order, BASIC 10.0 allows giving a calculation a higher priority by placing parentheses around it. Operations enclosed in parentheses will be calculated before any other operation. Make sure that the equations have the same number of left and right parentheses, or a SYNTAX ERROR message is posted when the program is run.

There are also operators for equalities and inequalities, called RELATIONAL operators. Arithmetic operators always take priority over relational operators.

=	is equal to
<	is less than
>	is greater than
<= or =<	is less than or equal to
>= or =>	is greater than or equal to
<> or ><	is not equal to

Finally, there are three LOGICAL operators, with lower priority than both arithmetic and relational operators:

AND
OR
NOT

These are most often used to join multiple formulas in IF ... THEN statements. When they are used with arithmetic operators, they are evaluated last (i.e., after + and -). If the relationship stated in the expression is the true the result is assigned an integer of -1 and if false a of 0 is assigned. There is also an XOR function.

EXAMPLES:

IF A=B AND C=D THEN 100	requires both A=B & C=D to be true
IF A=B OR C=D THEN 100	allows either A=B or C=D to be true
A=5:B=4:PRINT A=B	displays 0
A=5:B=4:PRINT A>3	displays -1
PRINT 123 AND 15:PRINT 5 OR 7	displays 11 and 7

3.1.6 ERROR MESSAGES -

3.1.6.1 BASIC ERROR MESSAGES -

The following error messages are displayed by BASIC. Error messages can also be displayed with the use of the ERR$() function. The error number refers only to the number assigned to the error for use with this function. In direct mode, DOS error messages (DS$) are automatically displayed. They are described in the section after this one.

ERROR #	ERROR NAME	DESCRIPTION
1	TOO MANY FILES	There is a limit of 10 files OPEN at one time.
2	FILE OPEN	An attempt was made to open a file using the number of an already open file.
3	FILE NOT OPEN	The file number specified in an I/O statement must be opened before use.
4	FILE NOT FOUND	No file with that name exists on the specified drive.
5	DEVICE NOT PRESENT	The required I/O device not available.
6	NOT INPUT FILE	An attempt made to read data from a file that was opened for writing.
7	NOT OUTPUT FILE	An attempt was made to write data to a file that was opened for reading.
8	MISSING FILE NAME	Filename was missing in command.
9	ILLEGAL DEVICE NUMBER	An attempt was made to use a device improperly (SAVE to the screen, etc) or an illegal device number was specified.
10	NEXT WITHOUT FOR	Either loops are nested incorrectly, or there is a variable name in a NEXT statement that doesn't correspond with one in FOR.
11	SYNTAX ERROR	A statement is unrecognizable by BASIC. This could be because of missing or extra parenthesis, parameters, delimiters, or a mispelled keyword.
12	RETURN WITHOUT GOSUB	A RETURN statement was encountered when no GOSUB statement was active.
13	OUT OF DATA	A READ statement was encountered with no DATA left unREAD.
14	ILLEGAL QUANTITY	A number used as an argument is outside the allowable range (too big or too small).
15	OVERFLOW	The result of a computation is larger than the largest number allowed (1.701411834E+38)
16	OUT OF MEMORY	There is not enough memory for the program, or variables, or there are too many DO, FOR or GOSUB statements in effect.

17	UNDEF'D STATEMENT	A line number referenced doesn't exist.
18	BAD SUBSCRIPT	The program tried to reference an element of an array out of the range specified by a DIM statement, a missing DIM statement, or a mistyped function name.
19	REDIM'D ARRAY	An array can only be DIMensioned once.
20	DIVISION BY ZERO	Division by zero is illegal.
21	ILLEGAL DIRECT	Command is only allowed to be used in a program.
22	TYPE MISMATCH	A numeric variable was used in place of a string variable or vice versa.
23	STRING TOO LONG	An attempt was made to assign more than 255 characters to a string, or enter more than 160 characters from the keyboard, or to input more than 255 characters from a file.
24	FILE DATA	The wrong type of data was read from a file.
25	FORMULA TOO COMPLEX	An expression is too complicated for BASIC to process all at one time. Break it into smaller pieces or use fewer parentheses.
26	CAN'T CONTINUE	The CONT command does not work if the program was not RUN, there was an error, or a line has been edited.
27	UNDEFINED FUNCTION	An attempt was made to use a user defined function that was never defined.
28	VERIFY	The program on disk does not match the program in memory.
29	LOAD	There was a problem loading.
30	BREAK	The program was halted by the STOP key or a STOP statement.
31	CAN'T RESUME	A RESUME statement was encountered without a TRAP in effect, or an error occurred in the trap handler itself.
32	LOOP NOT FOUND	The program encountered a DO statement and cannot find the corresponding LOOP.
33	LOOP WITHOUT DO	A LOOP was encountered without a DO statement active.
34	DIRECT MODE ONLY	A command was used in a program that can only be used in direct mode.
35	NO GRAPHICS AREA	A graphics command was used before a graphics screen was defined and opened.
36	BAD DISK	A BOOT SYS command failed because the disk could not be read.
37	BEND NOT FOUND	A BEND statement not found for BEGIN.
38	LINE NUMBER TOO LARGE	A line number cannot exceed 64000.

39	UNRESOLVED REFERENCE	Renumber failed because a referenced line number does not exist.
40	UNIMPLEMENTED COMMAND	The given command is not currently implemented in this computer.
41	FILE READ	There was a problem reading data from a disk file. Similar to LOAD ERROR.

3.1.6.2 DOS ERROR MESSAGES -

The following error messages are returned through the DS and DS$ variables. If a disk command is type in direct mode, these messages will be displayed automatically. NOTE: DOS message numbers less than 20 are advisory and are not necessarily errors. DOS messages may vary slightly depending upon the drive model. Refer to your DOS manual for details.

ERROR #	DESCRIPTION
00:	OK (no error)
01:	FILES SCRATCHED (not an error) The following number (track) tells how many files were deleted by the scratch command.
02:	PARTITION SELECTED (not an error) The requested disk partition (subdirectory) has been selected.
03:	FILES LOCKED The requested file(s) have been locked.
04:	FILES UNLOCKED The requested file(s) have been unlocked.
05:	FILES RESTORED The requested file(s) have been recovered (undeleted).
20:	READ ERROR (block header not found) The disk controller is unable to locate the header of the requested data block. Caused by an illegal sector number, or the header has been destroyed.
21:	READ ERROR (no sync character) The disk controller in unable to detect a sync mark on the desired track. Caused by misalignment of the read/write head, no diskette is present, or unformatted or improperly seated diskette. Can also indicate a hardware failure.
22:	READ ERROR (data block not present) The disk controller has been requested to read or verify a data block that was not properly written. This error occurs in conjunction with the BLOCK commands and indicates an illegal track and/or sector request.
23:	READ ERROR (checksum error in data block) This error message indicates that there is an error in one or more of the data bytes. The data has been read into the DOS memory, but the checksum over the data is in error. This message may also indicate grounding problems.
24:	READ ERROR (byte decoding error) The data or header has been read into the DOS memory, but a hardware error has been created due to an invalid bit pattern in the data byte. This message may also indicate grounding problems.
25:	WRITE ERROR (write-verify error) This message is generated if the controller detects a mismatch between the written data and the data in the DOS memory.
26:	WRITE PROTECT ON

This message is generated when the controller has been requested to write a data block while the write protect switch is depressed.

27: READ ERROR
This message is generated when a checksum error is in the header.

28: WRITE ERROR
This error message is generated when a data block is too long.

29: DISK ID MISMATCH
This message is generated when the controller has been requested to access a diskette which has not been initialized. The message can also occur if a diskette has a bad header.

30: SYNTAX ERROR (general syntax)
The DOS cannot interpret the command sent to the command channel. Typically, this is caused by an illegal number of file names, or patterns are illegally used. For example, two file names appear on the left side of the COPY command.

31: SYNTAX ERROR (invalid command)
The DOS does not recognize the command. The command must start in the first position.

32: SYNTAX ERROR (invalid command)
The command sent is longer than 58 characters.

33: SYNTAX ERROR (invalid file name)
Pattern matching is invalidly used in the OPEN or SAVE command.

34: SYNTAX ERROR (no file given)
The file name was left out of the command or the DOS does not recognize it as such.

39: SYNTAX ERROR (invalid command)
This error may result if the command sent to the command channel (secondary address 15) is unrecognized by the DOS.

40: UNIMPLEMENTED COMMAND
Command is not implemented at this time.

41: FILE READ
The file cannot be read

50: RECORD NOT PRESENT
Result of disk reading past the last record through INPUT# or GET# commands. This message will also occur after positioning to a record beyond end_of_file in a relative file. If the intent is to expand the file by adding the new record (with a PRINT# command), the error message may be ignored. INPUT and GET should not be attempted after this error is detected without first repositioning.

51: OVERFLOW IN RECORD
PRINT# statement exceeds record boundary. Information is truncated. Since the carriage return which is sent as a record terminator is counted in the record size, this message will occur if the total characters in the record (including the final carriage return) exceeds the defined size.

52: FILE TOO LARGE
Record position within a relative file indicates that disk overflow will result.

53: BIG RELATIVE FILES DISABLED

60: WRITE FILE OPEN
This message is generated when a write file that has not been closed is being opened for reading.

61: FILE NOT OPEN
This message is generated when a file is being accessed that has not been opened in the DOS. Sometimes, in this case, a message is not generated; the request is simply ignored.

62: FILE NOT FOUND
The requested file does not exist on the indicated drive.

63: FILE EXISTS
The file name of the file being created already exists on the diskette.

64: FILE TYPE MISMATCH
The requested access mode is not possible using the filetype given.

65: NO BLOCK
The sector you tried to allocate with the B-A command was already allocated. The Track and sector numbers hold the next higher, available track and sector. If the track number is zero, no higher sectors are free (try a lower track & sector).

66: ILLEGAL TRACK AND SECTOR
The DOS has attempted to access a track or block which does not exist in the format being used. This may indicate a problem reading the pointer of the next block.

67: ILLEGAL SYSTEM T OR S
This special error message indicates an illegal system track or sector.

70: NO CHANNEL
The requested channel is not available, or all channels are in use. A maximum of five sequential files may be opened at one time to the DOS. Direct access channels may have six opened files.

71: DIRECTORY ERROR
The BAM is corrupted. Try initializing the disk.

72: DISK FULL
Either the blocks on the diskette are used or the directory is at its entry limit. DISK FULL is sent when two blocks are available to allow the current file to be closed before its data is lost.

73: DOS MISMATCH (also the powerup message)
Initially given at powerup to identify the drive. On some drives this message is given as an error to indicate the media was formatted by an incompatible DOS.

74: DRIVE NOT READY
An attempt has been made to access the Floppy Disk Drive without any diskette present.

75: FORMAT ERROR

76: CONTROLLER ERROR
The DOS has determined that the hardware is malfunctioning.

77: SELECTED PARTITION ILLEGAL
An attempt was made to access a partition as a subdirectory, but it has no directory track or does not meet the criteria of a directory partition.

78: DIRECTORY FULL
There is no more room in the directory sector for another file entry. Delete a file to make room, or change disks.

79: FILE CORRUPTED
The DOS has determined that a file is bad, probably having bad links. Prepare a new disk and copy the good files to it. Could be the result of an unsuccessful file recovery.

3.2 MACHINE LANGUAGE MONITOR

3.2.1 INTRODUCTION

The MONITOR is a built in machine language program that lets the user easily write machine language programs. The C64DX MONITOR includes a machine language monitor, an assembler, and a disassembler.

Machine language programs written using the MONITOR can run by themselves, or be used as very fast 'subroutines' for BASIC programs. Care must be taken to position the assembly language programs in memory so that the BASIC program does not overwrite them and the proper memory is in context at all times (including during interrupts).

3.2.2 MONITOR COMMANDS

A	ASSEMBLE	- Assemble a line of 4502 code
C	COMPARE	- Compare two sections of memory
D	DISASSEMBLE	- Disassemble a line of 4502 code
F	FILL	- Fill a section of memory with a value
G	GO	- Start execution at specified address
H	HUNT	- Find specified data in a section of memory
L	LOAD	- Load a file from disk
M	MEMORY	- Dump a section of memory
R	REGISTERS	- Display the contents of the 4502 registers
S	SAVE	- Save a section of memory to a disk file
T	TRANSFER	- Transfer memory to another location
V	VERIFY	- Compare a section of memory with a disk file
X	EXIT	- Exit Monitor mode
.	<period>	- Assembles a line of 6502 code
>	<greater-than>	- Modifies memory
;	<semicolon>	- Modifies register contents
@	<at sign>	- Display disk status
$	<hex)	- Display hex, decimal, octal, and binary value
+	<decimal>	
&	<octal>	
%	<binary>	

The MONITOR accepts binary, octal, decimal and hexadecimal values for any numeric field. Numbers prefixed by one of the characters $ + & % are interpreted as base 16, 10, 8, or 2 values respectively. In the absence of a prefix, the base defaults to hexadecimal always.

The assembler will use the base page form of an instruction wherever possible unless the address field is preceeded by extra zeros to force the absolute form (except binary notation).

The most significant byte of a 24-bit (3-byte) address field specifies the memory BANK to implement at the time the given command is executed. BANK bytes with the MSB set (i.e., banks greater than $7F) mean "use the current system configuration", which always includes the I/O area. If a BANK is not specified, BANK 0 is assumed.

BANK 00	internal RAM bank 0	(System, BASIC program)
BANK 01	internal RAM bank 1	(DOS, BASIC vars, color bytes
BANK 02	internal ROM bank 0	(DOS, C64 mode, CHRSETS)
BANK 03	internal ROM bank 1	(Monitor, C65 mode)
BANK 04-07	reserved for future expansion	
BANK 08-7F	expansion RAM	(graphic screens, RAM disk, etc.)
BANK 80-FF	MSB set means current config & I/O	

The monitor supports the editor autoscroll feature for memory dumps (forwards and backwards) and disassemblies (forward disassembly only).

To send dump output to a printer, from BASIC open a CMD channel to the printer and enter the monitor (OPEN 4,4: CMD4: MONITOR). Give the dump command desired; output will be to the printer.

3.2.3 MONITOR COMMAND DESCRIPTIONS

COMMAND:	A
PURPOSE:	Enter a line of assembly code.
SYNTAX:	A <address> <mnemonic> <operand>
<address>	A number indicating the location in memory to place the assembled binary code.
<mnemonic>	A 4502 assembly language mnemonic, eg., LDA
<operand>	The operand, when required, can be of any of the legal addressing modes.

A RETURN is used to indicate the end of the assembly line. If are any errors on the line, a question mark is displayed to an error, and the cursor moves to the next line. The screen can be used to correct the error(s) on that line.

As each line is entered, the machine code is written to the specified address and the line is automatically disassembled.

Base page and relative addresses are calculated for you, and the appropriate word or byte relative mode selected automatically. To force an absolute addressing mode, supply leading zeros if necessary.

```
.A 1800 LDX #$00
.A 1802
```

NOTE: A period (.) is equal to the ASSEMBLE command.

```
. 1900 LDA #$23
```

COMMAND:	C
PURPOSE:	Compare two areas of memory
SYNTAX:	C <address 1> <address 2> <address 3>
<address 1>	A number indicating the start of the area of memory to compare against.
<address 2>	A number indicating the end of the area of memory to compare against.
<address 3>	A number indicating the start of the other area of memory to compare with.

The following example compares $8000-$9FFF in bank 0 with $8000-$9FFF in bank 1. Addresses of data that does not match are printed on the screen.

```
C 8000 9FFF 18000
```

COMMAND:	D
PURPOSE:	Disassemble machine code
SYNTAX:	D [address_1 [address_2]]
<address>	A number setting the address to start the disassembly.
<address 2>	An optional ending address of code to be disassembled.

The output of the disassembly is the same as that of an assembly, only preceded by a comma instead of an A or period. The object code is also displayed. Relative addresses in the disassembly are displayed as the 16-bit destination.

A disassembly listing can be modified using the screen editor. any changes to the mnemonic or operand on the screen, then hit the return. This enters the line and calls the assembler for instructions. The object code cannot be modified this way.

A disassembly can be paged. Typing a D <return> causes the next of disassembly to be displayed. The autoscroll feature works in forward mode only, because backwards disassembly is not possible since all 256 opcodes are defined in the 4502 processor.

The following example disassembles from ROM bank 3:

```
D 3F000 3F005
. 03F000  A9 09     LDA #$09
. 03F002  A0 FF     LDY #$FF
. 03F004  18        CLC
. 03F005  86 C2     STX $C2
```

Note that banks wrap to the next higher bank number.

COMMAND:	F
PURPOSE:	Fill a range of locations with a specified byte.
SYNTAX:	F <address 1> <address 2> <byte>

<address 1>	The first location to fill with the <byte>.
<address 2>	The last location to fill with the <byte>.
<byte>	The byte to fill with

This command is useful for initializing data structures or any other RAM area.

```
F 00600 007FF 00
```

Fills memory locations from $0600 to $07FF (RAM-0) with $00. Note that banks wrap to the next higher bank number. The maximum area that can be filled at one time is 64K, limited by the DMA device.

COMMAND:	G
PURPOSE:	Perform a JMP to a specified address
SYNTAX:	G <address>

<address>	The address where execution is to start. When the address is not specified, execution begins at the current PC. (The current PC can be viewed or changed with the R command.)

The GO command loads the processor's registers (displayable by the R command) and performs a JMP to the specified starting address. Caution is recommended in using the GO command. To return to MONITOR mode after performing a GO command, a BRK instruction must end the called routine. Also, the BANK specified must be able to handle interrupts (note that BANK bytes less than $80 do NOT include the operating system or I/O space).

```
G FFC800
```

JuMPs to address $C800 in bank $FF (system configuration).

COMMAND:	H
PURPOSE:	Hunt through memory within a specified range for all occurences of a set of bytes.
SYNTAX:	H <address 1> <address 2> <data>
<address 1>	Address to start at
<address 2>	Last address
<data>	Data to search for. May be a number, sequence of numbers, or a PETSCII string.

```
H 02000 0FFFF 46 52 45 44
```

Hunts for the series of bytes $46, $52, $45, $44 in memory bank 0 beginning at address $2000 and ending at $FFFF. The addresses of matches is displayed.

```
H 0200 0FFFF 'FRED
```

Hunts for the PETSCII string following an apostrophe. Note that banks wrap to the next higher bank number.

COMMAND:	L
PURPOSE:	Load a file from disk.
SYNTAX:	L <"filename"> [,device [,load_address]]
<"filename">	Is a filename in quotes..
[device]	Is a number indicating the device to load from.
[load_address]	Optional load address. If not given, the file is loaded into memory at the 16-bit address stored on disk (always RAM bank 0).

The LOAD command causes a file to be loaded into memory. If the load address (including BANK) is given, the data is placed there. Otherwise the file is loaded into RAM bank 0 at the 16-bit load address specified by the first two bytes read from the PRG (program) type file. An error occurs if a load overflow the specified bank.

```
L "filename"
```

Loads "filename" from default system drive into RAM bank 0 at the address read from the file.

```
L "filename",+10,80000
```

Loads "filename" from drive 10 (notice you must specify decimal for the drive number, or use hex equivalent) into expansion memory bank 8 at address $0000. Note that spaces between parameters after the filename are not permitted.

COMMAND:	M
PURPOSE:	Dump a section of memory in hex and PETSCII.
SYNTAX:	M [address_1 [address_2]]
[address_1]	Starting address of memory dump. If omitted, one page is displayed starting from the last address used.
[address_2]	Ending address of memory dump. If omitted, one page

is displayed starting at address_1.

Memory dump width is sized to 40 or 80 columns, depending upon the text screen width. All data is displayed in hexadecimal and followed by a PETSCII interpretation of the data in reverse field (non-printing characters appear as periods).

The autoscroll keys will scroll the dump forwards or backwards. Paging is also possible by typing M<return>.

The hex field of dump can be edited, and memory will be updated after a <return> is typed on the edited line.

```
M 29000 2900C

>029000 3C 66 6E 6E 60 62 3C 00 :<FNN-B<.
>029008 46 41 49 54 20 4C 55 58 :FAIT LUX
```

COMMAND: R
PURPOSE: Display "shadow" 4502 registers. The PC (address), SR (status), A,X,Y,Z registers, and SP (stack pointer) are displayed.
SYNTAX: R

```
R
    PC    SR AC XR YR SP
; BA1234 00 00 00 00 FB
```

The address field contains the 8-bit bank plus the 16-bit segment address. The register dump can be edited by changing any field and pressing return. The data is used by the G (JMP) and J (JSR) commands.

COMMAND: S
PURPOSE: Save a section of memory in a disk file.
SYNTAX: S <"filename">,<device>,<address 1>,<address 2>

<"filename">	Is a filename in quotes.
<address 1>	Starting address of memory to be saved.
<address 2>	Ending address PLUS ONE of memory to be saved.

The SAVE command creates a PRG (program) type file and copies data into it from the specified memory area. All parameters are required.

```
S "filename",8,A0000,AFFFF
```

Saves expansion bank A in "filename" on drive 8 (you must specify decimal for the drive number, or use hex equivalent). The last byte at $FFFF will not be saved. Note that spaces between parameters after the filename are not permitted. The 16-bit segment address is saved as the first two bytes of the file, but the BANK address is not saved.

The BANK wraps automatically to the next higher bank number, but note that LOAD is restricted to one bank, 64K bytes maximum.

COMMAND: T
PURPOSE: Transfer (copy) memory from one memory area to another.
SYNTAX: T <address 1> <address 2> <address 3>

<address 1>	Starting address of data to be copied.
<address 2>	Ending address of data to be copied.

<address 3>	Starting address of new location to copy data to.

Data can be copied forwards or backwards to any location, even within the source range (eg., shift data up or down one byte) without any problem. An automatic compare is performed for each byte, and mismatches displayed on the screen.

Because of the compare feature, it's not recommended you use the T command to copy data into write-only registers (the palette, for example). It works, but all the compares will fail.

```
T 32000 3BFFF 82000
```

Copies BASIC ROM area to expansion RAM.

COMMAND:	V
PURPOSE:	Verify (compare) a disk file with the memory contents.
SYNTAX:	V <"filename"> [,device [,load_address]]

<"filename">	Is a filename in quotes.
[device]	Is a number indicating the device the file is on.
[load_address]	Optional load address. If not given, the file is compared to memory at the 16-bit address stored on disk (always RAM bank 0).

The Verify command causes a file to be read and compared to memory. If the load address (including BANK) is given, the data read is compared to data there. Otherwise the data read is compared to RAM bank 0 at the 16-bit load address specified by the first two bytes of the PRG (program) type file. If there is a mismatch, the message 'VERIFYING ERROR' is displayed. If the data matches, nothing is displayed. An error occurs if the compare address overflows the specified bank.

```
V "filename"
```

Compares "filename" from the default system drive to RAM bank 0 at the address read from the file.

```
V "filename",+10,80000
```

Comapres "filename" from drive 10 (notice you must specify decimal for the drive number, or use hex equivalent) to expansion memory bank 8 at address $0000. Note that spaces between parameters after the filename are not permitted.

COMMAND:	X
PURPOSE:	Exit to BASIC
SYNTAX:	X

COMMAND:	> (greater than)
PURPOSE:	Pokes data (1 to 16 bytes) into memory
SYNTAX:	> <address> [byte]...

<address>	Address to start "poking" or displaying
[byte]	Data to be "poked". If not given, nothing is changed and the memory at that location is "peeked". Successive bytes are poked into successive locations.

COMMAND:	@	(at sign)
PURPOSE:	Disk operation: send command, display directory, status	
SYNTAX:	@ [device] [,command]	

[device]	Disk device number
[command]	Optional command (see DOS manual for specific commands)

This command can be used to read a drive's status message, send a drive a DOS command, or display a disk directory.

`@`	displays status of default system drive
`@9`	displays status of drive 9
`@+10  or @A`	displays status of drive 10
`@,$`	displays directory of default drive
`@9,$`	displays status of drive 9
`@,$0:*=SEQ`	displays all SEQ type files
`@,S0:FILE`	sends command to delete file "FILE"

3.3 EDITOR

3.3.1 EDITOR ESCAPE SEQUENCES

This section contains a definition of the escape sequences that are present in the C64DX and a brief description of what each does.

ESCape sequences are given by hitting the <ESCAPE> key and then another key. In PRINT strings, escape sequences are given by printing the escape character CHR$(27) followed by another character. In either case, the "other" character is defined as one of the following:

KEY	FUNCTION
@	Clear from cursor to end of screen
A	Enable auto-insert mode
B	Set bottom of screen window at cursor position
C	Disable auto-insert mode (set overwrite mode)
D	Delete current line
E	Set cursor to non-flashing mode
F	Set cursor to flashing mode
G	Enable bell (control-G)
H	Disable bell
I	Insert line
J	Move to start of current line
K	Move to end of current line
L	Enable scrolling
M	Disable scrolling
N	Normal screen fields [not implemented on C64DX]
O	Cancel insert, quote, reverse, underline & flash modes
P	Erase from cursor to start of current line
Q	Erase from cursor to end of current line
R	Set screen to reverse video [not implemented on C64DX]
S	Set bold attribute (VIC-III colors 16-31)
T	Set top of screen window at cursor postion
U	Unset bold attibute
V	Scroll up
W	Scroll down
X	Swap 40/80 column display output device
Y	Set default tab stops (8 spaces)
Z	Clear all tab stops
[	Set monochrome display (disable attributes)
\	Cancel insert, quote, rvs, ul & flash modes
]	Set color display (enable attributes)

3.3.2 EDITOR CONTROL CODES

This section contains a definition of the control codes that are present in the C64DX and a brief description of what each does.

Control codes are given by pressing the <CTRL>key at the same time as another key. In PRINT strings, control codes are given by printing the control character with the CHR$() function. Control codes appear within quoted strings as reverse field characters. In any case, the control characters are:

CHR$ VALUE	KEYBOARD CONTROL	FUNCTION
2	B	Underline on
7	G	Bell tone
9	I	Forward TAB
10	J	Line feed
11	K	Disable case change <shift>C= key (was code 9)
12	L	Enable case change <shift>C= key (was code 8)
14	N	Set display upper/lower case mode
15	O	Flash on
17	Q	Cursor down
18	R	Reverse on
19	S	Home cursor
20	T	Delete previous character
21	U	Backup word
23	W	Advance word
24	X	Tab set/clear
26	Z	Backup TAB
27	[	Escape character
29	]	Cursor right

Shifted codes

130	Underline off
142	Set uppercase/graphic mode
143	Flash off
145	Cursor up
146	Reverse mode off
147	Clear screen
148	Insert one character
157	Cursor left

Color codes

5	white
28	red
30	green
31	blue
129	orange
144	black
149	brown
150	light red
151	light gray
152	medium gray
153	light green
154	light blue
155	dark gray
156	purple
158	yellow
159	cyan

Function keys

3	Stop
16	F9
21	F10
22	F11
23	F12
25	F13
26	F14
131	Run
132	Help
133	F1
134	F3
135	F5
136	F7
137	F2
138	F4
139	F6
140	F8

3.4 KERNEL

3.4.1 C64DX KERNEL ENTRY POINTS

[*** THE FOLLOWING VECTORS AND JUMP TABLES ARE NOT FINAL ***]

Where the default indirect vectors point to:

```
FF09   nirq             ;IRQ handler
FF0B   monitor_brk      ;BRK handler (Monitor)
FF0D   nnmi             ;NMI handler
FF0F   nopen            ;open
FF11   nclose           ;close
FF13   nchkin           ;chkin
FF15   nckout           ;ckout
FF17   nclrch           ;clrch
FF19   nbasin           ;basin
FF1B   nbsout           ;bsout
FF1D   nstop            ;stop key scan
FF1F   ngetin           ;getin
FF21   nclall           ;clall
FF23   monitor_parser   ;monitor command parser
FF25   nload            ;load
FF27   nsave            ;save

FF29   talk             ;Low level serial bus routines
FF2B   listen
FF2D   talksa
FF2F   second
FF31   acptr
FF33   ciout
FF35   untalk
FF37   unlisten

FF39   DOS_talk         ;newDOS routines
FF3B   DOS_listen
FF3D   DOS_talksa
FF3F   DOS_second
FF41   DOS_acptr
FF43   DOS_ciout
FF45   DOS_untalk
FF47   DOS_unlisten

FF49   Get_DOS
FF4B   Leave_DOS

FF4D   jmp spin_spout   ;setup fast serial port for input or output
FF50   jmp close_all    ;close all logical files for a given device
FF53   jmp c64mode      ;reconfigure system as a c/64 (no return!)
FF56   jmp monitor_call ;map in Monitor & call it
FF59   jmp bootsys      ;boot alternate system from disk
FF5C   jmp phoenix      ;call cold start routines, disk boot loader
FF5F   jmp lkupla       ;search tables for given la
FF62   jmp lkupsa       ;search tables for given sa
FF65   jmp swapper      ;swap to alternate display device
FF68   jmp pfkey        ;program function key
FF6B   jmp setbnk       ;set bank for load/save/verify/open
FF6E   jmp jsr_far      ;JSR to any bank, RTS to calling bank
FF71   jmp jmp_far      ;JMP to any bank
FF74   jmp lda_far      ;LDA (X),Y from bank Z
FF77   jmp sta_far      ;STA (X),Y to   bank Z
FF7A   jmp cmp_far      ;CMP (X),Y to   bank Z
```

```
FF7D   jmp primm          ;print immediate  (always JSR to this routine!)

FF80   <FF>               ;release number of C65 Kernel ($FF=not released)

FF81   jmp cint           ;init screen editor & display chips
FF84   jmp ioinit         ;init I/O devices (ports, timers, etc.)
FF87   jmp ramtas         ;initialize RAM for system
FF8A   jmp restor         ;restore vectors to initial system
FF8D   jmp vector         ;change vectors for user
FF90   jmp setmsg         ;control o.s. messages
FF93   jmp (isecond)      ;send sa after listen
FF96   jmp (italksa)      ;send sa after talk
FF99   jmp memtop         ;set/read top of memory
FF9C   jmp membot         ;set/read bottom of memory
FF9F   jmp key            ;scan keyboard
FFA2   jmp settmo         ;old IEEE set timeout value
FFA5   jmp (iacptr)       ;read a byte from active serial bus talker
FFA8   jmp (iciout)       ;send a byte to active serial bus listener
FFAB   jmp (iuntalk)      ;command serial bus device to stop talking
FFAE   jmp (iunlisten)    ;command serial bus device to stop listening
FFB1   jmp (ilisten)      ;command serial bus device to listen
FFB4   jmp (italk)        ;command serial bus device to talk
FFB7   jmp readss         ;return I/O status byte
FFBA   jmp setlfs         ;set la, fa, sa
FFBD   jmp setnam         ;set length and fn adr
FFC0   jmp (iopen)        ;open logical file
FFC3   jmp (iclose)       ;close logical file
FFC6   jmp (ichkin)       ;open channel in
FFC9   jmp (ickout)       ;open channel out
FFCC   jmp (iclrch)       ;close I/O channel
FFCF   jmp (ibasin)       ;input from channel
FFD2   jmp (ibsout)       ;output to channel
FFD5   jmp load           ;load from file
FFD8   jmp save           ;save to file
FFDB   jmp Set_Time       ;set internal clock
FFDE   jmp Read_Time      ;read internal clock
FFE1   jmp (istop)        ;scan stop key
FFE4   jmp (igetin)       ;get char from queue
FFE7   jmp (iclall)       ;clear all logical files (see close_all)
FFEA   jmp ScanStopKey    ;(was increment clock) & scan stop key
FFED   jmp scrorg         ;return current screen window size
FFF0   jmp plot           ;read/set x,y coord
FFF3   jmp iobase         ;return I/O base

FFF6   c65mode            ;C64/C65 interface
FFF8   c64mode

FFFA   nmi                ;processor hardware vectors
FFFC   reset
FFFE   irq_kernel
```

3.4.2 C64DX EDITOR JUMP TABLE

[*** THE FOLLOWING VECTORS AND JUMP TABLES ARE NOT FINAL ***]

```
E000     cint            ;initialize editor & screen
E003     disply          ;display character in .a, color in .x
E006     lp2             ;get a key from IRQ buffer into .a
E009     loop5           ;get a chr from screen line into .a
E00C     print           ;print character in .a
E00F     scrorg          ;get size of window (rows,cols) in .x, .y
E012     keyboard_scan   ;scan keyboard subroutine
E015     repeat          ;repeat key logic & CKIT2 to store decoded key
E018     plot            ;read or set (.c) cursor position in .x, .y
E01B     mouse_cmd       ;install/remove mouse driver
E01E     escape          ;execute escape function using chr in .a
E021     keyset          ;redefine a programmable function key
E024     editor_irq      ;IRQ entry
E027     palette_init    ;initialize VIC palette
E02A     swap            ;40/80 mode change
E02D     window          ;set top left or bottom right (.c) of window
E030     cursor          ;turn on or off (.c) soft cursor
```

3.4.3 C64DX BASIC JUMP TABLE

[*** THE FOLLOWING VECTORS AND JUMP TABLES ARE NOT FINAL ***]

Format Conversions

7F00	ayint	;convert floating point to integer
7F03	givayf	;convert integer to floating point
7F06	fout	;convert floating point to ASCII string
7F09	val_1	;convert ASCII string to floating point
7F0C	getadr	;convert floating point to an address
7F0F	floatc	;convert address to floating point

Math Functions

7F12	fsub	;MEM - FACC
7F15	fsubt	;ARG - FACC
7F18	fadd	;MEM + FACC
7F1B	faddt	;ARG - FACC
7F1E	fmult	;MEM * FACC
7F21	fmultt	;ARG * FACC
7F24	fdiv	;MEM / FACC
7F27	fdivt	;ARG / FACC
7F2A	log	;compute natural log of FACC
7F2D	int	;perform BASIC INT() on FACC
7F30	sqr	;compute square root of FACC
7F33	negop	;negate FACC
7F36	fpwr	;raise ARG to the MEM power
7F39	fpwrt	;raise ARG to the FACC power
7F3C	exp	;compute EXP of FACC
7F3F	cos	;compute COS of FACC
7F42	sin	;compute SIN of FACC
7F45	tan	;compute TAN of FACC
7F48	atn	;compute ATN of FACC
7F4B	round	;round FACC
7F4E	abs	;absolute value of FACC
7F51	sign	;test sign of FACC
7F54	fcomp	;compare FACC with MEM
7F57	rnd_0	;generate random floating point number

Movement

7F5A	conupk	;move RAM MEM to ARG
7F5D	romupk	;move ROM MEM to ARG
7F60	movfrm	;move RAM MEM to FACC
7F63	movfm	;move ROM MEM to FACC
7F66	movmf	;move FACC to MEM
7F69	movfa	;move ARG to FACC
7F6C	movaf	;move FACC to ARG
7F6F	run	
7F72	runc	
7F75	clear	
7F78	new	
7F7B	link_program	
7F7E	crunch	
7F81	FindLine	
7F84	newstt	
7F87	eval	
7F8A	frmevl	
7F8D	run_a_program	
7F90	setexc	
7F93	linget	
7F96	garba2	

```
7F99        execute_a_line
7F9C        chrget
7F9F        chrgot
7FA2        chkcom
7FA5        frmnum
7FA8        getadr
7FAB        getnum
7FAE        getbyt
7FB1        plsv
```

Graphic Jump Table

```
8000        init            ;Graphics BASIC init (same as command=0)
8002        parse           ;Graphics BASIC command parser
8004        start           ;0       commands
8006        screendef       ;1
8008        screenopen      ;2
800A        screenclose     ;3
800C        screenclear     ;4
800E        screen          ;5
8010        setpen          ;6
8012        setpalette      ;7
8014        setdmode        ;8
8016        setdpat         ;9
8018        line            ;10
801A        box             ;11
801C        circle          ;12
801E        polygon         ;13
8020        ellipse         ;14
8022        viewpclr        ;15
8024        copy            ;16
8026        cut             ;17
8028        paste           ;18
802A        load            ;19
802C        char            ;20
802E        viewportdef     ;21
```

3.4.4 C64DX SOFT VECTORS

[*** THE FOLLOWING VECTORS AND JUMP TABLES ARE NOT FINAL ***]

BASIC indirect vectors

```
02F7   jmp USR              ;USR vector (must be set by application)

02FC   esc_fn_vec           ;Escape Function vector
02FE   graphic_vector       ;Graphic Kernel vector
0300   ierror               ;indirect error (output error in .x)
0302   imain                ;indirect main (system direct loop)
0304   icrnch               ;indirect crunch (tokenization routine)
0306   iqplop               ;indirect list (char list)
0308   igone                ;indirect gone (char dispatch)
030A   ieval                ;indirect eval (symbol evaluation)
030C   iesclk               ;escape token crunch
030E   iescpr               ;escape token list
0310   iescex               ;escape token execute
```

Kernel indirect vectors

```
02FA   iAutoScroll          ;AutoScroll used by BASIC, Monitor, Editor

0312   itime                ;(unused)
0314   iirq                 ;IRQ
0316   ibrk                 ;BRK
0318   inmi                 ;NMI
031A   iopen
031C   iclose
031E   ichkin
0320   ickout
0322   iclrch
0324   ibasin
0326   ibsout
0328   istop
032A   igetin
032C   iclall
032E   exmon                ;Monitor command indirect
0330   iload
0332   isave
```

Editor indirect vectors to routines & tables

```
0334   ctlvec               ;'contrl' characters
0336   shfvec               ;'shiftd' characters
0338   escvec               ;'escape' characters
033A   keyvec               ;post keyscan, pre-evaluation of keys
033C   keychk               ;post-evaluation, pre-buffering of keys
033E   decode               ;vectors to 6 keyboard matrix decode tables
   33E                       - Mode 1 --> normal keys
   340                       - Mode 2 --> <SHIFT> keys
   342                       - Mode 3 --> <C=> keys
   344                       - Mode 4 --> <CONTROL> keys
   346                       - Mode 5 --> <CAPS LOCK> keys
   348                       - Mode 6 --> <ALT> keys
```

3.4.5 KERNEL DOCUMENTATION

C64DX KERNEL JUMP TABLE

(PRELIMINARY)

by

Fred Bowen

The KERNEL is the ROM resident operating system of the Commodore 64DX computer. All input, output, and memory management is controlled by the KERNEL. The KERNEL JUMP TABLE provides a standardized interface to many useful routines within the operating system. Application programmers are encouraged to utilize the JUMP TABLEs to simplify their operations and guarantee their functionality should hardware or software modifications to the system become necessary.

B. CBM STANDARD KERNEL CALLS

The following system calls comprise the set of standard CBM system calls for the C64 class of machines, including the PLUS-4. Several of the calls, however, function somewhat differently or may require slightly different setups. This was necessary to accomodate specific features of the system, notably the 40/80 column windowing Editor and banked memory facilities. As with all Kernel calls, the system configuration (BANK $FF) must be in context at the time of the call.

1. $FF81 CINT ;initialize screen editor

Preparation:

Registers: none

Memory: system map

Flags: none

Calls: none

Results:

Registers: .A used
.X used
.Y used

Memory: init Editor RAM
init Editor I/O

Flags: none

Example:

```
SEI
JSR $FF81   ;initialize screen editor
CLI
```

CINT is the Editor's initialization routine. Editor indirect vectors installed, programmable key definitions assigned, and the ASC/DIN key scanned for NATIONAL keyboard/charset determination. CINT sets the VIC bank, VIC nybble bank, enables the character ROM, resets SID volume, and clears the screen.
The only thing it does not do that pertains to the Editor is I/O initialization,
which is is needed for IRQs (keyscan, VIC cursor blink, split screen modes), key lines, screen background colors, etc. (see IOINIT). Because CINT updates Editor indirect vectors that are used during IRQ processing, you should disable IRQs prior to calling it. CINT utilizes the status byte INIT_STATUS as follows:

```
$1104 bit 6 = 0  --> Full initialization.
                     (set INIT_STATUS bit 6)

            = 1  --> Partial initialization.
                     (not keymatrix pointers)
                     (not program key definitions)
```

2. $FF84 IOINIT ;init I/O devices

Preparation:

Registers:	none
Memory:	system map
Flags:	none
Calls:	none

Results:

Registers:	.A used .X used .Y used
Memory:	initialize I/O
Flags:	none

Example:

```
SEI
JSR $FF84    ;initialize system I/O
CLI
```

IOINIT is perhaps the major function of the Reset handler. It initializes both CIA's (timers, keyboard, serial port, user port), the 4510 port, the VIC chip, The UART and the DOS. It distinguishes a PAL system from an NTSC one and sets PALCNT if PAL. The system IRQ source, the VIC raster, is started (pending IRQs are cleared). IOINIT utilizes the status byte INIT_STATUS as follows:

```
$1104 bit 7 = 0  -->  Full initialization.
                      (set INIT_STATUS bit 7)

            = 1  -->  Partial initialization.
```

You should be sure IRQs are disabled before calling IOINIT to avoid interrupts while the various I/O devices are being initialized.

3. $FF87 RAMTAS ;init RAM and buffers

Preparation:

Registers:	none
Memory:	system map
Flags:	none
Calls:	none

Results:

Registers:	.A used .X used .Y used
Memory:	initializes RAM
Flags:	none

Example:

```
JSR $FF87   ;initialize system RAM
```

RAMTAS clears all base page RAM, allocates the sets pointers to the top and bottom of system RAM and points the SYSTEM_VECTOR to BASIC cold start. Lastly it sets a flag, DEJAVU, to indicate to other routines that system RAM has been initialized and that the SYSTEM_VECTOR is valid. It should be noted that the C64DX RAMTAS routine does NOT in any way test RAM.

4. $FF8A RESTOR ;init Kernel indirects

Preparation:

Registers: none

Memory: system map

Flags: none

Calls: none

Results:

Registers: .A used
.X used
.Y used

Memory: kernel indirects restored

Flags: none

Example:

```
SEI
JSR $FF8A    ;restore kernel indirects
CLI
```

RESTOR restores the default values of all the Kernel indirect vectors from the Kernel ROM list. It does NOT affect any other vectors, such as those used by the Editor (see CINT) and BASIC. Because it is possible for an interrupt (IRQ or NMI) to occur during the updating of the interrupt indirect vectors, you should disable interrupts prior to calling RESTOR. See also the VECTOR call.

5. $FF8D VECTOR ;init or copy indirects

Preparation:

Registers: .X = adr (low) of user list
.Y = adr (high) of user list

Memory: system map

Flags: .C = 0 --> load Kernel vectors
.C = 1 --> copy Kernel vectors

Calls: none

Results:

Registers: .A used
.Y used

Memory: as per call

Flags: none

Example:

```
LDX #save_lo
LDY #save_hi
SEC
JSR $FF87      ;copy indirects to 'save'
```

VECTOR reads or writes the Kernel RAM indirect vectors. Calling VECTOR with the carry status set stores the current contents of the indirect vectors to the RAM address passed in the .X and .Y registers (to the current RAM bank). Calling VECTOR with the carry status clear updates the Kernel indirect vectors from the user list passed in the .X and .Y registers (from the current RAM bank). Interrupts (IRQ and NMI) should be disabled when updating the indirects. See also the RESTOR call.

6. $FF90 SETMSG ;kernel messages on/off

Preparation:

Registers: .A = message control
Memory: system map
Flags: none
Calls: none

Results:

Registers: none
Memory: MSGFLG updated
Flags: none

Example:

```
LDA #0
JSR $FF90    ;turn OFF all Kernel messages
```

SETMSG updates the Kernel message flag byte MSGFLG which determines whether system error and/or control messages will be displayed. BASIC normally disables error messages always and disables control messages in 'run' mode. Note that the Kernel error messages are not the verbose ones printed by BASIC, but simply the 'I/O ERROR #' message that you see when in the Monitor, for example. Examples of Kernel control messages are 'LOADING' and 'FOUND'.
The MSGFLG control bits are:

```
MSGFLG bit 7 = 1 --> enable CONTROL messages
       bit 6 = 1 --> enable ERROR messages
```

7. $FF93 SECND ;serial: send SA after LISTN

Preparation:

Registers: .A = SA (secondary address)

Memory: system map

Flags: none

Calls: LISTN

Results:

Registers: .A used

Memory: STATUS ($90)

Flags: none

Example:

```
LDA #8
JSR $FFB1    ;LISTN device 8
LDA #15
JSR $FF93    ;pass it SA #15
```

SECND is a low-level serial routine used to send a secondary address (SA) to a LISTNing device (see LISTN Kernel call). An SA is usually used to provide setup information to a device before the actual data I/O operation begins. Attention is released after a call to SECND. SECND is not used to send an SA to a TALKing device (see TKSA). (Most applications should use the higher level I/O routines; see OPEN and CKOUT).

8. $FF96 TKSA ;serial: send SA after TALK

Preparation:

Registers:	.A = SA (secondary address)
Memory:	system map
Flags:	none
Calls:	TALK

Results:

Registers:	.A used
Memory:	STATUS ($90)
Flags:	none

Example:

```
LDA #8
JSR $FFB4     ;TALK device 8
LDA #15
JSR $FF93     ;pass it SA #15
```

TKSA is a low-level serial routine used to send a secondary address (SA) to a device commanded to TALK (see TALK Kernel call). An SA is usually used to provide setup information to a device before the actual data I/O operation begins. (Most applications should use the higher level I/O routines; see OPEN and CHKIN).

9. $FF99 MEMTOP ;set/read top of system RAM

Preparation:

Registers: .X = lsb of MEMSIZ
.Y = msb of MEMSIZ

Memory: system map

Flags: .C = 0 --> set top of memory
.C = 1 --> read top of memory

Calls: none

Results:

Registers: .X = lsb of MEMSIZ
.Y = msb of MEMSIZ

Memory: MEMSIZ

Flags: none

Example:

```
SEC
JSR $FF99   ;get top of user RAM
DEY
CLC
JSR $FF99   ;lower it 1 block
```

MEMTOP is used to read or set the top of system RAM, pointed to by MEMSIZ. This call is included in the C64DX for completeness, but neither the Kernel nor BASIC utilize MEMTOP as it has little meaning in the banked memory environment of the computer (even the RS-232 buffers are permanently allocated). None-the-less, set the carry status to load MEMSIZ into .X and .Y, and clear it to update the pointer from .X and .Y. Note that MEMSIZ references only system RAM. The Kernel initially sets MEMSIZ to $FF00.

10. $FF9C MEMBOT ;set/read bottom of system RAM

Preparation:

Registers: .X = lsb of MEMSTR
.Y = msb of MEMSTR

Memory: system map

Flags: .C = 0 --> set bot of memory
.C = 1 --> read bot of memory

Calls: none

Results:

Registers: .X = lsb of MEMSTR
.Y = msb of MEMSTR

Memory: MEMSTR

Flags: none

Example:

```
SEC
JSR $FF9C    ;get bottom of user RAM_0
INY
CLC
JSR $FF9C    ;raise it 1 block
```

MEMBOT is used to read or set the bottom of system RAM, pointed to by MEMSTR. This call is included in the C64DX for completeness, but neither the Kernel nor BASIC utilize MEMBOT as it has little meaning in the banked memory environment of the C64DX. None-the-less, set the carry status to load MEMSTR into .X and .Y, and clear it to update the pointer from .X and .Y. Note that MEMSTR references only system RAM. The Kernel initially sets MEMSTR to $2000 (BASIC text starts here).

11. $FF9F KEY ;scan keyboard

Preparation:

Registers:	none
Memory:	system map
Flags:	none
Calls:	none

Results:

Registers:	none
Memory:	keyboard buffer keyboard flags
Flags:	none

Example:

```
JSR $FF9F   ;scan the keyboard
```

KEY is an Editor routine which scans the entire keyboard. It distinguishes between shifted and unshifted keys, control keys, and programmable keys, setting keyboard status bytes and managing the keyboard buffer. After decoding the key, KEY will manage such features as toggling cases, pauses or delays, and key repeats. It is normally called by the operating system during the 60Hz IRQ processing. Upon conclusion, KEY leaves the keyboard hardware driving the key-line on which the STOP key is located.

There are two indirect RAM jumps encountered during a keyscan: KEYVEC ($33A) and KEYCHK ($33C). KEYVEC (alias KEYLOG) is taken whenever a key depression is discovered, before the key in .A has been decoded. KEYCHK is taken after the key has been decoded, just before putting it into the key buffer. KEYCHK carries the ASCII character in .A, the keycode in .Y, and the shift-key status in .X.

The keyboard decode matrices are addressed via indirect RAM vectors as well, located at DECODE.

12. $FFA2 SETTMO ;(reserved)

Preparation:

Registers:	none
Memory:	system map
Flags:	none
Calls:	none

Results:

Registers:	none
Memory:	TIMOUT
Flags:	none

Example:

```
LDA #value
JSR $FFA2   ;update TIMOUT byte
```

SETTMO is unused in the C64DX and is included for compatibility and completeness. It is used in the C64 by the IEEE communication cartridge to disable I/O timeouts.

13. $FFA5 ACPTR ;serial: byte input

Preparation:

Registers: none

Memory: system map

Flags: none

Calls: TALK
TKSA (if necessary)

Results:

Registers: .A = data byte

Memory: STATUS ($90)

Flags: none

Example:

```
JSR $FFA5   ;input a byte from serial bus
STA data
```

ACPTR is a low-level serial I/O utility to accept a single byte from the current serial bus TALKer using full handshaking. To prepare for this routine a device must first have been established as a TALKer (see TALK) and passed a secondary address if necessary (see TKSA). The byte is returned in .A. (Most applications should use the higher level I/O routines; see BASIN and GETIN).

14. $FFA8 CIOUT ;serial: byte output

Preparation:

Registers: .A = data byte

Memory: system map

Flags: none

Calls: LISTN
SECND (if necessary)

Results:

Registers: .A used

Memory: STATUS ($90)

Flags: none

Example:

```
LDA data
JSR $FFA8    ;send a byte via serial bus
```

CIOUT is a low-level serial I/O utility to transmit a single byte to the current serial bus LISTNer using full handshaking. To prepare for this routine a device must first have been established as a LISTNer (see LISTN) and passed a secondary address if necessary (see SECND). The byte is passed in .A. Serial output data is buffered by one character, with the last character being transmitted with EOI after a call to UNLSN. (Most applications should use the higher level I/O routines; see BSOUT).

15. $FFAB UNTLK ;serial: send untalk

Preparation:

Registers: none

Memory: system map

Flags: none

Calls: none

Results:

Registers: .A used

Memory: STATUS ($90)

Flags: none

Example:

```
JSR $FFAB   ;UNTALK serial device
```

UNTLK is a low-level Kernel serial bus routine that sends an UNTALK command to all serial bus devices. It commands all TALKing devices to stop sending data. (Most applications should use the higher level I/O routines; see CLRCH).

16. $FFAE UNLSN ;serial: send unlisten

Preparation:

Registers: none
Memory: system map
Flags: none
Calls: none

Results:

Registers: .A used
Memory: STATUS ($90)
Flags: none

Example:

```
JSR $FFAE   ;UNLISTEN serial device
```

UNLSN is a low-level Kernel serial bus routine that sends an UNLISTEN command to all serial bus devices. It commands all LISTENing devices to stop reading data. (Most applications should use the higher level I/O routines; see CLRCH).

17. $FFB1 LISTN ;serial: send listen command

Preparation:

Registers: .A = device (0-31)

Memory: system map

Flags: none

Calls: none

Results:

Registers: .A used

Memory: STATUS ($90)

Flags: none

Example:

```
JSR $FFB1    ;command device to LISTEN
```

LISTN is a low-level Kernel serial bus routine that sends an LISTEN command to the serial bus device in .A. It commands the device to start reading data. (Most applications should use the higher level I/O routines; see CKOUT).

18. $FFB4 TALK ;serial: send talk command

Preparation:

Registers: .A = device (0-31)

Memory: system map

Flags: none

Calls: none

Results:

Registers: .A used

Memory: STATUS ($90)

Flags: none

Example:

```
JSR $FFB4   ;command device to TALK
```

TALK is a low-level Kernel serial bus routine that sends an TALK command to the serial bus device in .A. It commands the device to start sending data. (Most applications should use the higher level I/O routines; see CHKIN).

19. $FFB7 READSS ;read I/O status byte

Preparation:

Registers: none

Memory: system map

Flags: none

Calls: none

Results:

Registers: .A = STATUS ($90 or $A6)

Memory: STATUS cleared if RS-232 ($A6)

Flags: none

Example:

```
JSR $FFB7   ;STATUS for last I/O
```

READSS (alias READST) returns the status byte associated with the last I/O operation (serial or RS-232) performed. Serial bus and newDOS devices update STATUS ($90) and RS-232 I/O updates RSSTAT ($A6). Note that, to simulate an 6551, RSSTAT is cleared after it is read via READSS. The last I/O operation is determined by the contents of FA ($BA), thus applications which drive I/O devices using the lower-level Kernel calls should not use READSS.

20. $FFBA SETLFS ;set channel LA, FA, SA

Preparation:

Registers: .A = LA (logical #)
.X = FA (device #)
.Y = SA (secondary adr)

Memory: system map

Flags: none

Calls: none

Results:

Registers: none

Memory: LA, FA, SA updated

Flags: none

Example:

see OPEN

SETLFS sets the logical file number (LA, $B8), device number (FA, $BA), and secondary address (SA, $B9) for the higher-level Kernel I/O routines. The LA must be unique among OPENed files and is used to identify specific files for I/O operations. The device number range is 0 to 31 and is used to target I/O. The SA is a command to be sent to the indicated device, usualy to place it in a particular mode. If the SA is not needed, the .Y register should pass $FF. SETLFS is often used along with SETNAM and SETBNK calls prior to OPENs. See the Kernel OPEN, LOAD, and SAVE calls for examples.

21. $FFBD SETNAM ;set filename pointers

Preparation:

Registers: .A = string length
.X = string adr_low
.Y = string adr_high

Memory: system map

Flags: none

Calls: SETBNK

Results:

Registers: none

Memory: FNLEN, FNADR updated

Flags: none

Example:

see OPEN

SETNAM sets up the filename or command string for higher-level Kernel I/O calls such as OPEN, LOAD, and SAVE. The string (filename or command) length is passed in .A and updates FNLEN ($B7). The address of the string is passed in .X (low) and .Y (high). See the companion call, SETBNK which specifies which RAM bank the string is found. If there is no string, SETNAM should still be called and a null ($00) length specified (the address does not matter). SETNAM is often used along with SETBNK and SETLFS calls prior to OPENs. See the Kernel OPEN, LOAD, and SAVE calls for examples.

22. $FFC0 OPEN ;open logical file

Preparation:

Registers: none

Memory: system map

Flags: none

Calls: SETLFS, SETNAM, SETBNK

Results:

Registers: .A = error code (if any)
.X used
.Y used

Memory: setup for I/O
STATUS, RSSTAT updated

Flags: .C = 1 --> error

Example: OPEN 1,8,15,"I0"

```
LDA #length     ;fnlen
LDX #<filename  ;fnadr (command)
LDY #>filename
JSR $FFBD       ;SETNAM

LDX #0          ;fnbank (RAM_0)
JSR $FF68       ;SETBNK

LDA #1          ;la
LDX #8          ;fa
LDY #15         ;sa
JSR $FFBA       ;SETLFS

JSR $FFC0       ;OPEN

BCS error

filename  .BYTE 'I0'
length    = 2
```

OPEN prepares a logical file for I/O operations. It creates a unique entry in the Kernel logical file tables LAT ($362), FAT ($36C), and SAT ($376) using its index LDTND ($98) and data supplied by the user via SETLFS. There can be up to ten logical files OPENed simultaneously. OPEN performs device specific opening tasks for serial, RS-232, keyboard & screen, devices, including clearing the previous status and transmitting any given filename or command string supplied by the user via SETNAM and SETBNK. The I/O status will be updated appropriately and can be read via READSS.

The path to OPEN is through an indirect RAM vector at $31A. Applications may therefore provide their own OPEN procedures or suppliment the system's by re-directing this vector to their own routine.

23. $FFC3 CLOSE ;close logical file

Preparation:

Registers: .A = LA (logical #)

Memory: system map

Flags: .C (see text below)

Calls: none

Results:

Registers: .A = error code (if any)
.X used
.Y used

Memory: logical tables updated
STATUS, RSSTAT updated

Flags: .C = 1 --> error

Example:

```
LDA #1      ;la
JSR $FFC3   ;CLOSE
BCS error
```

CLOSE removes the logical file (LA) passed in .A from the logical file tables and performs device specific closing tasks. Keyboard, screen, and any unOPENed files pass through. RS-232 devices are not closed until all buffered data has been transmitted. Serial files are closed by transmitting a 'close' command (if an SA was given when it was opened), sending any ,buffered character, and UNLSTNing the bus.

There is a special provision incorporated into the CLOSE routine of systems featuring BASIC DOS command. If the following conditions are all TRUE, a full CLOSE is NOT performed: the table entry is removed but a 'close' command is NOT transmitted to the device. This allows the disk command channel to be properly OPENed and CLOSEd without the disk operating system closing ALL files on its end:

```
.C = 1  --> indicates special CLOSE
FA >=8  --> device is a disk
SA = 15 --> command channel
```

The path to CLOSE is through an indirect RAM vector at $31C. Applications may therefore provide their own CLOSE procedures or suppliment the system's by re-directing this vector to their own routine.

24. $FFC6 CHKIN ;set input channel

Preparation:

Registers: .X = LA (logical #)

Memory: system map

Flags: none

Calls: OPEN

Results:

Registers: .A = error code (if any)
.X used
.Y used

Memory: LA, FA, SA, DFLTN
STATUS, RSSTAT updated

Flags: .C = 1 --> error

Example:

```
LDX #1       ;la
JSR $FFC6    ;CHKIN
BCS error
```

CHKIN establishes an input channel to the device associated with the logical address (LA) passed in .X, in preparation for a call to BASIN or GETIN. The Kernel variable DFLTN ($99) is updated to indicate the current input device and the variables LA, FA, and SA are updated with the file's parameters from its entry in the logical file tables (put there by OPEN). CHKIN performs certain device specific tasks: screen and keyboard channels pass through, and serial channels are sent a TALK command and the SA transmitted (if necessary). Call CLRCH to restore normal I/O channels.

CHKIN is required for all input except the keyboard. If keyboard input is desired and no other input channel is established, you do not need to call CHKIN or OPEN. The keyboard is the default input device for BASIN and GETIN.

The path to CHKIN is through an indirect RAM vector at $31E. Applications may therefore provide their own CHKIN procedures or suppliment the system's by re-directing this vector to their own routine.

25. $FFC9 CKOUT ;set output channel

Preparation:

Registers: .X = LA (logical #)

Memory: system map

Flags: none

Calls: OPEN

Results:

Registers: .A = error code (if any)
.X used
.Y used

Memory: LA, FA, SA, DFLTO
STATUS, RSSTAT updated

Flags: .C = 1 --> error

Example:

```
LDX #1      ;la
JSR $FFC9   ;CKOUT
BCS error
```

CKOUT establishes an output channel to the device associated with the logical address (LA) passed in .X, in preparation for a call to BSOUT. The Kernel variable DFLTO ($9A) is updated to indicate the current output device and the variables LA, FA, and SA are updated with the file's parameters from its entry in the logical file tables (put there by OPEN). CKOUT performs certain device specific tasks: keyboard channels are illegal, screen channels pass through, and serial channels are sent a LISTN command and the SA transmitted (if necessary). Call CLRCH to restore normal I/O channels.

CKOUT is required for all output except the screen. If screen output is desired and no other output channel is established, you do not need to call CKOUT or OPEN. The screen is the default output device for BSOUT.

The path to CKOUT is through an indirect RAM vector at $320. Applications may therefore provide their own CKOUT procedures or suppliment the system's by re-directing this vector to their own routine.

26. $FFCC CLRCH ;restore default channels

Preparation:

Registers:	none
Memory:	system map
Flags:	none
Calls:	none

Results:

Registers:	.A used .X used
Memory:	DFLTI, DFLTO updated
Flags:	none

Example:

```
JSR $FFCC   ;restore default I/O
```

CLRCH (alias CLRCHN) is used to clear all open channels and restore the system default I/O channels after other channels have been established via CHKIN and/or CHKOUT. The keyboard is the default input device and the screen is the default output device. If the input channel was to a serial device, CLRCH first UNTLKs it. If the output channel was to a serial device, it is UNLSNed first.

The path to CLRCH is through an indirect RAM vector at $322. Applications may therefore provide their own CLRCH procedures or suppliment the system's by re-directing this vector to their own routine.

27. $FFCF BASIN ;input from channel

Preparation:

Registers: none

Memory: system map

Flags: none

Calls: CHKIN (if necessary)

Results:

Registers: .A = character (or error code)

Memory: STATUS, RSSTAT updated

Flags: .C = 1 if error

Example:

```
        LDY #0       ;index
more    JSR $FFCF    ;input a character
        STA data,Y   ;buffer it
        INY
        CMP #$0D     ;carrage return?
        BNE more
```

BASIN (alias CHRIN) reads a character from the current input device (DFLTN $99) and returns it in .A. Input from devices other than the keyboard (the default input device) must be OPENed and CHKINed. The character is read from the input buffer associated with the current input channel:

1. RS-232 data is returned a character at a time from the RS-232 input buffer, waiting until a character is received if necessary. If RSSTAT is bad from a prior operation, input is skipped and null input (carrage return) is substituted.

2. Serial data is returned a character at a time directly from the serial bus, waiting until a character is sent if necessary. If STATUS ($90) is bad from a prior operation, input is skipped and null input (carrage return) is substituted.

3. Screen data is read from screen RAM starting at the current cursor position and ending with a faked carrage return at the end of the logical screen line.

4. Keyboard data is input by turning on the cursor, reading characters from the keyboard buffer and echoing them on the screen until a carrage return is encountered. Characters are then returned one at a time from the screen until all characters input have been passed, including the carrage return. Any calls after the eol will start the process over again.

The path to BASIN is through an indirect RAM vector at $324. Applications may therefore provide their own BASIN procedures or suppliment the system's by re-directing this vector to their own routine.

28. $FFD2 BSOUT ;output to channel

Preparation:

Registers: .A = character

Memory: system map

Flags: none

Calls: CKOUT (if necessary)

Results:

Registers: .A = error code (if any)

Memory: STATUS, RSSTAT updated

Flags: .C = 1 if error

Example:

```
LDA #character
JSR $FFD2        ;output a character
```

BSOUT (alias CHROUT) writes the character in .A to the current output device (DFLTO $9A). Output to devices other than the screen (the default output device) must be OPENed and CKOUTed. The character is written to the output buffer associated with the current output channel:

1. RS-232 data is put a character at a time into the RS-232 output buffer, waiting until there is room if necessary.

3. Serial data is passed to CIOUT which buffers one character and sends the previous character.

4. Screen data is put into screen RAM at the current cursor position.

5. Keyboard output is illegal.

The path to BSOUT is through an indirect RAM vector at $326. Applications may therefore provide their own BSOUT procedures or suppliment the system's by re-directing this vector to their own routine.

29. $FFD5 LOAD ;load from file

Preparation:

```
Registers:  .A = 0 --> LOAD
            .A > 0 --> VERIFY
            .X = load adr_lo (if SA=0)
            .Y = load adr_hi (if SA=0)

Memory:     system map

Flags:      none

Calls:      SETLFS, SETNAM, SETBNK
```

Results:

```
Registers:  .A = error code (if any)
            .X = ending adr_lo
            .Y = ending adr_hi

Memory:     per command
            STATUS updated

Flags:      .C = 1 --> error
```

Example: LOAD "program",8,1

```
        LDA #length     ;fnlen
        LDX #<filename  ;fnadr
        LDY #>filename
        JSR $FFBD       ;SETNAM

        LDA #0          ;load/verify bank (RAM_0)
        LDX #0          ;fnbank (RAM_0)
        JSR $FF68       ;SETBNK

        LDA #0          ;la (not used)
        LDX #8          ;fa
        LDY #$FF        ;sa (SA>0 normal load)
        JSR $FFBA       ;SETLFS

        LDA #0          ;load, not verify
        LDX #<load_adr  ;(used only if SA=0)
        LDY #>load_adr  ;(used only if SA=0)
        JSR $FFD5       ;LOAD
        BCS error
        STX end_lo
        STY end_hi

filename .BYTE 'program'
length   = 7
```

This routine LOADs data from an input device into memory. It can also be used to VERIFY that data in memory matches that in a file. LOAD performs device specific tasks for serial LOADs. You cannot LOAD from RS-232 devices, the screen, or the keyboard. While LOAD performs all the tasks of an OPEN, it does NOT create any logical files as an OPEN does. Also note that LOAD cannot 'wrap' memory banks. As with any I/O, the I/O status is updated appropriately and can be read via READSS. LOAD has two options that the user must select:

1. LOAD vs. VERIFY: the contents of .A passed at the call to LOAD determines which mode is in effect. If .A is zero, a LOAD operation will be performed and memory will be overwritten. If .A is non-zero, a VERIFY operation will be performed and the result passed via the error mechanism.

2. LOAD ADDRESS: the secondary address (SA) setup by the call to SETLFS determines where the LOAD starting address comes from. If the SA is zero, the user wants the address in .X and .Y at the time of the call to be used. If the SA is non-zero, the LOAD starting address is read from the file header itself and the file loaded to the same place from which it was SAVEd.

The serial LOAD routine automatically attempts to access a newDOS drive, then attempts to BURST load a file, and resorts to the normal load mechanism (but still using the FAST serial routines) if the BURST handshake is not returned.

The path to LOAD is through an indirect RAM vector at $330. Applications may therefore provide their own LOAD procedures or suppliment the system's by re-directing this vector to their own routine.

30. $FFD8 SAVE ;save to file

Preparation:

Registers: .A = pointer to start adr
.X = end_adr_lo
.Y = end_adr_hi

Memory: system map

Flags: none

Calls: SETLFS, SETNAM, SETBNK

Results:

Registers: .A = error code (if any)
.X = used
.Y = used

Memory: STATUS updated

Flags: .C = 1 --> error

Example: SAVE "program",8

```
        LDA #length     ;fnlen
        LDX #<filename  ;fnadr
        LDY #>filename
        JSR $FFBD       ;SETNAM

        LDA #0          ;save from bank (RAM_0)
        LDX #0          ;fnbank (RAM_0)
        JSR $FF68       ;SETBNK

        LDA #0          ;la (not used)
        LDX #8          ;fa
        LDY #0          ;sa (cassette only)
        JSR $FFBA       ;SETLFS

        LDA #start      ;pointer to start address
        LDX end         ;ending address lo
        LDY end+1       ;ending adr hi
        JSR $FFD8       ;SAVE
        BCS error


filename .BYTE 'program'
length   = 7
start    .WORD address1  ;page-0
end      .WORD address2
```

This routine SAVEs data from memory to an output device. SAVE performs device specific tasks for serial SAVEs. You cannot SAVE from RS-232 devices, the screen, or the keyboard. While SAVE performs all the tasks of an OPEN, it does NOT create any logical files as an OPEN does. The starting address of the area to be SAVEd must be placed in a base-page vector and the address of this vector passed to SAVE in .A at the time of the call. The address of the last byte to be SAVEd PLUS ONE is passed in .X and .Y at the same time.

SAVE first attempts to access a newDOS drive. There is no BURST save; the normal FAST serial routines are used. As with any I/O, the I/O status will be updated appropriately and can be read via READSS.

The path to SAVE is through an indirect RAM vector at $332. Applications may therefore provide their own SAVE procedures or suppliment the system's by re-directing this vector to their own routine.

31. $FFDB SETTIM ;set internal clock

Preparation:

Registers:
.A = hours
.X = minutes
.Y = seconds
.Z = tenths

Memory: system map

Flags: none

Calls: none

Results:

Registers: none

Memory: TOD at CIA $DC00 updated

Flags: none

Example:

```
LDA #0      ;reset clock
TAX
TAY
TAZ
JSR $FFDB   ;SETTIM
```

SETTIM sets the system CIA 24-hour TOD clock, which counts tenths of a second and automatically wraps at the 24-hour point.

32. $FFDE RDTIM ;read internal clock

Preparation:

Registers: none

Memory: system map

Flags: none

Calls: none

Results:

Registers: .A = hours
.X = minutes
.Y = seconds
.Z = tenths

Memory: none

Flags: none

Example:

```
JSR $FFDE   ;RDTIM
```

RDTIM reads the system CIA 24-hour TOD clock, which counts tenths of a second. The timer is automatically wrapped at the 24-hour point.

33. $FFE1 STOP ;scan stop key

Preparation:

Registers: none

Memory: system map

Flags: none

Calls: none

Results:

Registers: .A = last keyboard row
.X = used (if STOP key)

Memory: none

Flags: status valid

Example:

```
JSR $FFE1    ;scan STOP key
BEQ stop     ;branch if down
```

STOP checks a Kernel variable STKEY ($91), which is updated by UDTIM during normal IRQ processing and contains the last scan of keyboard column C7. The STOP key is bit-7, which will be zero if the key is down. If it is, default I/O channels are restored via CLRCH and the keyboard queue is flushed by reseting NDX ($D0). The keys on keyboard line C7 are:

bit:	7	6	5	4	3	2	1	0
key:	STOP	Q	C=	SPACE	2	CTRL	<--	1

The path to STOP is through an indirect RAM vector at $328. Applications may therefore provide their own STOP procedures or suppliment the system's by re-directing this vector to their own routine.

34. $FFE4 GETIN ;read buffered data

Preparation:

Registers: none

Memory: system map

Flags: none

Calls: CHKIN (if necessary)

Results:

Registers: .A = character (or error code)
.X used
.Y used

Memory: STATUS, RSSTAT updated

Flags: .C = 1 if error

Example:

```
wait   JSR $FFE4   ;get any key
       BEQ wait
       STA character
```

GETIN reads a character from the current input device (DFLTN $99) buffer and returns it in .A. Input from devices other than the keyboard (the default input device) must be OPENed and CHKINed. The character is read from the input buffer associated with the current input channel:

1. Keyboard input: a character is removed from the keyboard buffer and passed in .A. If the buffer is empty, a null ($00) is returned.
2. RS-232 input: a character is removed from the RS-232 input buffer and passed in .A. If the buffer is empty, a null ($00) is returned. (use READSS to check validity).
3. Serial input: GETIN automatically jumps to BASIN. See BASIN serial I/O.
4. Screen input: GETIN automatically jumps to BASIN. See BASIN serial I/O.

The path to GETIN is through an indirect RAM vector at $32A. Applications may therefore provide their own GETIN procedures or suppliment the system's by re-directing this vector to their own routine.

35. $FFE7 CLALL ;close all files and channels

Preparation:

Registers:	none
Memory:	system map
Flags:	none
Calls:	none

Results:

Registers:	.A used .X used
Memory:	LDTND, DFLTN, DFLTO updated
Flags:	none

Example:

```
JSR $FFE7    ;close files
```

CLALL deletes all logical file table entries by reseting the table index, LDTND ($98). It clears current serials channels (if any) and restores the default I/O channels via CLRCH.

The path to CLALL is through an indirect RAM vector at $32C. Applications may therefore provide their own CLALL procedures or suppliment the system's by re-directing this vector to their own routine.

36. $FFEA ScanStopKey
(was UDTIM , which has no purpose on C64DX)

Preparation:

Registers: none

Memory: system map

Flags: none

Calls: none

Results:

Registers: .A used
.X used

Memory: TIME, TIMER, STKEY updated

Flags: none

Example:

```
JSR $FFEA   ;ScanStopKey
```

scans key line C7, on which the STOP key lies, and stores the result in STKEY ($91). The Kernel routine STOP utilizes this variable.

37. $FFED SCRORG ;get current screen window size

Preparation:

Registers: none

Memory: system map

Flags: none

Calls: none

Results:

Registers: .A = screen width
.X = window width
.Y = window height

Memory: none

Flags: none

Example:

```
JSR $FFED    ;SCRORG
```

```
        SCRORG  returns active window's size (maximum row & column #) & origin
                               ^^^^^^^^
entry: nothing required.

exit:           .c = maximum screen width  (0=80, 1=40)           default = 0
                .x = maximum column number (# columns minus 1)   default = 79
                .y = maximum line   number (# lines   minus 1)   default = 24

                .a = window address (home position), low         default = $0800
                .z = window address,                 high
```

38. $FFF0 PLOT ;read/set cursor position

Preparation:

Registers: .X = cursor line
.Y = cursor column

Memory: system map

Flags: .C = 0 --> set cursor position
.C = 1 --> get cursor position

Calls: none

Results:

Registers: .X = cursor line
.Y = cursor column

Memory: TBLX, PNTR updated

Flags: .C = 1 --> error

PLOT Reads or sets the cursor position within current window

Entry: .c = 1 Returns the cursor position (.y=column, .x=line) relative to the current window origin (NOT screen origin).

.c = 0 Sets the cursor position (.y=column, .x=line) relative to the current window origin (NOT screen origin).

Exit: When reading position, .X=line, .Y=column, .C=1 if wrapped line

When setting new position, .X=line, .Y=column, and
.c = 0 Normal exit. The cursor has been moved to the position contained in .x & .y relative to window origin (see SCRORG).

.c = 1 Error exit. The requested position was outside the current window (see SCRORG). The cursor has not been moved.

When called with the carry status set, PLOT returns the current cursor position relative to the current window origin (NOT screen origin). When called with the carray status clear, PLOT attempt to move the cursor to the indicated line and column relative to the current window origin (NOT screen origin). PLOT will return a clear carry status if the cursor was moved, and a set carry status if the requested position was outside the current window (NO CHANGE has been made).

Editor variables that are useful:

```
SCBOT - $E4 --> window bottom
SCTOP - $E5 --> window top
SCLF  - $E6 --> window left side
SCRT  - $E7 --> window right side

TBLX  - $EC --> cursor line
PNTR  - $ED --> cursor column

LINES - $EE --> maximum screen height
COLUMNS $EF --> maximum screen width
```

39. $FFF3 IOBASE ;read base address of I/O block

Preparation:

Registers: none

Memory: system map

Flags: none

Calls: none

Results:

Registers: .X = lsb of I/O block
.Y = msb of I/O block

Memory: none

Flags: none

Example:

```
JSR $FFF3   ;find the I/O block
```

IOBASE is unused in the C64DX and is included for compatibility and completeness. It returns the address of the I/O block in .X and .Y.

C. NEW C64DX KERNEL CALLS

The following system calls comprise a set of extensions to the standard CBM jump table. They are specifically for the C64DX machine and and as such should not be considered as permanent additions to the standard jump table. With the exception of C64MODE, they are all true subroutines and will terminate via RTSs. As with all Kernel calls, the system configuration (BANK $FF) must be in context at the time of the call.

1. $FF4D SPIN_SPOUT ;setup fast serial ports for I/O

Preparation:

Registers: none

Memory: system map

Flags:
.C = 0 --> select SPINP
.C = 1 --> select SPOUT

Calls: none

Results:

Registers: .A used

Memory: CIA-1, FSDIR register

Flags: none

Example:

```
CLC
JSR $FF4D    ;setup for fast serial input
```

The fast serial protocol utilizes CIA_1 (6526 at $DC00) and a special driver circuit controlled in part by the FSDIR register. SPINP and SPOUT are routines used by the system to set up the CIA and fast serial driver circuit for input or output. SPINP sets up CRA (CIA_1 register 14) and clears the FSDIR bit for input.
SPOUT sets up CRA, ICR (CIA_1 register 13), timer A (CIA_1 registers 4 & 5), and sets the FSDIR bit for output. Note the state of the TODIN bit of CRA is always preserved. These routines are required only by applications driving the fast serial bus themselves from the lowest level.

2. $FF50 CLOSE_ALL ;close all files on a device

Preparation:

Registers: .A --> device # (FA: 0-31)

Memory: system map

Flags: none

Calls: none

Results:

Registers: .A used
.X used
.Y used

Memory: none

Flags: none

Example:

```
LDA #$08
JSR $FF50   ;close all files on device 8
```

The FAT is searched for the given FA. A proper CLOSE is performed for all matches. If one of the CLOSEd channels is the current I/O channel then the default channel is restored.

This call is utilized, for example, by the BASIC command 'DCLOSE'.

3. $FF53 C64MODE ;reconfigure system as a c/64

Preparation:

Registers:	none
Memory:	system map
Flags:	none
Calls:	none

Results:

Registers:	none
Memory:	none
Flags:	none

Example:

```
JMP $FF53   ;switch to C64 mode
```

THERE IS NO RETURN FROM THIS ROUTINE. The system downloads code to RAM which reMAPs the system to put the C64 ROM in context, resets all VIC-III modes, and jumps to the C64 start routine.

Return to C65 mode is by resetting the machine, although a program could do it very easily. A vector on the C64 side is provided to restart C64DX mode.

4. $FF56 MonitorCall ;enter Monitor mode

Preparation:

Registers:	none
Memory:	system map
Flags:	none
Calls:	none

Results:

Registers:	none
Memory:	none
Flags:	none

Turns off BASIC receipt of IRQ, maps BASIC out, maps the Monitor in, and calls it.

When the Monitor is exited, the system is restored, BASIC mapped in, and the system_vector taken (usually points to BASIC warm start entry).

5. $FF59 BOOT_SYS ;boot an alternate OS from disk

Preparation:

Registers:	none
Memory:	system map
Flags:	none
Calls:	none

Results:

Registers:	undefined
Memory:	undefined
Flags:	undefined

BOOT SYS

Boot an alternate system. Reads the "home" sector of any diskette (physical track 0 sector 1, 512 bytes) into memory at $00400, turns off BASIC, and JMPs to it. Nothing done if disk not present. JMP not made if first byte is not $4C.

It forces the "system" memory map, not user environment.

No support for C128-style BOOT sector. Not related to BASIC 10.0 BOOT command, which RUNs a BASIC program called "AUTOBOOT.C65*" if found.

6. $FF5C PHOENIX ;???? C64DX diagnostics ????

Preparation:

Registers:	none
Memory:	system map
Flags:	none
Calls:	none

Results:

Registers:	undefined
Memory:	undefined
Flags:	none

Example:

```
JSR $FF5C   ;PHOENIX
```

Not same thing as C128 Phoenix routine. In the C65 development system, this routine is called after BASIC inits and performs some system diagnostics, displaying results on the screen.

```
7. $FF5F LKUPLA        ;search tables for given la
8. $FF62 LKUPSA        ;search tables for given sa
```

Preparation:

```
Registers:  .A= LA (logical file number)
                if LKUPLA

            .Y= SA (secondary address)
                if LKUPSA

Memory:     system map

Flags:      none

Calls:      none
```

Results:

```
Registers:  .A = LA (only if found)
            .X = FA (only if found)
            .Y = SA (only if found)

Memory:     none

Flags:      .C = 0 if found
            .C = 1 if not found
```

Example:

```
        LDY #$60       ;find an available SA
again   INY
        CPY #$6F
        BCS too_many   ;too many files open
        JSR $FF62      ;LKUPSA
        BCC again      ;get another if in use
```

LKUPLA and LKUPSA are Kernel routines used primarily by BASIC DOS commands to work around a user's open disk channels. The Kernel requires unique logical device numbers (LAs) and the disk requires unique secondary addresses (SAs), therefore BASIC must find alternative unused values whenever it needs to establish a disk channel.

9. $FF65 SWAPPER ;switch between 40 & 80 column modes

Preparation:

Registers: none

Memory: system map

Flags: none

Calls: none

Results:

Registers: .A used
.X used
.Y used

Memory: screen cleared

Flags: none

Example:

```
LDA $D7       ;check display mode
BMI i.➤80     ;branch if 80 column
JSR $FF5F     ;switch from 40 to 80
```

MODE, location $D7, is toggled by SWAPPER to indicate the current display mode: $80= 80-column, $00= 40-column. Because they are both VIC screens, changing them requires clearing the screens since they share the same memory location.

10. $FF68 PFKEY ;program a function key

Preparation:

```
Registers:  .A = pointer to string adr
                 (lo/hi/bank)
            .Y = string length
            .X = key number (1-16)

Memory:     system map

Flags:      none

Calls:      none
```

Results:

```
Registers:  .A used
            .X used
            .Y used

Memory:     PKYBUF, PKYDEF tables updated

Flags:      .C = 0 if successful
            .C = 1 if no room
```

Example:

```
     LDA #$FA      ;pointer to string address
     LDY #6        ;length
     LDX #15       ;key # ('HELP' key)
     JSR $FF68     ;install new key def'n
     BCS no_room

>000FA 00 13 00           :ptr to $1300 bank 0

>01300 53 54 52 49 4E 47 :'string'
```

PFKEY (alias KEYSET) is an Editor utility to replace a function key string with a user's string. Keys 1-14 are F1-F14, 15 is the HELP key, and 16 is the <shift>RUN string. The example above replaces the 'help<cr>' string assigned at system initialization to the HELP key with the string 'string'. Both the key length table, PKYBUF ($1000-$100F), and the definition area, PKYDEF ($1010-$10FF) are compressed and updated. The maximum length of all 16 strings is 240 characters. No change is made if there is insufficient room for a new definition.

11. $FF6B SETBNK ;set bank for I/O operations
; and filename

Preparation:

Registers: .A = BA, memory bank (0-FF)
.X = FNBANK, filename bank

Memory: system map

Flags: none

Calls: SETNAM

Results:

Registers: none

Memory: BA, FNBANK updated

Flags: none

Example:

see OPEN

SETBNK is a prerequisite for any memory I/O operations and must be used along with SETLFS and SETNAM prior to OPENing files, etc. BA ($C6) sets the current 64KB memory bank for LOAD/SAVE/VERIFY operations. FNBANK ($C7) indicates the bank in which the filename string is found. the Kernel routine SETBNK is often used along with SETNAM and SETLFS calls prior to OPENs. See the Kernel OPEN, LOAD, and SAVE calls for examples.

12. $FF6E JSRFAR ;gosub in another bank
13. $FF71 JMPFAR ;goto another bank

Preparation:

Registers: none

Memory: system map, also:
$02 --> bank (0-FF)
$03 --> PC_high
$04 --> PC_low
$05 --> .S (status)
$06 --> .A
$07 --> .X
$08 --> .Y
$09 --> .Z

Flags: none

Calls: none

Results:

Registers: none

Memory: as per call, also:

$05 --> .S (status)
$06 --> .A
$07 --> .X
$08 --> .Y
$09 --> .Z

Flags: none

The two routines, JSRFAR and JMPFAR, enable code executing in the system bank of memory to call (or JMP to) a routine in any other bank. In the case of JSRFAR, the called routine must restore the system map before executing a return.

JSRFAR calls JMPFAR. Both are RAM routines, located at $39C and $3B1 respectively.

The user should take necessary precautions when calling a non-system bank that interrupts (IRQs & NMIs) will be handled properly (or disabled beforehand).

14\. $FF74 LDA_FAR ;LDA (.X),Y from bank .Z

Preparation:

Registers:
.A = none
.X = pointer to base page pointer
.Y = index
.Z = bank (0-FF)

Memory: setup indirect vector

Flags: none

Calls: none

Results:

Registers:
.A = data
.X used

Memory: DMA_LIST updated

Flags: status valid

LDA_FAR enables applications to read data from any other bank. It builds a DMA_LIST to fetch one byte, executes the DMA, and reads the byte. It's a ROM routine.

15. $FF77 STA_FAR ;STA (.X),Y from bank .Z

Preparation:

Registers:
.A = data
.X = pointer to base page pointer
.Y = index
.Z = bank (0-FF)

Memory:	setup indirect vector
Flags:	none
Calls:	none

Results:

Registers:	.X used
Memory:	DMA_LIST
Flags:	status invalid

STA_FAR enables applications to write data to any other bank. It builds a DMA_LIST to stash one byte, and executes the DMA. It's a ROM routine.

16. $FF7A CMP_FAR ;CMP (.X),Y from bank .Z

Preparation:

Registers:
.A = data
.X = pointer to a base page pointer
.Y = index
.Z = bank (0-FF)

Memory: setup indirect vector

Flags: none

Calls: none

Results:

Registers: .X used

Memory: none

Flags: status valid

CMP_FAR enables applications to compare data to any other bank. It builds calls LDA_FAR and compares the given byte with the byte fetched. It's a ROM routine.

17. $FF7D PRIMM ;print immediate utility

Preparation:

Registers: none

Memory: none

Flags: none

Calls: none

Results:

Registers: none

Memory: none

Flags: none

Example:

```
JSR $FF7D           ;display following text

.BYTE 'message'
.BYTE $00           ;terminator

JMP continue        ;execution resumes here
```

PRIMM is a Kernel utility used to print (to the default output device) a PETSCII string which immediately follows the call. The string must be no longer than 255 characters and be terminated by a null ($00) character. It cannot contain any embedded null characters. Because PRIMM uses the system stack to find the string and a return address, you MUST NOT JMP to PRIMM. There must be a valid address on the stack.

3.4.6 BASIC 10.0 MATH PACKAGE

This document details the many user-callable routines available in the C64DX BASIC 10.0 math package.

Floating Point Math Package Conventions

In BASIC memory the number is PACKED and looks like this:

```
      1        2         3        4         5
  ----------------------------------------------
 |signed |B7=SGN |         |         |          |
 |  EXP  |-------|M A N T I S S A|    LSB       |
 | +$80  |  MSB  |         |         |          |
  ----------------------------------------------
```

Because the mantissa is normalized such that its msb is always 1, BASIC stores the SIGN of the mantissa here to save a byte of storage. It must be normalized when put in the FACC (see CONUPK). In the FACC the NORMALIZED number looks like this:

```
    $63      $64      $65      $66      $67      $68
  FACEXP   FACHO    FACMOH   FACMO    FACLO    FACSGN
  ------------------------------------------------------
 |signed |BIT 7=1|         |         |        | SIGN   |
 |  EXP  |-------|M A N T I S S A|    LSB     |+ = $00 |
 | +$80  |  MSB  |         |         |        |- = $FF |
  ------------------------------------------------------
```

Negative exponents are not stored 2's complement. The maximum exponent is 10^38 ($FF) and the minimum is 10^-39 ($01). A zero value for the exponent means the number is zero. Since the exponent is a power of 2, it can be described as the number of left (EXP>$80) or right (EXP<=$80) shifts to be performed on the normalized mantissa to create the binary representation of the value. There is a second floating accumulator called ARG which has the same layout. It is located at $6A through $6F. Throughout the math package the floating point format is:

* the mantissa is 24 bits long.

* the binary point is to the left of the msb.

* the mantissa is always positive, and its msb is always 1.

* number = mantissa * 2^exponent, sign in FACSGN.

* the sign of the exponent is the msb of the exponent.

* the exponent is stored in excess $80 (i.e., it is a signed 8-bit number with $80 added to it.)

* an exponent of zero means the number is zero. (note that the rest of the accumulator cannot be assumed to be zero.)

* to keep the same number in the accumulator while shifting:
     right shifts --> increment exponent
     left shifts --> decrement exponent

Arithmetic routine calling conventions:

- * For one argument functions:
  the argument is in the FACC.
  the result is left in the FACC.

- * For two argument operations:
  the first argument is in MEMORY (packed) or ARG (unpacked).
  the second argument is in the FACC.
  the result is left in the FACC.

- * Always call ROM routines with SYSTEM memory in context (BANK $FF)

A note concerning precision. Since the mantissa is always normalized, the high order bit of the most significant byte is always one. This guarantees at least 40 bits (5 byte mantissa times 8 bits each) of precision, which is approximately 9 significant digits plus a few bits for rounding. In fact, there is a 'rounding' byte, FACOV ($71), which should, for the greatest degree of precision, be loaded whenever you load the FACC. The high order bit of FACOV is utilized in most of the math routines. While some of the 'movement' routines 'round' the loaded floating point number (i.e., FACOV = $00), others (such as CONUPK) do not- assuming the value of FACOV is the useful result of an operation in progress. In 99% of the cases you need not worry about it, as its significance is virtually nil. For the greatest degree of precision however, use it.

A few examples of normalized (FACC) floating point numbers:

VALUE		EXP	MANTISSA				SIGN
1E38	=	FF	96	76	99	53	00
4E10	=	A4	95	02	F9	00	00
2E10	=	A3	95	02	F9	00	00
1E10	=	A4	95	02	F9	00	00
10	=	84	A0	00	00	00	00
1	=	81	80	00	00	00	00
.5	=	80	80	00	00	00	00
.25	=	7F	80	00	00	00	00
.6	=	80	99	99	99	9A	00
1E-04	=	73	D1	B7	59	59	00
1E-37	=	06	88	1C	EA	15	00
1E-38	=	02	D9	C7	DC	EE	00
3E-39	=	01	82	AB	1E	2A	00
0	=	00	xx	xx	xx	xx	00
-1	=	81	80	00	00	00	FF
-5	=	83	A0	00	00	00	FF

Now for a simple example of deriving the actual binary from the FACC:

```
    5   =        83     A0      00      00      00      00
                  |       \
                  |        \
             ($83-$80)   ($A0)
                  |         |
which means:   2^3   *  .10100000,  or shift mantissa LEFT 3,

which gives:    101.00000 (binary) or 5.0 (hex)
```

NAME: **AYINT**
FUNCTION: CONVERT FLOATING POINT TO INTEGER

PREPARATION: FACC contains floating point number (-32768<=n<=32767)

RESULT: FACMO ($66) contains signed integer (msb)
FACLO ($67) contains signed integer (lsb)

ERROR: ?ILLEGAL QUANTITY ERROR if FACC too big.

EXAMPLE:

```
JSR AYINT       ;INT(FACC)
LDA $66         ;MSB
LDY $67         ;LSB
```

NAME: **GIVAYF**
FUNCTION: CONVERT INTEGER TO FLOATING POINT

PREPARATION: .A contains signed integer (msb)
.Y contains signed integer (lsb)

RESULT: FACC contains floating point number

EXAMPLE:

```
LDA #>INTEGER
LDY #<INTEGER
JSR GIVAYF      ;FLOAT (A,Y)
```

NAME: **FOUT**
FUNCTION: CONVERT FLOATING POINT TO ASCII STRING

PREPARATION: FACC contains floating point number

RESULT: FBUFFR ($100) contains ASCII string (null terminated)
.A contains pointer to string (lsb)
.Y contains pointer to string (msb)

EXAMPLE:

```
JSR FOUT        ;CONVERT FACC TO STRING AT $100
```

NAME: **VAL_1**
FUNCTION: CONVERT ASCII STRING TO FLOATING POINT

PREPARATION: INDEX1 ($24,$25) contains pointer to string
.A contains length of string

SPECIAL NOTES: String *must* be in var_bank. Any invalid character terminates conversion when encountered (i.e., acts like a terminator).

RESULT: FACC contains floating point number

EXAMPLE:

```
LDA #<POINTER
LDY #>POINTER
STA INDEX1      ;SET POINTER TO STRING
STY INDEX1+1
LDA #LENGTH     ;SET STRING LENGTH
JSR VAL_1       ;FACC = VAL(STRING)
```

NAME: **GETADR**
FUNCTION: CONVERT FLOATING POINT TO ADDRESS

PREPARATION: FACC contains floating point number (0<=n<=65535)

RESULT: POKER ($16,$17) contains unsigned integer address

ERROR: ?ILLEGAL QUANTITY ERROR if FACC too big.

EXAMPLE:

```
JSR GETADR      ;ADR(FACC)
LDA $16         ;LSB
LDY $17         ;MSB
```

NAME: **FLOATC**
FUNCTION: CONVERT ADDRESS TO FLOATING POINT

PREPARATION: FACHO ($64) contains address (msb)
FACMOH ($65) contains address (lsb)
.X   contains exponent ($90 always)
.C=1 if positive (always)

RESULT: FACC contains floating point number

ERROR: ?OVERFLOW ERROR if FACC too big.

EXAMPLE:

```
LDA #<ADDRESS
LDY #>ADDRESS
STA FACMOH      ;SET ADDRESS
STY FACHO
LDX #$90        ;EXPONENT
SEC             ;POSITIVE
JSR FLOATC      ;FLOAT ADDRESS
```

NAME: **FSUB**
FUNCTION: FACC = MEMORY - FACC

PREPARATION: FACC contains floating point subtrahend
.A = pointer (lsb) to packed floating point minuend
.Y = pointer (msb) to packed floating point minuend

SPECIAL NOTES: The minuend *MUST* be in VARBANK in packed format. FSUB calls CONUPK to normalize it.

RESULT: FACC contains floating point difference

ERROR: ?OVERFLOW ERROR if FACC too big.

EXAMPLE:

```
LDA #<POINTER
LDY #>POINTER   ;SET POINTER TO *PACKED* MINUEND
JSR FSUB        ;SUBTRACT MEMORY FROM FACC, DIFF IN FACC
```

NAME: **FSUBT**
FUNCTION: FACC = ARG - FACC

PREPARATION: FACC contains floating point subtrahend
ARG contains floating point minuend

SPECIAL NOTES: This routine is similar to FSUB. The only difference is the call to CONUPK- FSUBT assumes you have already loaded ARG with unpacked minuend.)

RESULT: FACC contains floating point difference

ERROR: ?OVERFLOW ERROR if FACC too big.

EXAMPLE:

```
JSR FSUBT       ;SUBTRACT ARG FROM FACC, DIFF IN FACC
```

NAME: **FADD**
FUNCTION: FACC = MEMORY + FACC

PREPARATION: FACC contains floating point addend
.A = pointer (lsb) to packed floating point addend
.Y = pointer (msb) to packed floating point addend

SPECIAL NOTES: The second addend *MUST* be in VARBANK in packed format. FADD calls CONUPK to normalize it.

RESULT: FACC contains floating point sum

ERROR: ?OVERFLOW ERROR if result too big

EXAMPLE:

```
LDA #<POINTER
LDY #>POINTER     ;SET POINTER TO *PACKED* ADDEND
JSR FADD          ;ADD MEMORY TO FACC, SUM IN FACC
```

NAME: **FADDT**
FUNCTION: FACC = ARG + FACC

PREPARATION: FACC contains floating point addend
ARG contains floating point addend
ARISGN ($70) contains EOR(FACSGN,ARGSGN)
.A contains FACEXP

SPECIAL NOTES: This routine is similar to FADD. The only difference is the call to CONUPK.)

```
**********************************************
*  You  *MUST*  put resultant sign in ARISGN. *
*  You  *MUST*  load FACEXP ($63) immediately *
*  before call so that status flags are set!  *
**********************************************
```

RESULT: FACC contains floating point sum

ERROR: ?OVERFLOW ERROR if result too big

EXAMPLE:

```
LDA FACSGN
EOR ARGSGN
STA ARISGN        ;SET RESULTANT SIGN
LDA FACEXP        ;SET STATUS FLAGS PER FACEXP
JSR FADDT         ;ADD ARG TO FACC, SUM IN FACC
```

NAME: **FMULT**
FUNCTION: FACC = MEMORY * FACC

PREPARATION: FACC contains floating point multiplier
.A = pointer (lsb) to packed floating point multiplicand
.Y = pointer (msb) to packed floating point multiplicand

SPECIAL NOTES: The multiplicand *MUST* be in VARBANK in packed format. FMULT calls CONUPK to normalize it.

RESULT: FACC contains floating point product

ERROR: ?OVERFLOW ERROR if result too big

EXAMPLE:

```
LDA #<POINTER
LDY #>POINTER    ;SET POINTER TO *PACKED* MULTIPLICAND
JSR FMULT        ;MULTIPLY MEMORY BY FACC, PRODUCT IN FACC
```

NAME: **FMULTT**
FUNCTION: FACC = ARG * FACC

PREPARATION: FACC contains floating point multiplier
ARG contains floating point multiplicand

SPECIAL NOTES: This routine is similar to FMULT. The only difference is the call to CONUPK- FMULTT assumes you have already loaded ARG with unpacked multiplicand.)

RESULT: FACC contains floating point product

ERROR: ?OVERFLOW ERROR if result too big

EXAMPLE:

```
JSR FMULTT       ;MULTIPLY ARG BY FACC, PRODUCT IN FACC
```

NAME: **FDIV**
FUNCTION: FACC = MEMORY / FACC

PREPARATION: FACC contains floating point divisor
.A = pointer (lsb) to packed floating point dividend
.Y = pointer (msb) to packed floating point dividend

SPECIAL NOTES: The dividend *MUST* be in VARBANK in packed format. FDIV calls CONUPK to normalize it.

RESULT: FACC contains floating point quotient

ERROR: ?DIVISION BY ZERO ERROR if FACC zero

EXAMPLE:

```
LDA #<POINTER
LDY #>POINTER   ;SET POINTER TO *PACKED* DIVIDEND
JSR FDIV        ;DIVIDE MEMORY BY FACC, QUOTIENT IN FACC
```

NAME: **FDIVT**
FUNCTION: FACC = ARG / FACC

PREPARATION: FACC contains floating point divisor
ARG contains floating point dividend
ARISGN ($70) contains EOR(FACSGN,ARGSGN)
.A   contains FACEXP

SPECIAL NOTES: This routine is similar to FDIV. The only difference is the call to CONUPK- FDIVT assumes you have already loaded ARG with unpacked dividend.)

```
*********************************************
*  You  *MUST*  put resultant sign in ARISGN. *
*  You  *MUST*  load FACEXP ($63) immediately *
*  before call so that status flags are set!  *
*********************************************
```

RESULT: FACC contains floating point quotient

ERROR: ?DIVISION BY ZERO ERROR if FACC zero

EXAMPLE:

```
LDA FACSGN
EOR ARGSGN
STA ARISGN      ;SET RESULTANT SIGN
LDA FACEXP      ;SET STATUS FLAGS PER FACEXP
JSR FDIVT       ;DIVIDE ARG BY FACC, QUOTIENT IN FACC
```

NAME: **LOG**
FUNCTION: FACC = LOG(FACC) natural logarithm (base e)

PREPARATION: FACC contains floating point number

RESULT: FACC contains floating point logarithm

ERROR: ?ILLEGAL QUANTITY ERROR if FACC negative or zero

EXAMPLE: JSR LOG ;FACC = LOG(FACC)

NAME: **INT**
FUNCTION: FACC = INT(FACC)

PREPARATION: FACC contains floating point number

RESULT: FACC contains floating point greatest integer

EXAMPLE: JSR INT ;FACC = INT(FACC)

NAME: **SQR**
FUNCTION: FACC = SQR(FACC)

PREPARATION: FACC contains floating point number

RESULT: FACC contains floating point square root

ERROR: ?ILLEGAL QUANTITY ERROR if FACC negative

EXAMPLE: JSR SQR ;FACC = SQR(FACC)

NAME: **NEGOP**
FUNCTION: FACC = -FACC (invert sign of FACC)

PREPARATION: FACC contains floating point number

RESULT: FACC contains floating point number with sign inverted

EXAMPLE: JSR NEGOP ;FACC = -FACC

NAME:	**FPWR**
FUNCTION:	FACC = ARG ^ MEMORY
PREPARATION:	ARG contains floating point number .A = pointer (lsb) to packed floating point power .Y = pointer (msb) to packed floating point power
SPECIAL NOTES:	The power *MUST* be in ROM or SYSTEM RAM in packed format as FPWR calls MOVFM to unpack it into FACC.
RESULT:	FACC contains floating point result
ERROR:	?ILLEGAL QUANTITY ERROR if ARG negative ?OVERFLOW ERROR if result too big
EXAMPLE:	LDA #<POINTER LDY #>POINTER ;SET POINTER TO *PACKED* POWER JSR FPWR ;COMPUTE ARG ^ MEM, RESULT IN FACC

NAME:	**FPWRT**
FUNCTION:	FACC = ARG ^ FACC
PREPARATION:	ARG contains floating point number FACC contains floating point power .A contains FACEXP
SPECIAL NOTES:	This routine is similar to FPWR. The only difference is the call to MOVFM- FPWRT assumes you have already loaded FACC with unpacked power. *** * You *MUST* load FACEXP ($63) immediately * * before call so that status flags are set! * ***
RESULT:	FACC contains floating point result
ERROR:	?ILLEGAL QUANTITY ERROR if ARG negative ?OVERFLOW ERROR if result too big
EXAMPLE:	LDA FACEXP ;SET STATUS FLAGS PER FACEXP JSR FPWRT ;COMPUTE ARG ^ FACC, RESULT IN FACC

NAME:	**EXP** (compute e ^ FACC)
FUNCTION:	FACC = EXP(FACC)
PREPARATION:	FACC contains floating point number
RESULT:	FACC contains floating point result
ERROR:	?OVERFLOW ERROR if FACC too big
EXAMPLE:	JSR EXP ;FACC = EXP(FACC)

NAME: **COS**
FUNCTION: FACC = COS(FACC)

PREPARATION: FACC contains floating point number

RESULT: FACC contains floating point cosine (in radians)

EXAMPLE: JSR COS ;FACC = COS(FACC)

NAME: **SIN**
FUNCTION: FACC = SIN(FACC)

PREPARATION: FACC contains floating point number

RESULT: FACC contains floating point sine (in radians)

EXAMPLE: JSR SIN ;FACC = SIN(FACC)

NAME: **TAN**
FUNCTION: FACC = TAN(FACC)

PREPARATION: FACC contains floating point number

RESULT: FACC contains floating point tangent (in radians)

EXAMPLE: JSR TAN ;FACC = TAN(FACC)

NAME: **ATN**
FUNCTION: FACC = ATN(FACC)

PREPARATION: FACC contains floating point number

RESULT: FACC contains floating point arctangent (in radians)

EXAMPLE: JSR ATN ;FACC = ATN(FACC)

NAME:	**ROUND**	(round to 40 bits of precision)
FUNCTION:	FACC = FACC + FACOV(msb)	
PREPARATION:	FACC contains floating point number FACOV (msb) contains 'extra' precision	
RESULT:	none if FACC zero or FACOV (msb) zero one extra bit ADDED to FACC lsb if FACOV (msb) is set	
EXAMPLE:	JSR ROUND	;ROUND FACC

=-=

NAME:	**ABS**	(make FACSGN(msb) = $00)
FUNCTION:	FACC = ABS(FACC)	
PREPARATION:	FACC contains (SIGNED) floating point number	
RESULT:	FACC contains (POSITIVE) floating point	
EXAMPLE:	JSR ABS	;FACC = ABS(FACC)

=-=

NAME:	**SGN**	**(test SIGN of FACC)**
FUNCTION:	.A = SGN(FACC)	
PREPARATION:	FACC contains floating point number	
RESULT:	.A --> $FF if FACC negative (FACC < 0) $00 if FACC zero (FACC = 0) $01 if FACC positive (FACC > 0) (status flags reflect contents of .A, carry invalid)	
EXAMPLE:	JSR SGN	;SGN(FACC) ; BEQ will trap =0 ; BNE will trap <>0 ; BMI will trap <0 ; BPL will trap >=0 etc.

=-=

NAME: **FCOMP** **(compare FACC with MEMORY)**

FUNCTION: .A = FCOMP(FACC,MEMORY)

PREPARATION: FACC contains floating point number
.A = pointer (lsb) to packed floating point number
.Y = pointer (msb) to packed floating point number

SPECIAL NOTES: The number *MUST* be in ROM, or RAM currently in context below ROM, in PACKED format. *** FACOV is significant!

RESULT:

```
.A  --> $FF if FACC < MEMORY
        $00 if FACC = MEMORY
        $01 if FACC > MEMORY
(status flags reflect contents of .A, carry invalid)
```

EXAMPLE:

```
LDA #<POINTER
LDY #>POINTER     ;SET POINTER TO *PACKED* NUMBER
JSR FCOMP         ;COMPARE FACC WITH MEMORY
                  ; BEQ will trap FACC =  MEM
                  ; BNE will trap FACC <> MEM
                  ; BMI will trap FACC <  MEM
                  ; BPL will trap FACC >= MEM     etc.
```

NAME: **RND0**

FUNCTION: FACC = random floating point number (0<n<1)

PREPARATION:

```
.A  --> $00 to generate a 'true' random number
        $01 to generate next random number in sequence
        $FF to start a new sequence of random numbers
            based upon current contents of FACC.
```

SPECIAL NOTES: *MUST* be called with the system bank in context.
MUST load .A immediately before call so that status flags reflect contents of .A

RESULT: FACC = floating point random number

EXAMPLE:

```
LDA #$FF          ;START REPRODUCEABLE SEQUENCE BASED ON FACC
JSR RND0
LDA #$01
JSR RND0          ;GENERATE (FIRST) RANDOM NUMBER IN SEQUENCE
```

NAME: **CONUPK**
FUNCTION: ARG = UNPACK(RAM_CONSTANT)

PREPARATION: .A = pointer (lsb) to packed floating point number
.Y = pointer (msb) to packed floating point number

SPECIAL NOTES: The number *MUST* be in VARBANK or SYSTEM RAM in packed format.

RESULT:

```
ARG      loaded with normalized floating point number
ARISGN   ($6F) contains EOR(FACSGN,ARGSGN)
.A       contains FACEXP (status reflects contents of .A)
```

EXAMPLE:

```
LDA #<POINTER
LDY #>POINTER     ;SET POINTER TO *PACKED* NUMBER
JSR CONUPK        ;LOAD ARG
                  ; BEQ traps ARG = $00
```

NAME: **ROMUPK**
FUNCTION: ARG = UNPACK(ROM_CONSTANT)

PREPARATION: .A = pointer (lsb) to packed floating point number
.Y = pointer (msb) to packed floating point number

SPECIAL NOTES: The number *MUST* be in ROM or SYSTEM RAM currently in context (otherwise identical to CONUPK).

RESULT:

```
ARG      loaded with normalized floating point number
ARISGN   ($6F) contains EOR(FACSGN,ARGSGN)
.A       contains FACEXP (status reflects contents of .A)
```

EXAMPLE:

```
LDA #<POINTER
LDY #>POINTER     ;SET POINTER TO *PACKED* NUMBER
JSR ROMUPK        ;LOAD ARG
                  ; BEQ traps ARG = $00
```

NAME: **MOVFRM**
FUNCTION: FACC = UNPACK(RAM_CONSTANT)

PREPARATION: .A = pointer (lsb) to packed floating point number
.Y = pointer (msb) to packed floating point number

SPECIAL NOTES: The number *MUST* be in VARBANK or SYSTEM RAM in packed format.

RESULT:

```
FACC     loaded with normalized floating point number
FACOV    ($71) cleared
```

EXAMPLE:

```
LDA #<POINTER
LDY #>POINTER     ;SET POINTER TO *PACKED* NUMBER
JSR MOVFRM        ;LOAD FACC
```

NAME: **MOVFA**
FUNCTION: FACC = ARG

PREPARATION: ARG contains floating point number

RESULT:
FACC contains same number as ARG
FACOV ($71) cleared
.A contains FACEXP (but status invalid!)

EXAMPLE: JSR MOVFA ;COPY ARG TO FACC

NAME: **MOVAF**
UNCTION: ARG = FACC

PREPARATION: FACC contains floating point number

RESULT:
FACC will be ROUNDed and FACOV cleared.
ARG contains same number as FACC
.A contains FACEXP (but status invalid!)

EXAMPLE: JSR MOVAF ;COPY FACC TO ARG

*** End of MATH ROUTINE documentation ***

3.5 C65 DOS Documentation

DIRECTORY HEADER DEFINITION

BYTE	DESCRIPTION
0	TRACK number which points to the 1st dir. sector
1	SECTOR number which points to the 1st dir. sector
2	Disk format version number, which is currently 'D' 512 byte sectors 20 per track 20 Sectors per track 40 Tracks per side 2 sides (note they're inverted from normal MFM dsk)
3	Must = 0
4	Bytes 4 thru 21 contain the volume name (label)
22	Bytes 22 and 23 contain the disk id (fake)
24	Must contain an $A0
25	DOS version number (CBDOS = 1, 1581 = 3
26	Format version number (currently = 'D' (fake))
27	Bytes 27 thru 28 = $A0
29	NOT USED AT THIS TIME
30	NOT USED AT THIS TIME
30	NOT USED AT THIS TIME
32	NOT USED AT THIS TIME
33	NOT USED AT THIS TIME
34	Track number which points to this directory header
35	Sector number which points to this directory header
36	Bytes 36 thru 255 are not used at this time

NOTE: If this is a subdirectory header then BYTES 32 and 33 contain the TRACK & SECTOR number of the DIRECTORY SECTOR that points to this DIRECTORY HEADER. See the partition command for a better discription. If this is the ROOT header then they will contain a $00.

BAM DEFINITION

BYTE	DESCRIPTION
0	Track link for next bam sector, if last then end of bams
1	Sector link
2	Format type this disk was formatted under
3	Compliment version number of byte 2 above
4 - 5	Disk ID used when this disk was formatted
6	I/O byte used as follows;
	BIT 7 - When set Verify is performed after each disk write.
	BIT 6 - Perform CRC check (not used by CBDOS)
	BIT 1 - Huge relative files disabled
7	Auto loader flag (not used by CBDOS)
8 - 15	Not used at this time by any CBM DOS versions
16 - 255	BAM image

BAM IMAGE

0 -	Number of free sectors on this track
1 -	MSB flag for sector 7, LSB flag for sector 0
2 -	MSB flag for sector15, LSB flag for sector 8
3 -	MSB flag for sector23, LSB flag for sector16
4 -	MSB flag for sector31, LSB flag for sector24
5 -	MSB flag for sector39, LSB flag for sector32

DIRECTORY SECTOR DEFINITION

BYT	BIT	DESCRIPTION
0		TRACK -- Points to the next directory track.
1		SECTOR-- Points to the next directory sector.
		[IF TRACK = 0 THEN THIS IS THE LAST DIRECTORY SECTOR]

FILE ENTRY DESCRIPTION

BYT	BIT	DESCRIPTION
0		File status byte which is used as follows;
	7	Set indicates properly closed file
	6	File is locked (read only)
	5	Save with replace is CURRENTLY in effect,
		when file is closed this bit is deleted.
	4	NOT USED AT THIS TIME
	X	Bits 3 thru 0 are used to indicate the filetype
		0 = DEL, 1 = SEQ, 2 = PRG, 3 = USER, 4 = REL, 5 = CBM, 6 =not used
		7 = used by dos to represent DIRECT type of file access
1		TRACK - link to the 1st sector of data for this file.
2		SECTOR - link to the 1st sector of data for this file.
3		Bytes 3 thru 18 contain the filename in ASCII, padded with $A0
19		Side Sector TRACK link for relative files
		GEOS - Track number of GEOS file header
20		Side Sector SECTOR link for relative files
		GEOS - Sector number of GEOS file header
21		Record size for relative files
		GEOS - File structure type 0 = seq, 1 = VLIR
22		GEOS - FILE TYPES:
	›	13= Swap file 12= System boot 11= Disk device 10= Input device
		09= Printer 08= Font 07= Appl. data 06= Applications
		05= Desk Acc. 04= System 03= Basic data 02= Assembly
		01= Basic 00= Not GEOS
23		Not used by CBM DOS previous to CBDOS
		GEOS - DATE: Year last modified (offset from 1990)
		CBDOS- Bits 7-4 contain the upper 4 bit's from the file type byte
		(see byte 0 above) for the UNNEW, UNSRATCH commands used by CBDOS
24		Not used by CBM DOS previous to CBDOS
		GEOS - DATE: Month last modified (1 thru 12)
		CBDOS- Bit's 7 thru 4 contain the lower 4
		bit's from the file type byte (see byte 23 above)
25		GEOS - DATE: Day last modified (1 thru 31)
26		TRACK (from 1) for the save with replace file
		GEOS - DATE: Hour last modified (0 thru 23)
27		SECTOR (from 2) for the save with replace
		GEOS - DATE: Minute last modified (0 thru 59)
28		LSB of the # of sectors used by this file
29		MSB of the # of sectors used by this file

NOTE: Each sector in the directory contains 8 entries of 32 bytes each

SIDE SECTOR FORMAT DEFINITION

BYTE	DESCRIPTION
0	Next Side Sector TRACK link ($FF if last)
1	Next Side Sector SECTOR
2	Side Sector number If this is a SUPER SIDE SECTOR then this contains an $FE (see the description of the SUPER SIDE SECTOR below)
3	Record Size
4 - 5	TRACK & SECTOR link of Side Sector number 0
6 - 7	TRACK & SECTOR link of Side Sector number 1
8 - 9	TRACK & SECTOR link of Side Sector number 2
10 - 11	TRACK & SECTOR link of Side Sector number 3
12 - 13	TRACK & SECTOR link of Side Sector number 4
14 - 15	TRACK & SECTOR link of Side Sector number 5
16 - 17	TRACK & SECTOR link of the DATA BLOCK #0
18 - 19	TRACK & SECTOR link of the DATA BLOCK #1
etc...	

NOTE: There are 91 groups to the largest file that this DOS can handle.

SUPER SIDE SECTOR FORMAT DEFINITION

BYTE	DESCRIPTION
0	Next Side Sector TRACK link ($FF if last)
1	Next Side Sector SECTOR
2	Contains an $FE to indicate this is a SUPER SIDED SECTOR
3 - 4	TRACK & SECTOR link of Side Sector number 0
5 - 6	TRACK & SECTOR link of Side Sector number 1
7 - 8	TRACK & SECTOR link of Side Sector number 2
9 - 10	TRACK & SECTOR link of Side Sector number 3
11 - 12	TRACK & SECTOR link of Side Sector number 4
13 - 14	TRACK & SECTOR link of Side Sector number 5
253 - 254	TRACK & SECTOR link of Side Sector number 125

NOTE: There are 91 groups to the largest file that this DOS can handle.

DATA SECTOR DEFINITION

BYTE	DESCRIPTION
0 - 1	TRACK and SECTOR link to the next data block. If track = 0 then sector contains the number of bytes used in this sector (which will always be at least 2 on the last block for the T&S link bytes).

NOTE: Used by DEL, SEQ, PRG, REL (data blocks) and USR

```
;*-----------------------------------------------------------*
;* Format a track                                            *
;* 10 sectors per track numbered 1-10, 512 byte sectors      *
;*-----------------------------------------------------------*
;*  12 Sync marks                             00             *
;*   3 Header ID marks w/missing clock        A1             *
;*   1 Header ID                              FE             *
;*   4 Header bytes                           Track          *
;*                                            Side           *
;*                                            Sector         *
;*                                            Sector size    *
;*   2 Header CRC bytes                       xx,xx          *
;*  22 Data gap bytes                         4E             *
;*  12 Sync marks                             00             *
;*   3 Data block ID marks w/missing clock    A1             *
;*   1 Data block ID                          FB             *
;* 512 Data block fill bytes                  00             *
;*   2 Data block CRC bytes                   xx,xx          *
;*  24 Sector gap bytes                       4E             *
;*-----------------------------------------------------------*
```

```
;*-----------------------------------------------------------------------*
;* Calculate the 2 byte CRC for each sector header of an entire track    *
;* of 10 sectors.   AXYZ are trashed.                                    *
;*                                                                       *
;*  This routine is based on the Cyclical Redundancy Check on the        *
;*  polynomial:  A^16+A^12+A^5+1.                                        *
;*                                                                       *
;*      HEADER contains TRACK,SIDE,SECTOR,2 [sector size]                *
;*                                                                       *
;*      DO WHILE ne = 0                                                  *
;*        DO FOR each bit in the data byte (.a) [from lsb to msb]        *
;*          IF (LSB of crc) EOR (LSB of data)                            *
;*      >     THEN CRC = (CRC/2) EOR polynomial                          *
;*          ELSE CRC = (CRC/2)                                           *
;*          FI                                                           *
;*          LOOP                                                         *
;*        LOOP                                                           *
;*-----------------------------------------------------------------------*
```

```
;*-----------------------------------------------------------------------*
;*     SIDE           = (LogicalSector >= 20) AND 1                      *
;*     TRACK          = LogicalTrack -1                                  *
;*     StartingSector = SIDE * 20                                        *
;*     SECTOR         = (LogicalSector - StartingSector) /2 +1           *
;*     HALF           = (LogicalSector - StartingSector) AND 1           *
;*-----------------------------------------------------------------------*
```

C65 Partition and Subdirectory Syntax

910212 Fred Bowen

This specification describes a proposed C65 partition/subdirectory parser.

```
OPEN la,fa,sa, "[#]/path/:filename"
OPEN la,fa,15, "<cmd>#/path/:[cmd_string]"
```

```
where:   #              is an optional "drive" number, 0-9.
         /path/         is a partition or subdirectory name
         :              delimits the path from the filename

and:     <cmd>          is a DOS command (such as I,N,S,C, etc.)
         [cmd_string]   is an optional string required by some commands.
```

The first example illustrates a typical filename specification, the second example illustrates a command channel instruction.

```
OPEN la,fa,sa, "0/SUBDIR1/SUBDIR2/:FILE,S,W"
```

Action taken	Why
1. Select the "root"	0
2. Find & enter two subdirectories	/SUBDIR1/SUBDIR2/: (the trailing "/" is required to be compatible with CMD?)
3. Create & open file for writing	FILE,S,W

The "root" or "drive number", path, and ":" are all optional. If they are omitted, the file is opened in the current partition. Some similar, and legal, syntaxes are:

```
OPEN la,fa,sa, "FILE,S,W"              (create "FILE" in current part)
OPEN la,fa,sa, ":FILE,S,W"             (create "FILE" in current part)
OPEN la,fa,sa, "0:FILE,S,W"            (create "FILE" in current part)
OPEN la,fa,sa, "/SUBDIR/:FILE,S,W"     (from current partition, enter
                                        "SUBDIR" and create "FILE")
OPEN la,fa,sa, "//SUBDIR/:FILE,S,W"    (from Root partition, enter
                                        "SUBDIR" and create "FILE")
OPEN la,fa,sa, "@0/SUBDIR/:FILE"       (open "FILE" in "SUBDIR" for
                                        writing)
```

Some questionable syntaxes, and their affect, are:

```
OPEN la,fa,sa, "0FILE,S,W"             (this would create file "0FILE")
OPEN la,fa,sa, "/SUBDIR/FILE,S,W"      (creates file "/SUBDIR/FILE")
OPEN la,fa,sa, "@0:FILE,S,W"           (open file "FILE" in current
                                        partition for writing)
OPEN la,fa,sa, "/0:FILE,S,W"           (? should create file "0:FILE",
                                        note this is not the cmd chnl)
```

Some legal commands:

```
OPEN la,fa,15, "I0"                    (initialize current partition)
OPEN la,fa,15, "I//"                   (initialize Root)
OPEN la,fa,15, "I0/SUBDIR/:"           (enter "SUBDIR" and initialize)
OPEN la,fa,15, "N0/SUBDIR/:NAME,ID"    (enter "SUBDIR" and "new" it)
OPEN la,fa,15, "S0/SUBDIR/:FILE"       (delete "FILE" in "SUBDIR")
OPEN la,fa,15, "/0:SUBDIR"             (1581 partition select, "/" in
                                        this context is a command itself)
```

Some proposed general rules, designed to be compatible with both the 1581 subpartitioning syntax and CMD syntax:

1. The name of a subdirectory must always be separated from the filename by a colon (":").
2. Each subdirectory name must be delimited by a slash ("/").
3. To select Root directory (partiton), specify two slashes ("//"). This allows older applications specifying the drive number ("0:") to be run in a partition.

CURRENT PARTITION ROUTINES

reate Partition:
"/0:PAR_NAME,"+(START-TRK)+(START-SECTOR)+(LO-BLKS)+(HI-BLKS)

Select Partition:

"/0:PAR_NAME"	will select given filname as subdirectory
"/0"	will select root directory

SELECT PARTITION

This routine will allow the user to quickly select partition paths using the normal SA values other than 15. To use this new method the user opens the file using a normal SA and the filename MUST be structured as follows;

"/<drive>:PATH_1/PATH_2/PATH_3..... ETC"

If the dos does not find one of the filenames in the file path stream it will check to see if the file exists in the current directory and if it does it will open the file in the normal method as it does now.

```
;**************************************************************************
;*                           FILE_COMMANDS                               *
;*                                                                        *
;* The following set of command channel routines were added to allow the *
;* user a graceful way of manupilating files:                             *
;*                                                                        *
;*      "F-L"  Locate a file to prevent it from being scratched           *
;*      "F-U"  Unlock a file and allow it to be scratched                 *
;*      "F-R"  Restore a file after it has been scratched                 *
;*                                                                        *
;* Following each command above is the drive number, followed by a colon *
;* then followed by the filename(s).  For example, to lock all the files *
;* on drive 0 you would send the following file command:                  *
;*                                                                        *
;*            OPENXX,xX,15,"F-L0:*"                                       *
;*                                     or                                 *
;*            OPENXX,XX,15,"F-L0:FNAME,FNAME1,FNAME2, ... etc.            *
;*                                                                        *
;**************************************************************************

    ;**********************************************************************
    ;*                          BLOCK STATUS                              *
    ;*                                                                    *
    ;*  Syntax : "B-S:CHANNEL NUMBER, DRIVE NUMBER, TRACK, SECTOR"        *
    ;*                                                                    *
    ;*  Then check error channel for normal errors then get one byte     *
    ;*   from the channel number. If it is a 0 then the sector is free   *
    ;*   1 indicates the sector is in use.                                *
    ;*                                                                    *
    ;*  This command was added to enable an easy method of finding out   *
    ;* if a given track or sector is currently marked as being used in   *
    ;* a drive's BAM or not.                                              *
    ;*                                                                    *
    ;*                          CBDOS CHGUTIL                             *
    ;*                                                                    *
    ;*   COMMAND             COMMENTS                  DRIVES USED ON     *
    ;* "U0>B"+chr$(n) b  = set fast/slow serial bus   1581                *
    ;* "U0>D"+chr$(n) d  = set dirsecinc              CBDOS               *
    ;* "U0>H"+chr$(n) h  = set head selection 0, 1    1571                *
    ;* "U0>M"+chr$(n) m  = set dos mode               1571                *
    ;* "U0>R"+chr$(n) r  = set dos retries on errors  1571, 1581          *
    ;* "U0>S"+chr$(n) s  = set secinc                 1571,1581,CBDOS     *
    ;* "U0>V"+chr$(n) v  = set verify oN/oFF          1581,CBDOS          *
    ;* "U0>?"+chr$(n) ?  = set device number          1571,1581,CBDOS     *
    ;* "U0>L"+chr$(n)    = set large rel files on/off CBDOS               *
    ;* "U0>MR"+ xx       = perform memory read        1581                *
    ;* "U0>MW"+ xx       = perform memory write       1581                *
    ;*  12345                                                             *
    ;*      ^--------------- CMDSIZ points to end of string starting @1*
    ;**********************************************************************
```

FLOPPY DISK CONTROLLER ERRORS

IP	FDC	DESCRIPTION
0	(0)	no error
20	(2)	can't find block header
23	(5)	checksum error in data
25	(7)	write-verify error
26	(8)	write w/ write protect on
27	(9)	crc error in header

Information description

1	files scratched
2	selected partition
3	files locked
4	files unlocked
5	files restored

Parameter errors

30	general syntax
31	invalid command
32	long line
33	invalid filname
34	no filenames given

Relative file errors

50	record not present
51	overflow in record
52	file too large
53	big relative files disabled

Open routine errors

60	file open for write
61	file not open
62	file not found
63	file exists
64	file type mismatch

Sector management errors

65	no block
66	illegal track or sector
67	illegal system t or s

General channel/block errors

02	channel selected
70	no channels available
71	bam corrupted error
72	disk full
73	cbdos v1.0
74	drive not ready
75	format error
76	controller error
77	slected partition illegal
78	directory full
79	file corrupted

3.6 C64DX RS-232 DRIVER

00A7	rs232_status	- UART status byte
00A8	rs232_flags	- open flag, xon/xoff status
		- b7: channel open (reset)
		- b6: flow control (1=x-line)
		- b5: duplex (1=half)
		- b1: XOFF received
		- b0: XOFF sent
00A9	rs232_jam	- system character to xmit
00AA	rs232_xon_char	- XON character (null=disabled)
00AB	rs232_xoff_char	- XOFF character (null=disabled)
00B0	rs232_xmit_empty	- xmit buffer empty flag (0=empty)
00B1	rs232_rcvr_buffer_lo	- lowest page of input buffer
00B2	rs232_rcvr_buffer_hi	- highest page of input buffer
00B3	rs232_xmit_buffer_lo	- lowest page of output buffer
00B4	rs232_xmit_buffer_hi	- highest page of output buffer
00B5	rs232_high_water	- point at which receiver XOFFs
00B6	rs232_low_water	- point at which receiver XONs
00C4	rs232_rcvr_head	- pointer to end of buffer
00C6	rs232_rcvr_tail	- pointer to start of buffer
00C8	rs232_xmit_head	- pointer to end of buffer
00CA	rs232_xmit_tail	- pointer to start of buffer

RS-232 interrupt-driven handler

How it works: when an RS232 channel is OPENed, buffers are flushed, all flags and states are reset, and the receiver IRQ is enabled. When a byte is put into the xmit buffer by BSOUT, the xmit IRQ is enabled. The xmit IRQ is disabled whenever the xmit buffer is found to be empty or an XOFF is received (it is enabled whenever an XON is received). CLOSE will hang until the xmit buffer is empty, and BSOUT will hang when the xmit buffer is full. IRQs must be allowed by the user at all times (and especially during BSOUT calls) for proper operation (The RS232 channel will work even if IRQs are disabled by the user, but thoughput will be reduced to the frame rate (normal system raster IRQ) and the system can hang forever should the xmit buffer become full and BSOUT is called with a byte to xmit). A sucessful CLOSE will disable all RS232 interrupts and re-init everything.

Note that DOS calls disable both IRQ and NMI interrupts while the DOS code is in context. The remote should be XOFFed to avoid loss of data.

Refer to the UART specification for register description & baud rate tables.

Open an RS-232 channel

This is different from the usual C64/C128 command string.

	1	2	3	4	5	6
Command string bytes:	baud	word	parity	stop (unused)	duplex	xline

4.0 C64DX DEVELOPMENT SUPPORT

Please photocopy the attached 'C64DX PROBLEM REPORT' and use it to report any problems.

If you have any requests or recommendations, please send a good description of it and explain why you want it.

C64DX PROBLEM REPORT	Date

Please complete this form as completely as possible and mail or express it to:

Commodore Business Machines, Inc.
1200 Wilson Drive
West Chester, PA 19380

Telephone: 215-431-9427
Fax: 215-431-9156
Email: fred@cbmvax.commodore.com

Attention: Fred Bowen, Engineering

Company Name

Company Address

Your Name

Your Phone

Your system

Serial No.________ PCB rev________ Software ver________ ROM Cksum________

4510 rev________ 4567 rev________ F011(DOS)________ F018(DMA)________

Peripherals:

Your problem

____ C64 mode
____ C64DX mode
____ Hardware
____ Software
____ Mechanical
____ Documentation
____ Compatibility

Explain problem here and show how to cause it. Attach sample program.

It happens: ____ all the time ____ frequently ____ occasionally

In your opinion, how bad is the problem?

____ Must fix, no workaround
____ I can work around it
____ Minor problem

____ Check here if you need to be contacted

Please leave this space blank

Number Received Contacted Completed

Use this space for additional comments or program listing

- * The Monitor parser now allows PETSCII input/conversion:

```
'A                      prints ASC() value of character
>1800 'text             puts text into memory
LDA #'A
```

- * IRQ runs during graphics (Kernel finds its own base page). IRQ still does not run during DOS activity (not sure if they ever will).

- * The following Kernel Jump Table Entries have moved (and are still subject to further changes):

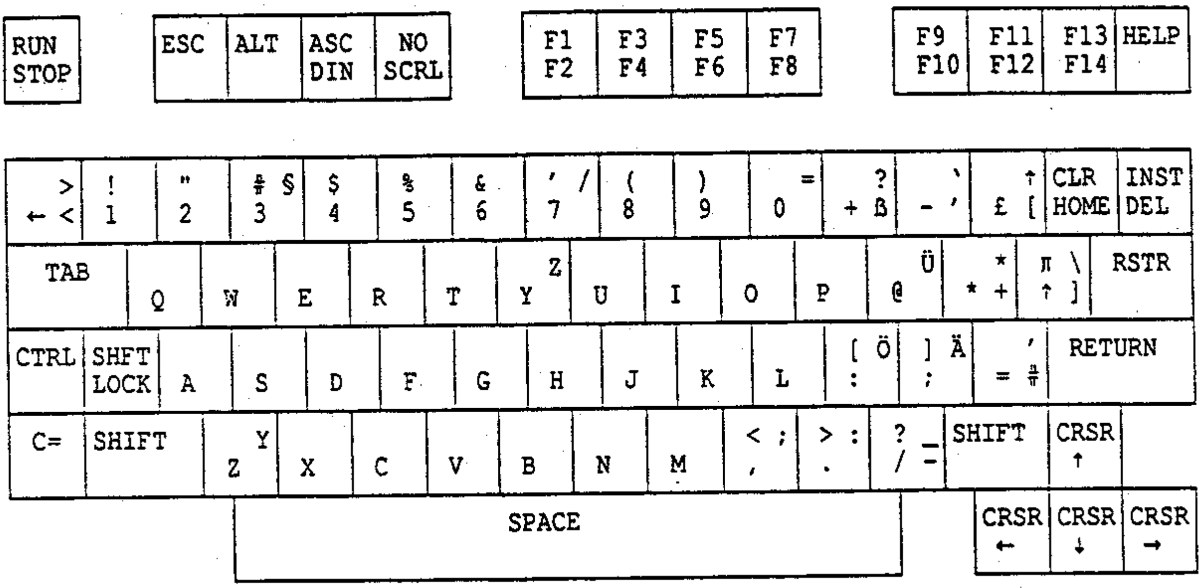
```
FF05    nirq             ;IRQ handler
FF07    monitor_brk      ;BRK handler (Monitor)
FF09    nnmi             ;NMI handler
FF0B    nopen            ;open
FF0D    nclose           ;close
FF0F    nchkin           ;chkin
FF11    nckout           ;ckout
FF13    nclrch           ;clrch
FF15    nbasin           ;basin
FF17    nbsout           ;bsout
FF19    nstop            ;stop key scan
FF1B    ngetin           ;getin
FF1D    nclall           ;clall
FF1F    monitor_parser   ;monitor command parser
FF21    nload            ;load
FF23    nsave            ;save

FF25    talk
FF27    listen
FF29    talksa
FF2B    second
FF2D    acptr
FF2F    ciout
FF31    untalk
FF33    unlisten

FF35    DOS_talk
FF37    DOS_listen
FF39    DOS_talksa
FF3B    DOS_second
FF3D    DOS_acptr
FF3F    DOS_ciout
FF41    DOS_untalk
FF43    DOS_unlisten

FF45    Get_DOS
FF47    Leave_DOS
FF49    ColdStartDOS             <<< new
FF4B    WarmStartDOS             <<< new
```

2.1.2 German/Austrian Keyboard Layout



Notes:

1/ The operation of national keyboards is identical to C128 implementation. The ASCII/DIN key replaces the CAPS LOCK key, and can be toggled anytime to switch keyboard modes and automatically change the display.

2/ The national keyboard contains key legends for both national and ASCII modes. The national legends appear on the right top/bottom of the keys.

3/ The German keyboard has three (3) "deadkeys." They are accent d'aigue, accent grave, and accent circonflex. Pressing the "deadkey" followed by a valid vowel or accent character will 'build' the desired character:

accent d'aigue:	é
accent grave:	à, è, ù
accent circonflex:	â, ê, î, ô, û

4/ National character ROM graphic characters differ from the C64 and ASCII (English) graphic character sets.

PAINT x, y [,color]	Working, but not completely to spec. Uses draw pen color and fills emptyness to any border.
RND(0)	Improved for better "randomness". Uses unused POT of second SID chip. PCB must allow lines to float.
SET DISK #	(without [TO #] parameter) allows user to clear DS$ message and specify which drive next DS$ comes from.
SET VERIFY <ON|OFF>	The new DOS65 defaults to verify-after-write OFF. This command works with 1581 drive, too.

* Negative Coordinates are now allowed for all graphics commands. Some commands require their arguments to be "onscreen", such as PAINT.

* BASIC errors now force text mode, and TYPE, LIST, DISK, KEYLOAD, LOADIFF now catch all DOS errors. Autoboot filename= AUTOBOOT.C64DX.*

* Opening an RS-232 channel, command string allows setting new features:

1	baud (0-16, where 16=MIDI rate)
2	word len
3	parity
4	stop bits (not used)
5	duplex
6	xline
7	xon char (0=incoming flow control disabled)
8	xoff char (0=outgoing flow control disabled)
9,10	input buffer pointer (page lo, hi)
11,12	output buffer pointer (page lo, hi)
13	high water mark (point at which xoff is xmitted)
14	low water mark (point at which xon is xmitted)

For debug purposes, the border color will change if an RS232 buffer overflow occurs. To differentiate between a GET# of a null and a 'no data' null, test bit 3 of STatus (same as C64).

* Support for latest DOS controller chip, F011D, includes error LED blink (border color still changes too, for now). Changes to improve FASTLOAD speed and improve SAVE speed. Will work with F011C chip, but error LED does not blink. Requires latest 'ELMER' PAL for disk LED to work correctly for either controller chip. External drive LED will not work correctly until new PCB & F016 chip are designed. New DOS functions include COPY D0 TO D1, ability to change sector skews for files (U0>S#) and directory (U0>D#), and directory compress (i.e., empty trash) via "E" command. Physical interleave is now 7.

* The DOS COPY/CONCAT bugs have been fixed, and COPY now allows forms such as COPY D0,"*.SRC" TO D1,"*" and COPY D0,"*=SEQ" TO D1,"*". Directory/partition paths not yet implemented, but will be.

C64DX System Specification UPDATE

F.BOWEN 5/1/91

The following changes/updates/fixes have been made to the C64DX ROM code since the March 1, 1991 C64DX System Specification was printed. Please make note of them. Current ROM as of this update is 910501.

CHAR — Now works to spec and supports the following imbedded control characters (although some are buggy; others are planned):

^F	6	flip
^I	9	invert
^O	15	overwrite
^R	18	reverse field on
	146	reverse field off
^U	21	underline
^Y	25	tilt
^Z	26	mirror

When specifying a character set from ROM, note that national versions of the C64DX will have the national character set at $39000 and the C64 character set at $3D000. In US/English systems, the default C64DX-mode character set will be at $39000.

CLR ERR$ — Clears BASIC error stuff, useful after a TRAP

CURSOR [<ON|OFF>,] [column] [,row] [,style]

where: column,row = x,y logical screen position
style = flashing (0) or solid (1)
ON,OFF = to turn the cursor on or off

LINE x0, y0 [,[x1] [,y1]]...

where: (x1,y1)=(x0,y0) if not specified, drawing a dot. Additional coordinates (x2,y2), etc. draw a line from the previous point.

LOADIFF "file" [,U#,D#]

Loads an IFF picture from disk. Requires a suitable graphic screen to be already opened (this may change). The file must contain std IFF data in PRG file type. IFF pics can be ported directly from Amiga (eg., using XMODEM). Returns 'File Data Error' if it finds data it does not like.

MOD (number, modulus)

New function.

MOUSE ON [,[port] [,[sprite] [,[hotspot] [,X/Yposition]]]]
MOUSE OFF

where: port = (1...3) for joyport 1, 2, or either (both)
sprite = (0...7) sprite pointer
hotspot = x,y offset in sprite, default 0,0
position = normal, relative, or angluar coordinates

Defaults to sprite 0, port 2, last hotspot (0,0), and position. Kernel doesn't let hotspot leave the screen.