Commander X16 Reference Manual

This is the official Commander X16 reference manual.

Being a reference manual it is light on some details with some expected fundamental knowledge. If you are brand new to the X16, consider consulting the User Guide first.

Chapters

External Links

- Official Website
- Documentation Source
- User Guide Source

Chapter 1: Overview

The Commander X16 is a modern home computer in the philosophy of Commodore computers like the VIC-20 and the C64.

Features:

- 8-bit 65C02S CPU at 8 MHz (*)
- 512 KB banked RAM (upgradeable to 2 MB on the X16 Developer Edition)
- 512 KB ROM
- Expansion Cards (Gen 1) & Cartridges (Gen 1 and Gen 2)
  - Up to 3.5MB of RAM/ROM
  - 5 32-byte Memory-Mapped IO slots
- VERA video controller
  - Up to 640x480 resolution
  - 256 colors from a palette of 4096
  - 128 sprites
  - VGA, NTSC and RGB output
  - Powered by a Lattice ICE40UP5K FPGA
- Three sound sources
  - Yamaha YM2151: 8 channels, 4-operator FM synthesis
  - VERA PSG: 16 channels, 4 waveforms
  - VERA PCM: Up to 48 kHz, 16 bit, stereo
- Connectivity:
  - PS/2 keyboard and mouse
  - 4 NES/SNES controllers
  - SD card
  - Commodore Serial Bus ("IEC")
  - Many Free GPIOs ("user port")

As a modern sibling of the line of Commodore home computers, the Commander X16 is reasonably compatible with computers of that line.

- Pure BASIC programs are fully backwards compatible with the VIC-20 and the C64.
- POKEs for video and audio are not compatible with any Commodore computer. (There are no VIC or SID chips, for example.)
- Pure machine language programs ($FF81+ KERNAL API) are compatible with Commodore computers.

Future 65C816 Support

A future upgrade path for the X16 may involve the 65C816. It is almost fully compatible with the 65C02 except for 4 instructions (`BBRx` , `BBSx` , `RMBx` , and `SMBx`). It is advisable not to use these instructions when writing programs for the X16.

Chapter 2: Getting Started

This is a brief guide to your first few minutes on the Commander X16. For a complete New User experience, please refer to the Commander X16 User Guide .

Finding and starting programs

When starting your Commander X16, you'll notice that it's not like other computers. There is no GUI, and command line commands like `DIR` or `LS` don't get you anywhere. Here are some quick tips to getting started:

The Commander X16 uses a full screen interface known as "Editor". This was unique when it was introduced on the PET in 1977, when most computers still treated the screen as if it was a teletype display. The full screen Editor lets you use the arrow keys to move around the screen and edit or re-enter input from previous interactions.

The first thing you will want to do is view a list of files on your SD card. Type the below command and press the Return key (or Enter key) to see a list of files:

DOS

```
DOS "$"
```

You can also type `@$` and press Return. All of the commands you type must be followed by the Return or Enter key, to actually execute the command.

Let's try some variations on this command:

`DOS "$=D"` lists just the subdirectories in the current directory.

To get the DOS command a little faster, try pressing F8, then typing `$=D` . You can even leave off the last quote; DOS doesn't care.

So now that you have a list of directories, try moving to one:

```
DOS "CD:BASIC"
```

Press F7 or type `DOS"$` again to list the files in this directory. A file with .PRG at the end is a "Program" file and can be loaded with the LOAD command. The shortcut for LOAD" is the F3 key. Try it now:

LOAD

```
LOAD "MAD.PRG"
```

You can see that the program list loaded by typing `LIST` and pressing Enter.

RUN

Now type `RUN` and Enter. This will start the loaded program.

STOP

STOP isn't a command: it's a key. Press it to stop the running program.

If you are using the official Commander X16 keyboard, the key is labeled `RUN STOP` and is up near the upper right corner of the keyboard.

If you are using a PC keyboard, it's probably labeled `Pause` or `Pause Brk` .

Holding Control and pressing C (also written as `Control+C` or `^C`) will also stop the running program.

There are a few ways to get back to the text screen, but the quickest is to hold Control, Alt, and press the Del key. (Or just press the RESET button.)

Using The Keyboard

The Commander X16's keyboard is a little different than a standard PC: there are three distinct modes of operation, and the keyboard can create graphic symbols known as PETSCII characters. There are also some special keys used for controlling the computer.

PETSCII Characters

When the system first boots up, the X16 will be in PETSCII Upper Case/Graphic mode. Pressing a letter key without the shift key will generate an upper case letter. Unlike a PC or Mac, this mode does not have any lower case text, so everything you type is UPPER CASE.

Now, notice the extra symbols on your keycaps? There are two sets of extra symbols: the ones on the lower-right can be accessed by holding SHIFT and a letter. Go ahead: try pressing Shift and S. You should see a small heart symbol on your screen. We know you'll love the Commander X16 as much as we do. Press Alt and a letter, and you'll get the symbol on the lower-left corner of the screen. Try pressing Alt and the ` key next to the nummber 1. You should get a large + symbol. One of the Plusses of PETSCII is using these line drawing symbols to draw shapes on the screen.

You can also change colors by pressing Control and a number. Go ahead: Press Control+1 and type a few letters. Notice they come out in black. Now try Alt+1. Notice the cursor changes to orange, and notice the next thing you type comes out orange.

You can also use Control+9 to turn on Reverse Print and Control+0 to turn it off.

There are some unexpected changes to the PC keyboard layout, as follows:

- The Grave key (`) prints a left arrow (←) symbol.
- Shift+Grave prints the Pi symbol (π). This is actually the constant "pi". Try it by typing `PRINT π` and RETURN.
- Shift+6 prints an up arrow (↑)
- The \ key prints the British Pound (£).
- The pipe (|) is replaced with a triangle corner symbol.
- { and } are replaced with two box drawing symbols.
- Underline (Shift+-) is replaced with a | symbol.

Note that programming languages that need {, }, and _ will alter the character set to show those symbols on the appropriate keys when needed. Or you can use ISO mode when editing C code in EDIT.

Lower Case Mode

WORKING IN *PETSCII* MIGHT MAKE PEOPLE THINK YOU'RE YELLING ALL THE TIME. Fortunately, there's an upper/lower case mode, too: Hold the Alt key and tap Shift to activate lower case. Notice that the upper case letters shift to lower case, and the shifted graphic symbols (such as the heart) shift to upper case letters. The tradeoff of upper/lower case mode is that half of the graphic symbols are unavailable, but you you get lower case letters.

Now try typing a command. `print "Hello World"` and press RETURN. Notice that you need to type `print` in lower case. If you did it right, you should see "Hello World" appear on the next line.

Now tap Alt+Shift again. The text will change to |ELLO oORLD. Again, this is the tradeoff: you can have the Shifted graphic symbols or lower case, but not both.

ISO Mode

Finally, the computer has ISO mode. The ISO mode character set operates more like a PC, with upper case text, lower case text, and an assortment of accented and other letters. In addition, ISO mode has the , ~, {, and } symbols, which are not available in PETSCII modes. ISO mode is useful when you need PC compatibility or want the letters with accents. Elsewhere in this guide, we have a full manual on using the Right Alt key to compose accented symbols, like é or ō. Getting back to PETSCII mode from ISO mode is a little more complicated. Press Control+Alt+RESTORE (or Control+Alt+PrintScreen) to warm start BASIC and switch back to PETSCII mode.

EDIT text modes

The built-in EDIT utility includes a character set mode switch: Press Control+E to cycle through Upper/Graphic, Upper/Lower, and ISO mode.

Special Keys

RUN STOP

This key actually has two separate functions: "RUN" and "STOP". Holding Shift+RUN will load the first program on your SD card and automatically run it. If you are using the SD card that came with your Commander X16, this will print some information on getting started with your computer.

If you are running a BASIC program, pressing STOP will stop the program.

RESTORE

As mentioned above, RESTORE can be used with Control+Alt to perform a warm start of BASIC. Less drastic than a cold boot, this stops a running program and returns you to the `READY.` prompt. If you had a BASIC program loaded, you can still re-start it with RUN or view it with LIST.

Control+Alt_Delete

Yes, the Commander X16 has the famous "3 fingered salute." This performs a cold boot of the computer, including a full power cycle. You will be returned to the boot screen, and if you have an AUTOEXEC.X16, it will execute on startup.

40/80 DISPLAY

This switches the computer between 80x60 text mode and 40x30 text mode. 40x30 is more useful on CRT screens, so you may want to boot up into 40x30 mode. You can set these modes with BASIC by typing

`SCREEN 1` or `SCREEN 3`.

Protip: you can force your computer to start in 40-column mode by modifying your AUTOBOOT.X16 file:

```
LOAD "AUTOBOOT.X16"
0 SCREEN 3
SAVE "@:AUTOBOOT.X16"
BOOT
```

Don't worry, if you don't like this change, you can change it back:

```
LOAD "AUTOBOOT.X16"
SCREEN 1
SAVE "@:AUTOBOOT.X16"
BOOT
```

F-KEYS

The F-keys, also known as the "Function Keys" are pre-loaded with special shortcuts:

F1 `LIST` Displays your currently loaded BASIC program.

F2 `SAVE"@:` is a quick shortcut for saving a program. The @: allows you to overwrite an existing file with the same name.

F3 `LOAD "` helps you load a program. Protip: if you use @$ to get a directory listing, you can then use the arrow keys to move up to a line with a filename. Press F3 and press RETURN to load a file.

F4 and RETURN swaps between 40 and 80 column screen modes.

F5 `RUN` runs the currently loaded program

F6 `MONITOR` Runs the machine monitor. The monitor allows you to directly edit memory, view assembly language dumps, and even write short assembly language programs at your keyboard.

F7 `DOS"$` Lists the current directory

F8 `DOS"` allows you to enter a disk command, such as CD:. More info can be found in chapter 13.

WHAT IS `PC RA RO AC XR YR SP NV#BDIZC`?

There are times when the computer will drop to the MONITOR prompt. That looks like this:

```
C*
   PC  RA RO AC XR YR SP NV#BDIZC
.;E3BB 01 04 00 65 2B F6 ........
.
```

This is the MONITOR screen. You can get there in BASIC by typing `MON`.

Type `X` and Enter to exit back to BASIC. If you just get bounced to MONITOR again, then you'll need to Control+Alt+Restore or Control+Alt+Delete to restore to a working state.

MONITOR is covered in Chapter 7.

Chapter 3: Editor

The X16 has a built-in screen editor that is backwards-compatible with the C64, but has many new features.

Modes

The editor's default mode is 80x60 text mode. The following text mode resolutions are supported:

Mode	Description
$00	80x60 text
$01	80x30 text
$02	40x60 text
$03	40x30 text
$04	40x15 text
$05	20x30 text
$06	20x15 text
$07	22x23 text
$08	64x50 text
$09	64x25 text
$0A	32x50 text
$0B	32x25 text
$80	320x240@256c 40x30 text

Mode $80 contains two layers: a text layer on top of a graphics screen. In this mode, text color 0 is translucent instead of black.

To switch modes, use the BASIC statement `SCREEN` or the KERNAL API `screen_mode`. In the BASIC editor, the F4 key toggles between modes 0 (80x60) and 3 (40x30).

ISO Mode

In addition to PETSCII, the X16 also supports the ISO-8859-15 character encoding. In ISO-8859-15 mode ("ISO mode"):

- The character set is switched from Commodore-style (with PETSCII drawing characters) to a new ASCII/ISO-8859-15 compatible set, which covers most Western European writing systems.
- The encoding (`CHR$()` in BASIC and `BSOUT` in machine language) now complies with ASCII and ISO-8859-15.
- The keyboard driver will return ASCII/ISO-8859-15 codes.

This is the encoding:

	x0	x1	x2	x3	x4	x5	x6	x7	x8	x9	xA	xB	xC	xD	xE	xF
0x																
1x																
2x		!	"	#	$	%	&	'	(	)	*	+	,	-	.	/
3x	0	1	2	3	4	5	6	7	8	9	:	;	<	=	>	?
4x	@	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
5x	P	Q	R	S	T	U	V	W	X	Y	Z	[	\	]	^	_
6x	`	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o
7x	p	q	r	s	t	u	v	w	x	y	z	{	|	}	~	
8x																
9x																
Ax		¡	¢	£	€	¥	Š	§	š	©	ª	«	¬	🦋	®	¯
Bx	°	±	²	³	Ž	µ	¶	·	ž	¹	º	»	Œ	œ	Ÿ	¿
Cx	À	Á	Â	Ã	Ä	Å	Æ	Ç	È	É	Ê	Ë	Ì	Í	Î	Ï
Dx	Ð	Ñ	Ò	Ó	Ô	Õ	Ö	×	Ø	Ù	Ú	Û	Ü	Ý	Þ	ß
Ex	à	á	â	ã	ä	å	æ	ç	è	é	ê	ë	ì	í	î	ï
Fx	ð	ñ	ò	ó	ô	õ	ö	÷	ø	ù	ú	û	ü	ý	þ	ÿ

- The non-printable areas $00-$1F and $80-$9F in the character set are filled with inverted variants of the codes $40-$5F and $60-$7F, respectively.
- The code $AD is a non-printable soft hyphen in ISO-8859-15. The ROM character set contains the Commander X16 logo at this location.

ISO mode can be enabled and disabled using two new control codes:

- `CHR$($0F)` : enable ISO mode
- `CHR$($8F)` : enable PETSCII mode (default)

You can also enable ISO mode in direct mode by pressing Ctrl+ `0` .

Important: In ISO mode, BASIC keywords need to be written in upper case, that is, they have to be entered with the Shift key down, and abbreviating keywords is no longer possible.

Background Color

In regular BASIC text mode, the video controller supports 16 foreground colors and 16 background colors for each character on the screen.

The new "swap fg/bg color" code is useful to change the background color of the cursor, like this:

```
PRINT CHR$(1);   : REM SWAP FG/BG
PRINT CHR$($1C); : REM SET FG COLOR TO RED
PRINT CHR$(1);   : REM SWAP FG/BG
```

The new BASIC instruction `COLOR` makes this easier, but the trick above can also be used from machine code programs.

To set the background color of the complete screen, it just has to be cleared after setting the color:

```
PRINT CHR$(147);
```

Scrolling

The C64 editor could only scroll the screen up (when overflowing the last line or printing or entering DOWN on the last line). The X16 editor scrolls both ways: When the cursor is on the first line and UP is printed or entered, the screen contents scroll down by a line.

New Control Characters

This is the set of all supported PETSCII control characters. Entries in bold indicate new codes compared to the C64:

If there are two meanings listed, the first indicates input (a keypress) and the second indicates output.

Code			Code
$00	NULL	**VERBATIM MODE**	$80
$01	**SWAP COLORS**	COLOR: ORANGE	$81
$02	**PAGE DOWN**	**PAGE UP**	$82
$03	STOP	RUN	$83
$04	**END**	**HELP**	$84
$05	COLOR: WHITE	F1	$85
$06	**MENU**	F3	$86
$07	**BELL**	F5	$87
$08	DISALLOW CHARSET SW (SHIFT+ALT)	F7	$88
$09	**TAB** / ALLOW CHARSET SW	F2	$89
$0A	**LF**	F4	$8A
$0B	-	F6	$8B
$0C	-	F8	$8C
$0D	RETURN	SHIFTED RETURN	$8D
$0E	CHARSET: LOWER/UPPER	CHARSET: UPPER/PETSCII	$8E
$0F	**CHARSET: ISO ON**	**CHARSET: ISO OFF**	$8F
$10	**F9**	COLOR: BLACK	$90
$11	CURSOR: DOWN	CURSOR: UP	$91
$12	REVERSE ON	REVERSE OFF	$92
$13	HOME	CLEAR	$93
$14	DEL (PS/2 BACKSPACE)	INSERT	$94
$15	**F10**	COLOR: BROWN	$95
$16	**F11**	COLOR: LIGHT RED	$96
$17	**F12**	COLOR: DARK GRAY	$97
$18	**SHIFT+TAB**	COLOR: MIDDLE GRAY	$98
$19	**FWD DEL (PS/2 DEL)**	COLOR: LIGHT GREEN	$99
$1A	-	COLOR: LIGHT BLUE	$9A

$1B	ESC	COLOR: LIGHT GRAY	$9B
$1C	COLOR: RED	COLOR: PURPLE	$9C
$1D	CURSOR: RIGHT	CURSOR: LEFT	$9D
$1E	COLOR: GREEN	COLOR: YELLOW	$9E
$1F	COLOR: BLUE	COLOR: CYAN	$9F

Notes:

- $01: SWAP COLORS swaps the foreground and background colors in text mode
- $07/$09/$0A/$18/$1B: have been added for ASCII compatibility. *[$0A/$18/$1B do not have any effect on output. Outputs of $08/$09 have their traditional C64 effect]*
- $80: VERBATIM MODE prints the next character (only!) as a glyph without interpretation. This is similar to quote mode, but also includes codes CR ($0D) and DEL ($14).
- F9-F12: these codes match the C65 additions
- $84: This code is generated when pressing SHIFT+END.
- Additionally, the codes $04/$06/$0B/$0C are interpreted when printing in graphics mode using `GRAPH_put_char`.

Keyboard Layouts

The editor supports multiple keyboard layouts.

Default Layout

On boot, the US layout (`ABC/X16`) is active:

- In PETSCII mode, it matches the US layout where possible, and can reach all PETSCII symbols.
- In ISO mode, it matches the Macintosh US keyboard and can reach all ISO-8859-15 characters. Some characters are reachable through key combinations:

Key	Result
Alt+1	¡
Alt+3	£
Alt+4	¢
Alt+5	§
Alt+7	¶
Alt+9	ª
Alt+0	º
Alt+q	œ
Alt+r	®
Alt+t	Þ
Alt+y	¥
Alt+o	ø
Alt+\	«
Alt+s	ß
Alt+d	ð
Alt+g	©
Alt+l	¬
Alt+'	æ
Alt+m	µ
Alt+/	÷
Shift+Alt+2	€
Shift+Alt+8	°
Shift+Alt+9	·
Shift+Alt+-	X16 logo
Shift+Alt+=	±
Shift+Alt+q	Œ
Shift+Alt+t	þ
Shift+Alt+\	»
Shift+Alt+a	¹

Shift+Alt+`d`	Đ
Shift+Alt+`k`	X16 logo
Shift+Alt+`'`	Æ
Shift+Alt+`c`	³
Shift+Alt+`b`	²
Shift+Alt+`/`	¿

(The X16 logo is code point \xad, SHY, soft-hyphen.)

The following combinations are dead keys:

- Alt+`` ` ``
- Alt+ `6`
- Alt+ `e`
- Alt+ `u`
- Alt+ `p`
- Alt+ `a`
- Alt+ `k`
- Alt+ `;`
- Alt+ `x`
- Alt+ `c`
- Alt+ `v`
- Alt+ `n`
- Alt+ `,`
- Alt+ `.`
- Shift+Alt+ `S`

They generate additional characters when combined with a second keypress:

First Key	Second Key	Result
Alt+`` ` ``	`a`	à
Alt+`` ` ``	`e`	è
Alt+`` ` ``	`i`	ì
Alt+`` ` ``	`o`	ò
Alt+`` ` ``	`u`	ù
Alt+`` ` ``	`A`	À
Alt+`` ` ``	`E`	È
Alt+`` ` ``	`I`	Ì
Alt+`` ` ``	`O`	Ò
Alt+`` ` ``	`U`	Ù
Alt+`` ` ``	`␣`	`` ` ``
Alt+`6`	`e`	ê
Alt+`6`	`u`	û
Alt+`6`	`i`	î
Alt+`6`	`o`	ô
Alt+`6`	`a`	â
Alt+`6`	`E`	Ê

Alt+6	U	Û
Alt+6	I	Î
Alt+6	O	Ô
Alt+6	A	Â
Alt+e	e	é
Alt+e	y	ý
Alt+e	u	ú
Alt+e	i	í
Alt+e	o	ó
Alt+e	a	á
Alt+e	E	É
Alt+e	Y	Ý
Alt+e	U	Ú
Alt+e	I	Í
Alt+e	O	Ó
Alt+e	A	Á
Alt+u	e	ë
Alt+u	y	ÿ
Alt+u	u	ü
Alt+u	i	ï
Alt+u	o	ö
Alt+u	a	ä
Alt+u	E	Ë
Alt+u	Y	Ÿ
Alt+u	U	Ü
Alt+u	I	Ï
Alt+u	O	Ö
Alt+u	A	Ä
Alt+p	␣	¸
Alt+a	␣	˙
Alt+k	a	å
Alt+k	A	Å
Alt+x	␣	.
Alt+c	c	ç
Alt+c	C	Ç
Alt+v	s	š
Alt+v	z	ž

Alt+v	s	Š
Alt+v	z	Ž
Alt+n	o	õ
Alt+n	a	ã
Alt+n	n	ñ
Alt+n	O	Õ
Alt+n	A	Ã
Alt+n	N	Ñ
Shift+Alt+s	␣	\xa0
Shift+Alt+;	=	×

"␣" denotes the space bar.

ROM Keyboard Layouts

The following keyboard layouts are available from ROM. You can select one directly with the BASIC `KEYMAP` command, e.g. `KEYMAP"ABC/X16"`, or via the X16 Control Panel with the BASIC `MENU` command.

Identifier	Description	Code
ABC/X16	ABC - Extended (X16)	-
EN-US/INT	United States - International	00020409
EN-GB	United Kingdom	00000809
SV-SE	Swedish	0000041D
DE-DE	German	00000407
DA-DK	Danish	00000406
IT-IT	Italian	00000410
PL-PL	Polish (Programmers)	00000415
NB-NO	Norwegian	00000414
HU-HU	Hungarian	0000040E
ES-ES	Spanish	0000040A
FI-FI	Finnish	0000040B
PT-BR	Portuguese (Brazil ABNT)	00000416
CS-CZ	Czech	00000405
JA-JP	Japanese	00000411
FR-FR	French	0000040C
DE-CH	Swiss German	00000807
EN-US/DVO	United States - Dvorak	00010409
ET-EE	Estonian	00000425
FR-BE	Belgian French	0000080C
EN-CA	Canadian French	00001009
IS-IS	Icelandic	0000040F

PT-PT	Portuguese	00000816
HR-HR	Croatian	0000041A
SK-SK	Slovak	0000041B
SL-SI	Slovenian	00000424
LV-LV	Latvian	00000426
LT-LT	Lithuanian IBM	00000427

All remaining keyboards are based on the respective Windows layouts. `EN-US/INT` differs from `EN-US` only in Alt/AltGr combinations and some dead keys.

The BASIC command `KEYMAP` allows activating a specific keyboard layout. It can be added to the auto-boot file, e.g.:

```
10 KEYMAP"NB-NO"
SAVE"AUTOBOOT.X16
```

Loadable Keyboard Layouts

The tables for the active keyboard layout reside in banked RAM, at $A000 on bank 0:

Addresses	Description
$A000-$A07F	Table 0
$A080-$A0FF	Table 1
$A100-$A17F	Table 2
$A180-$A1FF	Table 3
$A200-$A27F	Table 4
$A280-$A07F	Table 5
$A300-$A37F	Table 6
$A380-$A3FF	Table 7
$A400-$A47F	Table 8
$A480-$A4FF	Table 9
$A500-$A57F	Table 10
$A580-$A58F	big-endian bitfield: keynum codes for which Caps means Shift
$A590-$A66F	dead key table
$A670-$A67E	ASCIIZ identifier (e.g. "ABC/X16")

The first byte of each of the 11 tables is the table ID which contains the encoding and the combination of modifiers that this table is for.

Bit	Description
7	0: PETSCII, 1: ISO
6-3	always 0
2	Ctrl
1	Alt
0	Shift

- AltGr is represented by Ctrl+Alt.

- ID $C6 represents Alt *or* AltGr (ISO only)
- ID $C7 represents Shift+Alt *or* Shift+AltGr (ISO only)
- Empty tables have an ID of $FF.

The identifier is followed by 127 output codes for the keynum inputs 1-127.

- Dead keys (i.e. keys that don't generate anything by themselves but modify the next key) have a code of 0 and are further described in the dead key table (ISO only)
- Keys that produce nothing have an entry of 0. (They can be distinguished from dead keys as they don't have an entry in the dead key table.)

The dead key table has one section for every dead key with the following layout:

Byte	Description
0	dead key ID (PETSCII/ISO and Shift/Alt/Ctrl)
1	dead key scancode
2	full length of this table in bytes
3	first additional key ISO code
4	first effective key ISO code
5	second additional key ISO code
6	second effective key ISO code
...	...
n-1	terminator 0xFF

Custom layouts can be loaded from disk like this:

```
BLOAD"KEYMAP",8,0,$A000
```

Here is an example that activates a layout derived from "ABC/X16", with unshifted Y and Z swapped in PETSCII mode:

```
100 KEYMAP"ABC/X16"                                :REM START WITH DEFAULT LAYOUT
110 BANK 0                                         :REM ACTIVATE RAM BANK 0
120 FORI=0TO11:B=$A000+128*I:IFPEEK(B)<>0THENNEXT :REM SEARCH FOR TABLE $00
130 POKEB+$2E,ASC("Y")                             :REM SET KEYNUM $2E ('Z') to 'Y'
140 POKEB+$16,ASC("Z")                             :REM SET KEYNUM $16 ('Y') to 'Z'
170 REM
180 REM *** DOING THE SAME FOR SHIFTED CHARACTERS
190 REM *** IS LEFT AS AN EXERCISE TO THE READER
```

Custom BASIN PETSCII code override handler

Note: This is a new feature in R44

Some use cases of the BASIN (CHRIN) API call may benefit from being able to modify its behavior, such as intercepting or redirecting certain PETSCII codes. The Machine Language Monitor uses this mechanism to implement custom behavior for F-keys and for loading additional disassembly or memory display when scrolling the screen.

To set up a custom handler, one must configure it before each call to BASIN.

The key handler vector is in RAM bank 0 at addresses $ac03-$ac05. The first two bytes are the call address, and the next byte is the RAM or ROM bank. If your callback routine is in low ram, specifying the bank in $ac05 is not necessary.

The editor will call your callback for every keystroke received and pass the PETSCII code in the A register with carry set. If your handler does not want to override, simply return with carry set.

If you do wish to override, return with carry clear. The editor will then unblink the cursor and call your callback a second time with carry clear *for the same PETSCII code*. This is your opportunity to override. Before returning, you are free to update the screen or perform other KERNAL API calls (with the exception of BASIN). At the end of your routine, set `A` to the PETSCII code you wish the editor to process. If you wish to suppress the input keystroke, set `A` to `0`.

```
ram_bank = $00
edkeyvec = $ac03
edkeybk  = $ac05

BASIN    = $ffcf
BSOUT    = $ffd2

.segment "ONCE"
.segment "STARTUP"
    jmp start
.segment "CODE"

keyhandler:
    bcs @check
    cmp #$54 ; 'T'
    bne :+
    lda #$57 ; 'W'
    rts
:   lda #$54 ; 'T'
    rts
@check:
    cmp #$54 ; 'T'
    beq @will_override
    cmp #$57 ; 'W'
    beq @will_override
    sec
    rts
@will_override:
    clc
    rts

enable_basin_callback:
    lda ram_bank
    pha
    stz ram_bank ; RAM bank 0 contains the handler vector
    php
    sei
    lda #<keyhandler
    sta edkeyvec
    lda #>keyhandler
    sta edkeyvec+1
    ; setting the bank is optional and unnecessary
    ; if the handler is in low RAM.
    ; lda #0
    ; sta edkeybk
    plp
    pla
    sta ram_bank
    rts

start:
    jsr enable_basin_callback
    ; T and W are swapped
@1: jsr BASIN
    cmp #13
    bne @1
    jsr BSOUT
    ; normal BASIN
@2: jsr BASIN
    cmp #13
    bne @2
```

```
    rts
```

Custom Keyboard Keynum Code Handler

Note: This is new behavior for R43, differing from previous releases.

If you need more control over the translation of keynum codes into PETSCII/ISO codes, or if you need to intercept any key down or up event, you can hook the custom scancode handler vector at $032E/$032F.

On all key down and key up events, the keyboard driver calls this vector with

- .A: keycode, where bit 7 (most-significant) is clear on key down, and set on key up.

The keynum codes are enumerated here , and their names, similar to that of PS/2 codes, are based on their function in the US layout.

The handler needs to return a key event the same way in .A

- To remove a keypress so that it is not added to the keyboard queue, return .A = 0.
- To manually add a key to the keyboard queue, use the `kbdbuf_put` KERNAL API.

You can even write a completely custom keyboard translation layer:

- Place the code at $A000-$A58F in RAM bank 0. This is safe, since the tables won't be used in this case, and the active RAM bank will be set to 0 before entry to the handler.
- Fill the locale at $A590.
- For every keynum that should produce a PETSCII/ISO code, use `kbdbuf_put` to store it in the keyboard buffer.
- Always set .A = 0 before return from the custom handler.

```
;EXAMPLE: A custom handler that prints "A" on Alt key down

setup:
    sei
    lda #<keyhandler
    sta $032e
    lda #>keyhandler
    sta $032f
    cli
    rts

keyhandler:
    pha

    and #$ff    ;ensure A sets flags
    bmi exit    ;A & 0x80 is key up

    cmp #$3c    ;Left Alt keynum
    bne exit

    lda #'a'
    jsr $ffd2

exit:
    pla
    rts
```

Function Key Shortcuts

The following Function key macros are pre-defined for your convenience. These shortcuts only work in the screen editor. When a program is running, the F-keys generate the corresponding PETSCII character code.

Key	Function	Comment
F1	`LIST:`	Lists the current program
F2	`SAVE"@:`	Press F2 and then type a filename to save your program. The `@:` instructs DOS to allow overwrite.

F3	`LOAD "`	Load a file directly, or cursor up over a file listing and press F3 to load a program.
F4	40/80	Toggles between 40 and 80 column screen modes, clearing the screen. Pressing return is required to prevent accidental mode switches.
F5	`RUN:`	Run the current program.
F6	`MONITOR`	Opens the Supermon machine language monitor.
F7	`DOS"$<cr>`	Displays a directory listing.
F8	`DOS"`	Issue DOS commands.
F9	-	Not defined. Formerly cycled through keyboard layouts. Instead, use the `MENU` command to enter the X16 Control Panel, select one, and optionally save the layout as a boot preference.
F10	-	Not defined
F11	-	Not defined
F12	debug	debug features in emulators

Chapter 4: BASIC Programming

Table of BASIC statements and functions

Keyword	Type	Summary	Origin
ABS	function	Returns absolute value of a number	C64
AND	operator	Returns boolean "AND" or bitwise intersection	C64
ASC	function	Returns numeric PETSCII value from string	C64
ATN	function	Returns arctangent of a number	C64
BANK	command	Sets the RAM and ROM banks to use for PEEK, POKE, and SYS	C128
BIN$	function	Converts numeric to a binary string	X16
BINPUT#	command	Reads a fixed-length block of data from an open file	X16
BLOAD	command	Loads a headerless binary file from disk to a memory address	X16
BOOT	command	Loads and runs AUTOBOOT.X16	X16
BSAVE	command	Saves a headerless copy of a range of memory to a file	X16
BVERIFY	command	Verifies that a file on disk matches RAM contents	X16
BVLOAD	command	Loads a headerless binary file from disk to VRAM	X16
CHAR	command	Draws a text string in graphics mode	X16
CHR$	function	Returns PETSCII character from numeric value	C64
CLOSE	command	Closes a logical file number	C64
CLR	command	Clears BASIC variable state	C64
CLS	command	Clears the screen	X16
CMD	command	Redirects output to non-screen device	C64
CONT	command	Resumes execution of a BASIC program	C64
COLOR	command	Sets text fg and bg color	X16
COS	function	Returns cosine of an angle in radians	C64
DA$	variable	Returns the date in YYYYMMDD format from the system clock	X16
DATA	command	Declares one or more constants	C64
DEF	command	Defines a function for use later in BASIC	C64
DIM	command	Allocates storage for an array	C64
DOS	command	Disk and SD card directory operations	X16
EDIT	command	Open the built-in text editor	X16
END	command	Terminate program execution and return to READY.	C64
EXEC	command	Play back a script from RAM into the BASIC editor	X16
EXP	function	Returns the inverse natural log of a number	C64
FMCHORD	command	Start or stop simultaneous notes on YM2151	X16
FMDRUM	command	Plays a drum sound on YM2151	X16
FMFREQ	command	Plays a frequency in Hz on YM2151	X16

FMINIT	command	Stops sound and reinitializes YM2151	X16
FMINST	command	Loads a patch preset into a YM2151 channel	X16
FMNOTE	command	Plays a musical note on YM2151	X16
FMPAN	command	Sets stereo panning on YM2151	X16
FMPLAY	command	Plays a series of notes on YM2151	X16
FMPOKE	command	Writes a value into a YM2151 register	X16
FMVIB	command	Controls vibrato and tremolo on YM2151	X16
FMVOL	command	Sets channel volume on YM2151	X16
FN	function	Calls a previously defined function	C64
FOR	command	Declares the start of a loop construct	C64
FRAME	command	Draws an unfilled rectangle in graphics mode	X16
FRE	function	Returns the number of unused BASIC bytes free	C64
GET	command	Polls the keyboard cache for a single keystroke	C64
GET#	command	Polls an open logical file for a single character	C64
GOSUB	command	Jumps to a BASIC subroutine	C64
GOTO	command	Branches immediately to a line number	C64
HELP	command	Displays a brief summary of online help resources	X16
HEX$	function	Converts numeric to a hexadecimal string	X16
I2CPEEK	function	Reads a byte from a device on the I²C bus	X16
I2CPOKE	command	Writes a byte to a device on the I²C bus	X16
IF	command	Tests a boolean condition and branches on result	C64
INPUT	command	Reads a line or values from the keyboard	C64
INPUT#	command	Reads lines or values from a logical file	C64
INT	function	Discards the fractional part of a number	C64
JOY	function	Reads gamepad button state	X16
KEYMAP	command	Changes the keyboard layout	X16
LEFT$	function	Returns a substring starting from the beginning of a string	C64
LEN	function	Returns the length of a string	C64
LET	command	Explicitly declares a variable	C64
LINE	command	Draws a line in graphics mode	X16
LINPUT	command	Reads a line from the keyboard	X16
LINPUT#	command	Reads a line or other delimited data from an open file	X16
LIST	command	Outputs the program listing to the screen	C64
LOAD	command	Loads a program from disk into memory	C64
LOCATE	command	Moves the text cursor to new location	X16
LOG	function	Returns the natural logarithm of a number	C64
MENU	command	Invokes the Commander X16 utility menu	X16

MID$	function	Returns a substring from the middle of a string	C64
MON	command	Enters the machine language monitor	X16
MOUSE	command	Hides or shows mouse pointer	X16
MOVSPR	command	Set the X/Y position of a sprite	X16
MX/MY/MB	variable	Reads the mouse position and button state	X16
MWHEEL	variable	Reads the mouse wheel movement	X16
NEW	command	Resets the state of BASIC and clears program memory	C64
NEXT	command	Declares the end of a loop construct	C64
NOT	operator	Bitwise or boolean inverse	C64
OLD	command	Undoes a NEW command or warm reset	X16
ON	command	A GOTO/GOSUB table based on a variable value	C64
OPEN	command	Opens a logical file to disk or other device	C64
OR	operator	Bitwise or boolean "OR"	C64
OVAL	command	Draws a filled oval in graphics mode	X16
PEEK	function	Returns a value from a memory address	C64
π	function	Returns the constant for the value of pi	C64
POINTER	function	Returns the address of a BASIC variable	C128
POKE	command	Assigns a value to a memory address	C64
POS	function	Returns the column position of the text cursor	C64
POWEROFF	command	Immediately powers down the Commander X16	X16
PRINT	command	Prints data to the screen or other output	C64
PRINT#	command	Prints data to an open logical file	C64
PSET	command	Changes a pixel's color in graphics mode	X16
PSGCHORD	command	Starts or stops simultaneous notes on VERA PSG	X16
PSGFREQ	command	Plays a frequency in Hz on VERA PSG	X16
PSGINIT	command	Stops sound and reinitializes VERA PSG	X16
PSGNOTE	command	Plays a musical note on VERA PSG	X16
PSGPAN	command	Sets stereo panning on VERA PSG	X16
PSGPLAY	command	Plays a series of notes on VERA PSG	X16
PSGVOL	command	Sets voice volume on VERA PSG	X16
PSGWAV	command	Sets waveform on VERA PSG	X16
READ	command	Assigns the next DATA constant to one or more variables	C64
REBOOT	command	Performs a warm reboot of the system	X16
RECT	command	Draws a filled rectangle in graphics mode	X16
REM	command	Declares a comment	C64
REN	command	Renumbers a BASIC program	X16
RESET	command	Performs a hard reset of the system	X16

RESTORE	command	Resets the READ pointer to a DATA constant	C64
RETURN	command	Returns from a subroutine to the statement following a GOSUB	C64
RIGHT$	function	Returns a substring from the end of a string	C64
RING	command	Draws an oval outline in graphics mode	X16
RND	function	Returns a floating point number 0 <= n < 1	C64
RPT$	function	Returns a string of repeated characters	X16
RUN	command	Clears the variable state and starts a BASIC program	C64
SAVE	command	Saves a BASIC program from memory to disk	C64
SCREEN	command	Selects a text or graphics mode	X16
SGN	function	Returns the sign of a numeric value	C64
SIN	function	Returns the sine of an angle in radians	C64
SLEEP	command	Introduces a delay in program execution	X16
SPC	function	Returns a string with a set number of spaces	C64
SPRITE	command	Sets attributes for a sprite including visibility	X16
SPRMEM	command	Set the VRAM address for a sprite's visual data	X16
SQR	function	Returns the square root of a numeric value	C64
ST	variable	Returns the status of certain DOS/peripheral operations	C64
STEP	keyword	Used in a FOR declaration to declare the iterator step	C64
STOP	command	Breaks out of a BASIC program	C64
STR$	function	Converts a numeric value to a string	C64
STRPTR	function	Returns the address of a BASIC string	X16
SYS	command	Transfers control to machine language at a memory address	C64
TAB	function	Returns a string with spaces used for column alignment	C64
TAN	function	Return the tangent for an angle in radians	C64
TATTR	function	Returns a tile attribute from the tile/text layer	X16
TDATA	function	Returns a tile from the tile/text layer	X16
THEN	keyword	Control structure as part of an IF statement	C64
TI	variable	Returns the jiffy timer value	C64
TI$	variable	Returns the time HHMMSS from the system clock	C64
TILE	command	Changes a tile or character on the tile/text layer	X16
TO	keyword	Part of the FOR loop declaration syntax	C64
USR	function	Call a user-defined function in machine language	C64
VAL	function	Parse a string to return a numeric value	C64
VERIFY	command	Verify that a BASIC program was written to disk correctly	C64
VPEEK	function	Returns a value from VERA's VRAM	X16
VPOKE	command	Sets a value in VERA's VRAM	X16
VLOAD	command	Loads a file to VERA's VRAM	X16

`WAIT`	command	Waits for a memory location to match a condition	C64

Commodore 64 Compatibility

The Commander X16 BASIC interpreter is 100% backwards-compatible with the Commodore 64 one. This includes the following features:

- All statements and functions
- Strings, arrays, integers, floats
- Max. 80 character BASIC lines
- Printing control characters like cursor control and color codes, e.g.:
  - `CHR$(147)` : clear screen
  - `CHR$(5)` : white text
  - `CHR$(18)` : reverse
  - `CHR$(14)` : switch to upper/lowercase font
  - `CHR$(142)` : switch to uppercase/graphics font
- The BASIC vector table ($0300-$030B, $0311/$0312)
- SYS arguments in RAM

Because of the differences in hardware, the following functions and statements are incompatible between C64 and X16 BASIC programs.

- `POKE` : write to a memory address
- `PEEK` : read from a memory address
- `WAIT` : wait for memory contents
- `SYS` : execute machine language code (when used with ROM code)

The BASIC interpreter also currently shares all problems of the C64 version, like the slow garbage collector.

Saving Files

By default, you cannot automatically overwrite a file with SAVE, BSAVE, or OPEN. To overwrite a file, you must prefix the filename with `@:`, like this: `SAVE "@:HELLO WORLD"`. (`"@0:filename"` is also acceptable.)

This follows the Commodore convention, which extended to all of their diskette drives and third party hard drives and flash drive readers.

Always confirm you have successfully saved a file by checking the DOS status. When you use the SAVE command from Immediate (or Direct) mode, the system does this for you. In Program mode, you have to do it yourself.

There are two ways to check the error channel from inside a program:

1. You can use the DOS command and make the user perform actions necessary to recover from an error (such as re-saving the file with an @: prefix).
2. You can read the error yourself, using the following BASIC code:

```
10 OPEN 15,8,15
20 INPUT#15,A,B$
30 PRINT A;B$
40 CLOSE 15
```

Refer to Chapter 13 for more details on CMDR-DOS and the command channel.

New Statements and Functions

There are several new statement and functions. Note that all BASIC keywords (such as `FOR`) get converted into tokens (such as `$81`), and the tokens for the new keywords have likely shifted from one ROM version to the next. Therefore, loading BASIC program saved from an old revision of BASIC may mix up keywords. As of ROM version R42, the keyword token positions should no longer shift and programs saved in R42 BASIC should be compatible with future versions.

ASC

TYPE: Integer Function
FORMAT: ASC(<string>)

Action: Returns an integer value representing the PETSCII code for the first character of `string`. If `string` is the empty string, `ASC()` returns 0.

EXAMPLE of ASC Function:

```
?ASC("A")
 65

?ASC("")
 0
```

BIN$

TYPE: String Function
FORMAT: BIN$(n)

Action: Return a string representing the binary value of n. If n <= 255, 8 characters are returned and if 255 < n <= 65535, 16 characters are returned.

EXAMPLE of BIN$ Function:

```
PRINT BIN$(200)   : REM PRINTS 11001000 AS BINARY REPRESENTATION OF 200
PRINT BIN$(45231) : REM PRINTS 1011000010101111 TO REPRESENT 16 BITS
```

BANK

TYPE: Command
FORMAT: BANK m[,n]

Action: Set the active RAM (m) and ROM bank (n) for the purposes of `PEEK`, `POKE`, and `SYS`. Specifying the ROM bank is optional. If it is not specified, its previous value is retained.

EXAMPLE of BANK Statement:

```
BANK 1,10    : REM SETS THE RAM BANK TO 1 AND THE ROM BANK TO 10
?PEEK($A000) : REM PRINTS OUT THE VALUE STORED IN $A000 IN RAM BANK 1
SYS $C063    : REM CALLS ROUTINE AT $C09F IN ROM BANK 10 AUDIO (YM_INIT)
```

Note: In the above example, the `SYS $C063` in ROM bank 10 is a call to ym_init, which does the first half of what the BASIC command `FMINIT` does, without setting any default instruments. It is generally not recommended to call routines in ROM directly this way, and most BASIC programmers will never have a need to call `SYS` directly, but advanced users may find a good reason to do so.

Note: BANK uses its own register to store the the command's desired bank numbers; this will not always be the same as the value stored in `$00` or `$01`. In fact, `$01` is always going to read `4` when PEEKing from BASIC. If you need to know the currently selected RAM and/or RAM banks, you should explicitly set them and use variables to track your selected bank number(s).

Note: Memory address `$00`, which is the hardware RAM bank register, will usually report the bank set by the `BANK` command. The one exception is after a `BLOAD` or `BVERIFY` inside of a running BASIC program. `BLOAD` and `BVERIFY` change the RAM bank (as if you called `BANK`) to the bank that `BLOAD` or `BVERIFY` stopped at.

BINPUT#

TYPE: Command
FORMAT: BINPUT# <n>,<var$>,<len>

Action: `BINPUT#` Reads a block of data from an open file and stores the data into a string variable. If there are fewer than `<len>` bytes available to be read from the file, fewer bytes will be stored. If the end of the file is reached, `ST AND 64` will be true.

EXAMPLE of BINPUT# Statement:

```
10 OPEN 8,8,8,"FILE.BIN,S,R"
20 BINPUT#8,A$,10
30 PRINT "I GOT";LEN(A$);"BYTES"
40 IF ST<>0 THEN 20
50 CLOSE 8
```

BOOT

TYPE: Command
FORMAT: BOOT

Action: Load and run a PRG file named `AUTOBOOT.X16` from device 8. If the file is not found, nothing is done and no error is printed.

EXAMPLE of BOOT Statement:

```
BOOT
```

BLOAD

TYPE: Command
FORMAT: BLOAD <filename>, <device>, <bank>, <address>

Action: Loads a binary file directly into RAM

Note: If the file is loaded to high RAM (starting in the range `$A000-$BFFF`), and the file is larger than what would fit in the current bank, the load will wrap around into subsequent banks.

After a successful load, `$030D` and `$030E` will contain the address of the final byte loaded + 1. If relevant, the value in memory location `$00` will point to the bank in which the next byte would have been loaded.

EXAMPLES of BLOAD:

```
BLOAD "MYFILE.BIN",8,1,$A000:REM LOADS A FILE NAMED MYFILE.BIN FROM DEVICE 8 STARTING IN BANK 1 AT $A000.
BLOAD "WHO.PCX",8,10,$B000:REM LOADS A FILE NAMED WHO.PCX INTO RAM STARTING IN BANK 10 AT $B000.
```

BSAVE

TYPE: Command
FORMAT: BSAVE <filename>, <device>, <bank>, <start address>, <end address>

Action: Saves a region of memory to a binary file.

Note: The save will stop one byte before `end address`.

This command does not allow for automatic bank advancing, but you can achieve a similar result with successive BSAVE invocations to append additional memory locations to the same file.

EXAMPLES of BSAVE:

```
BSAVE "MYFILE.BIN",8,1,$A000,$C000
```

The above example saves a region of memory from $A000 in bank 1 through and including $BFFF, stopping before $C000.

```
BSAVE "MYFILE.BIN,S,A",8,2,$A000,$B000
```

The above example appends a region of memory from $A000 through and including $AFFF, stopping before $B000. Running both of the above examples in succession will result in a file MYFILE.BIN 12KiB in size.

BVLOAD

TYPE: Command
FORMAT: BVLOAD <filename>, <device>, <VERA_high_address>, <VERA_low_address>

Action: Loads a binary file directly into VERA RAM.

EXAMPLES of BVLOAD:

```
BVLOAD "MYFILE.BIN", 8, 0, $4000  :REM LOADS MYFILE.BIN FROM DEVICE 8 TO VRAM $4000.
BVLOAD "MYFONT.BIN", 8, 1, $F000  :REM LOAD A FONT INTO THE DEFAULT FONT LOCATION ($1F000).
```

CHAR

TYPE: Command
FORMAT: CHAR <x>,<y>,<color>,<string>

Action: This command draws a text string on the graphics screen in a given color.

The string can contain printable ASCII characters (`CHR$($20)` to `CHR$($7E)`), as well most PETSCII control codes.

EXAMPLE of CHAR Statement:

```
10 SCREEN $80
20 A$="The quick brown fox jumps over the lazy dog."
24 CHAR 0,6,0,A$
30 CHAR 0,6+12,0,CHR$($04)+A$   :REM UNDERLINE
40 CHAR 0,6+12*2,0,CHR$($06)+A$ :REM BOLD
50 CHAR 0,6+12*3,0,CHR$($0B)+A$ :REM ITALICS
60 CHAR 0,6+12*4,0,CHR$($0C)+A$ :REM OUTLINE
70 CHAR 0,6+12*5,0,CHR$($12)+A$ :REM REVERSE
```

CLOSE

TYPE: Command FORMAT: CLOSE <file number>

Action: Closes any files used by `OPEN` statements. The `CLOSE` statement takes a single argument that is the file number to be closed.

EXAMPLE of CLOSE Statement:

```
CLOSE 0   : REM CLOSE FILE OPENED AS 0
CLOSE 4   : REM CLOSE FILE OPENED AS 4
```

CLS

TYPE: Command
FORMAT: CLS

Action: Clears the screen. Same effect as `?CHR$(147);` .

EXAMPLE of CLS Statement:

```
CLS
```

COLOR

TYPE: Command
FORMAT: COLOR <fgcol>[,<bgcol>]

Action: This command works sets the text mode foreground color, and optionally the background color.

EXAMPLES of COLOR Statement:

```
COLOR 2   : REM SET FG COLOR TO RED, KEEP BG COLOR
COLOR 2,0 : REM SET FG COLOR TO RED, BG COLOR TO BLACK
```

DOS

TYPE: Command
FORMAT: DOS <string>

Action: This command works with the command/status channel or the directory of a Commodore DOS device and has different functionality depending on the type of argument.

- Without an argument, `DOS` prints the status string of the current device.
- With a string argument of `"8"` or `"9"` , it switches the current device to the given number.
- With an argument starting with `"$"` , it shows the directory of the device.
- Any other argument will be sent as a DOS command.

EXAMPLES of DOS Statement:

```
DOS"$"          : REM SHOWS DIRECTORY
DOS"S:BAD_FILE" : REM DELETES "BAD_FILE"
DOS             : REM PRINTS DOS STATUS, E.G. "01,FILES SCRATCHED,01,00"
```

EDIT

TYPE: Command
FORMAT: EDIT [<filename>]

Action: Opens the built-in text editor, X16-Edit, a modeless editor with features similar to GNU Nano.

- Without an argument, the editor begins with an empty file.
- With a string argument, it attempts to load a file before displaying it.

The EDIT command loads the editor in the screen mode and character set that was active at the time the command was run.

EXAMPLE of EDIT Statement:

```
EDIT "README.TXT"
```

A more elaborate X16-Edit manual can be found here

EXEC

TYPE: Command
FORMAT: EXEC <memory address>[,<ram bank>]

Action: Plays back a null-terminated script from MEMORY into the BASIC editor. Among other uses, this can be used to "type" in a program from a plain text file.

- If the `ram bank` argument is omitted and the address is in the range $A000-$BFFF, the RAM bank selected by the `BANK` command is used.
- The input can span multiple RAM banks. The input will stop once it reaches a null byte ($00) or if a BASIC error occurs.
- The redirected input only applies to BASIC immediate mode. While programs are running, the EXEC handling is suspended.

EXAMPLE of EXEC Statement:

```
BLOAD "MYPROGRAM.BAS",8,1,$A000 : REM "BANK PEEK(0)" NO LONGER NEEDED
POKE PEEK($30D)+(PEEK($30E)*256),0 : REM NULL TERMINATE IN END BANK
EXEC $A000,1
```

This program will load a plain ASCII or PETSCII FILE.BAS from disk and tokenize it for you:

```
10 BLOAD "FILE.BAS", 8, 1, $A000
20 POKE PEEK(781) + 256 * PEEK(782), 0
30 EXEC $A000, 1
40 NEW
```

FMCHORD

TYPE: Command
FORMAT: FMCHORD <first channel>,<string>

Action: This command uses the same syntax as `FMPLAY`, but instead of playing a series of notes, it will start all of the notes in the string simultaneously on one or more channels. The first parameter to `FMCHORD` is the first channel to use, and will be used for the first note in the string, and subsequent notes in the string will be started on subsequent channels, with the channel after 7 being channel 0.

All macros are supported, even the ones that only affect the behavior of `PSGPLAY` and `FMPLAY`.

The full set of macros is documented here.

EXAMPLE of FMCHORD statement:

```
10 FMINIT
20 FMVIB 195,10
```

```
30 FMINST 1,16:FMINST 2,16:FMINST 3,16 : REM ORGAN
40 FMVOL 1,50:FMVOL 2,50:FMVOL 3,50 : REM MAKE ORGAN QUIETER
50 FMINST 0,11 : REM VIBRAPHONE
60 FMCHORD 1,"O3CG>E T90" : REM START SOME ORGAN CHORDS (CHANNELS 1,2,3)
70 FMPLAY 0,"O4G4.A8G4E2." : REM PLAY MELODY (CHANNEL 0)
80 FMPLAY 0,"O4G4.A8G4E2."
90 FMCHORD 1,"O2G>DB" : REM SWITCH ORGAN CHORDS (CHANNELS 1,2,3)
100 FMPLAY 0,"O5D2D4<B2" : REM PLAY MORE MELODY
110 FMCHORD 1,"O2F" : REM SWITCH ONE OF THE ORGAN CHORD NOTES
120 FMPLAY 0,"R4" : REM PAUSE FOR THE LENGTH OF ONE QUARTER NOTE
130 FMCHORD 1,"O3CEG" : REM SWITCH ALL THREE CHORD NOTES
140 FMPLAY 0,"O5C2C4<G2." : REM PLAY THE REST OF THE MELODY
150 FMCHORD 1,"RRR" : REM RELEASE THE CHANNELS THAT ARE PLAYING THE CHORD
```

This will play the first few lines of *Silent Night* with a vibraphone lead and organ accompaniment.

FMDRUM

TYPE: Command
FORMAT: FMDRUM <channel>,<drum number>

Action: Loads a drum preset onto the YM2151 and triggers it. Valid range is from 25 to 87, corresponding to the General MIDI percussion note values. FMDRUM will load a patch preset corresponding to the selected drum into the channel. If you then try to play notes on that same channel without loading an instrument patch, it will use the drum patch that was loaded for the drum sound instead, which may not sound particularly musical.

FMFREQ

TYPE: Command
FORMAT: FMFREQ <channel>,<frequency>

Action: Play a note by frequency on the YM2151. The accepted range is in Hz from 17 to 4434. FMFREQ also accepts a frequency of 0 to release the note.

EXAMPLE of FMFREQ statement:

```
0 FMINST 0,160 : REM LOAD PURE SINE PATCH
10 FMINST 1,160 : REM HERE TOO
20 FMFREQ 0,350 : REM PLAY A SINE WAVE AT 350 HZ
30 FMFREQ 1,440 : REM PLAY A SINE WAVE AT 440 HZ ON ANOTHER CHANNEL
40 FOR X=1 TO 10000 : NEXT X : REM DELAY A BIT
50 FMFREQ 0,0 : FMFREQ 1,0 : REM RELEASE BOTH CHANNELS
```

The above BASIC program plays a sound similar to a North American dial tone for a few seconds.

FMINIT

TYPE: Command
FORMAT: FMINIT

Action: Initialize YM2151, silence all channels, and load a set of default patches into all 8 channels.

FMINST

TYPE: Command
FORMAT: FMINST <channel>,<patch>

Load an instrument onto the YM2151 in the form of a patch preset into a channel. Valid channels range from 0 to 7. Valid patches range from 0 to 162.

FMNOTE

TYPE: Command
FORMAT: FMNOTE <channel>,<note>

Action: Play a note on the YM2151. The note value is constructed as follows. Using hexadecimal notation, the first nybble is the octave, 0-7, and the second nybble is the note within the octave as follows:

$x0	$x1	$x2	$x3	$x4	$x5	$x6	$x7	$x8	$x9	$xA	$xB	$xC	$xD-$xF
Release	C	C♯/D♭	D	D♯/E♭	E	F	F♯/G♭	G	G♯/A♭	A	A♯/B♭	B	no-op

Notes can also be represented by negative numbers to skip retriggering, and will thus snap to another note without restarting the playback of the note.

EXAMPLE of FMNOTE statement:

```
0 FMINST 1,64 : REM LOAD SOPRANO SAX
10 FMNOTE 1,$4A : REM PLAYS CONCERT A
20 FOR X=1 TO 5000 : NEXT X : REM DELAYS FOR A BIT
30 FMNOTE 1,0 : REM RELEASES THE NOTE
40 FOR X=1 TO 1000 : NEXT X : REM DELAYS FOR A BIT
50 FMNOTE 1,$3A : REM PLAYS A IN THE 3RD OCTAVE
60 FOR X=1 TO 2500 : NEXT X : REM SHORT DELAY
70 FMNOTE 1,-$3B : REM UP A HALF STEP TO A# WITHOUT RETRIGGERING
80 FOR X=1 TO 2500 : NEXT X : REM SHORT DELAY
90 FMNOTE 1,0 : REM RELEASES THE NOTE
```

FMPAN

TYPE: Command
FORMAT: FMPAN <channel>,<panning>

Action: Sets the simple stereo panning on a YM2151 channel. Valid values are as follows:

- 1 = left
- 2 = right
- 3 = both

FMPLAY

TYPE: Command
FORMAT: FMPLAY <channel>,<string>

Action: This command is very similar to `PLAY` on other BASICs such as GWBASIC. It takes a string of notes, rests, tempo changes, note lengths, and other macros, and plays all of the notes synchronously. That is, the FMPLAY command will not return control until all of the notes and rests in the string have been fully played.

The full set of macros is documented here .

EXAMPLE of FMPLAY statement:

```
10 FMINIT : REM INITIALIZE AND LOAD DEFAULT PATCHES, WILL USE E.PIANO
20 FMPLAY 1,"T90 O4 L4" : REM TEMPO 90 BPM, OCTAVE 4, NOTE LENGTH 4 (QUARTER)
30 FMPLAY 1,"CDECCDECEFGREFGR" : REM FIRST TWO LINES OF TUNE
40 FMPLAY 1,"G8A8G8F8EC G8A8G8F8EC" : REM THIRD LINE
50 FMPLAY 1,"C<G>CRC<G>CR" : REM FOURTH LINE
```

FMPOKE

TYPE: Command
FORMAT: FMPOKE <register>,<value>

Action: This command uses the AUDIO API to write a value to one of the the YM2151's registers at a low level.

EXAMPLE of FMPOKE statement:

```
10 FMINIT
20 FMPOKE $28,$4A : REM SET KC TO A4 (A-440) ON CHANNEL 0
30 FMPOKE $08,$00 : REM RELEASE CHANNEL 0
40 FMPOKE $08,$78 : REM START NOTE PLAYBACK ON CHANNEL 0 W/ ALL OPERATORS
```

FMVIB

TYPE: Command
FORMAT: FMVIB <speed>,<depth>

Action: This command sets the LFO speed and the phase and amplitude modulation depth values on the YM2151. The speed value ranges from 0 to 255, and corresponds to an LFO frequency from 0.008 Hz to 32.6 Hz. The depth value ranges from 0-127 and affects both AMD and PMD.

Only some patch presets (instruments) are sensitive to the LFO. Those are marked in this table with the † symbol. The LFO affects all channels equally, and it depends on the instrument as to whether it is affected.

Good values for most instruments are speed somewhere between 190-220. A good light vibrato for most wind instruments would have a depth of 10-15, while tremolo instruments like the Vibraphone or Tremolo Strings are most realistic around 20-30.

EXAMPLE of FMVIB statement:

```
10 FMVIB 200,30
20 FMINST 0,11 : REM VIBRAPHONE
30 FMPLAY 0,"T60 O4 CDEFGAB>C"
40 FMVIB 0,0
50 FMPLAY 0,"C<BAGFEDC"
```

The above BASIC program plays a C major scale with a vibraphone patch, first with a vibrato/tremolo effect, and then plays the scale in reverse with the vibrato turned off.

FMVOL

TYPE: Command
FORMAT: FMVOL <channel>,<volume>

Action: This command sets the channel's volume. The volume remains at the requested level until another `FMVOL` command for that channel or `FMINIT` is called. Valid range is from 0 (completely silent) to 63 (full volume)

FRAME

TYPE: Command
FORMAT: FRAME <x1>,<y1>,<x2>,<y2>,<color>

Action: This command draws a rectangle frame on the graphics screen in a given color.

EXAMPLE of FRAME Statement:

```
10 SCREEN$80
20 FORI=1TO20:FRAMERND(1)*320,RND(1)*200,RND(1)*320,RND(1)*200,RND(1)*128:NEXT
30 GOTO20
```

HEX$

TYPE: String Function
FORMAT: HEX$(n)

Action: Return a string representing the hexadecimal value of n. If n <= 255, 2 characters are returned and if 255 < n <= 65535, 4 characters are returned.

EXAMPLE of HEX$ Function:

```
PRINT HEX$(200)   : REM PRINTS C8 AS HEXADECIMAL REPRESENTATION OF 200
PRINT HEX$(45231) : REM PRINTS B0AF TO REPRESENT 16 BIT VALUE
```

HELP

TYPE: Command
FORMAT: HELP

Action: The `HELP` command displays a brief summary of the ROM build, and points users to this guide at its home on GitHub, and to the community forums website.

I2CPEEK

TYPE: Integer Function
FORMAT: I2CPEEK(<device>,<register>)

Action: Returns the value from a register on an I²C device.

EXAMPLE of I2CPEEK Function:

```
PRINT HEX$(I2CPEEK($6F,0) AND $7F)
```

This command reports the seconds counter from the RTC by converting its internal BCD representation to a string.

I2CPOKE

TYPE: Command
FORMAT: I2CPOKE <device>,<register>,<value>

Action: Sets the value to a register on an I²C device.

EXAMPLE of I2CPOKE Function:

```
I2CPOKE $6F,$40,$80
```

This command sets a byte in NVRAM on the RTC to the value `$80`

JOY

TYPE: Integer Function
FORMAT: JOY(n)

Action: Return the state of a joystick.

`JOY(1)` through `JOY(4)` return the state of SNES controllers connected to the system, and `JOY(0)` returns the state of the "keyboard joystick", a set of keyboard keys that map to the SNES controller layout. See `joystick_get` for details.

If no controller is connected to the SNES port (or no keyboard is connected), the function returns -1. Otherwise, the result is a bit field, with pressed buttons `OR` ed together:

Value	Button
$800	A
$400	X
$200	L
$100	R
$080	B
$040	Y
$020	SELECT
$010	START
$008	UP
$004	DOWN
$002	LEFT
$001	RIGHT

Note that this bitfield is different from the `joystick_get` KERNEL API one. Also note that the keyboard joystick will allow LEFT and RIGHT as well as UP and DOWN to be pressed at the same time, while controllers usually prevent this mechanically.

EXAMPLE of JOY Function:

```
10 REM DETECT CONTROLLER, FALL BACK TO KEYBOARD
20 J = 0: FOR I=1 TO 4: IF JOY(I) >= 0 THEN J = I: GOTO40
30 NEXT
40 :
50 V=JOY(J)
60 PRINT CHR$(147);V;": ";
70 IF V = -1 THEN PRINT"DISCONNECTED ": GOTO50
80 IF V AND 8 THEN PRINT"UP ";
90 IF V AND 4 THEN PRINT"DOWN ";
100 IF V AND 2 THEN PRINT"LEFT ";
110 IF V AND 1 THEN PRINT"RIGHT ";
120 GOTO50
```

KEYMAP

TYPE: Command
FORMAT: KEYMAP <string>

Action: This command sets the current keyboard layout. It can be put into an AUTOBOOT file to always set the keyboard layout on boot.

EXAMPLE of KEYMAP Statement:

```
10 KEYMAP"SV-SE"    :REM SMALL BASIC PROGRAM TO SET LAYOUT TO SWEDISH/SWEDEN
SAVE"AUTOBOOT.X16"  :REM SAVE AS AUTOBOOT FILE
```

LINE

TYPE: Command
FORMAT: LINE <x1>,<y1>,<x2>,<y2>,<color>

Action: This command draws a line on the graphics screen in a given color.

EXAMPLE of LINE Statement:

```
10 SCREEN128
20 FORA=0TO2*πSTEP2*π/200
30 :  LINE100,100,100+SIN(A)*100,100+COS(A)*100
40 NEXT
```

If you're pasting this example into the Commander X16 emulator, use this code block instead so that the π symbol is properly received.

```
10 SCREEN128
20 FORA=0TO2*\XFFSTEP2*\XFF/200
30 :  LINE100,100,100+SIN(A)*100,100+COS(A)*100
40 NEXT
```

LINPUT

TYPE: Command
**FORMAT: LINPUT <var$>

Action: `LINPUT` Reads a line of data from the keyboard and stores the data into a string variable. Unlike `INPUT` , no parsing or cooking of the input is done, and therefore quotes, commas, and colons are stored in the string as typed. No prompt is displayed, either.

The input is taken from the KERNAL editor, hence the user will have the freedom of all of the features of the editor such as cursor movement, mode switching, and color changing.

Due to how the editor works, an empty line will return `" "` – a string with a single space, and trailing spaces are not preserved.

EXAMPLE of LINPUT Statement:

```
10 LINPUT A$
20 IF A$=" " THEN 50
```

```
30 PRINT "YOU TYPED: ";A$
40 END
50 PRINT "YOU TYPED AN EMPTY STRING: ";A$
```

LINPUT#

TYPE: Command
FORMAT: LINPUT# <n>,<var$>[,<delimiter>]

Action: `LINPUT#` Reads a line of data from an open file and stores the data into a string variable. The delimiter of a line by default is 13 (carriage return). The delimiter is not part of the stored value. If the end of the file is reached while reading, `ST AND 64` will be true.

`LINPUT#` can be used to read structured data from files. It can be particularly useful to extract quoted or null-terminated strings from files while reading.

EXAMPLE of LINPUT# Statement:

```
10 I=0
20 OPEN 1,8,0,"$"
30 LINPUT#1,A$,$22
40 IF ST<>0 THEN 130
50 LINPUT#1,A$,$22
60 IF I=0 THEN 90
70 PRINT "ENTRY: ";
80 GOTO 100
90 PRINT "LABEL: ";
100 PRINT CHR$($22);A$;CHR$($22)
110 I=I+1
120 IF ST=0 THEN 30
130 CLOSE 1
```

The above example parses and prints out the filenames from a directory listing.

LIST

TYPE: Command FORMAT: LIST [start] [-] [end]

Action: `LIST` Displays the currently loaded BASIC program on the screen. The start and ending line numbers are both optional.

The start and/or end may be specified. If both are specified, a hyphen must be included. So LIST has 4 modes:

`LIST` by itself will display the entire program.

`LIST 10-20` will display lines 10 to 20, inclusive.

`LIST -100` will display from the start to line 100

`LIST 50-` will display line 50 to the end of the program.

Pressing the `CONTROL` key during a listing will slow the listing down once printing reaches the bottom of the screen. Approxmately one line per second will be displayed.

Pressing the `SPACE BAR` during the listing will cause the listing to pause. Pressing the `SPACE BAR` a second time will unpause the listing. You may also use the down arrow key to scroll by one line or use the `PgDn` key to scroll approximately one screen full of text.

LOCATE

TYPE: Command
FORMAT: LOCATE <line>[,<column>]

Action: This command positions the text mode cursor at the given location. The values are 1-based. If no column is given, only the line is changed.

EXAMPLE of LOCATE Statement:

```
100 REM DRAW CIRCLE ON TEXT SCREEN
110 SCREEN0
120 R=25
```

```
130 X0=40
140 Y0=30
150 FORT=0TO360STEP1
160 :  X=X0+R*COS(T)
170 :  Y=Y0+R*SIN(T)
180 :  LOCATEY,X:PRINTCHR$($12);" ";
190 NEXT
```

MENU

TYPE: Command
FORMAT: MENU

Action: This command currently invokes the Commander X16 Control Panel. In the future, the menu may instead present a menu of ROM-based applications and routines.

EXAMPLE of MENU Statement:

```
MENU
```

MON

TYPE: Command
FORMAT: MON (Alternative: MONITOR)

Action: This command enters the machine language monitor. See the Chapter 7: Machine Language Monitor for a description.

EXAMPLE of MON Statement:

```
MON
MONITOR
```

MOUSE

TYPE: Command
FORMAT: MOUSE <mode>

Action: This command configures the mouse pointer.

Mode	Description
0	Hide mouse
1	Show mouse, set default mouse pointer
-1	Show mouse, don't configure mouse cursor

`MOUSE 1` turns on the mouse pointer and `MOUSE 0` turns it off. If the BASIC program has its own mouse pointer sprite configured, it can use `MOUSE -1`, which will turn the mouse pointer on, but not set the default pointer sprite.

The size of the mouse pointer's area will be configured according to the current screen mode. If the screen mode is changed, the MOUSE statement has to be repeated.

EXAMPLES of MOUSE Statement:

```
MOUSE 1 : REM ENABLE MOUSE
MOUSE 0 : REM DISABLE MOUSE
```

MOVSPR

TYPE: Command
FORMAT: MOVSPR <sprite idx>,<x>,<y>

Action: This command positions a sprite's upper left corner at a specific pixel location. It does not change its visibility.

`sprite idx` is a value between 0-127 inclusive. `x` and `y` have a range of -32768 to 32767 inclusive, but their meanings wrap every 1024 values. Values approaching 1023 will peek out from the left and top of the screen for x and y respectively as if they were negative and approaching 0. -1024, 1024, 0, and 2048 are all equivalent. Likewise, -10 and 1014 are equivalent.

EXAMPLE of MOVSPR Statement:

```
10 BVLOAD "MYSPRITE.BIN",8,1,$3000
20 SPRMEM 1,1,$3000,1
30 SPRITE 1,3,0,0,3,3
40 MOVSPR 1,320,200
```

MX/MY/MB

TYPE: System variable
FORMAT: MX
FORMAT: MY
FORMAT: MB

Action: Return the horizontal (`MX`) or vertical (`MY`) position of the mouse pointer, or the mouse button state (`MB`).

`MB` returns the sum of the following values depending on the state of the buttons:

Value	Button
0	none
1	left
2	right
4	third

EXAMPLE of MX/MY/MB variables:

```
REM SIMPLE DRAWING PROGRAM
10 SCREEN$80
20 MOUSE1
25 OB=0
30 TX=MX:TY=MY:TB=MB
35 IFTB=0GOTO25
40 IFOBTHENLINEOX,OY,TX,TY,16
50 IFOB=0THENPSETTX,TY,16
60 OX=TX:OY=TY:OB=TB
70 GOTO30
```

MWHEEL

TYPE: System variable
FORMAT: MWHEEL

Action: Return the mouse scroll wheel movement since the value was last read. The value is negative if the scroll wheel is moved away from the user, and positive if it is moved towards the user. The range of the returned value is -128 to +127.

OLD

TYPE: Command
FORMAT: OLD

Action: This command recovers the BASIC program in RAM that has been previously deleted using the `NEW` command or through a RESET.

EXAMPLE of OLD Statement:

```
OLD
```

OVAL

TYPE: Command
FORMAT: OVAL <x1>,<y1>,<x2>,<y2>,<color>

Action: This command draws a filled oval on the graphics screen in a given color.

The coordinate arguments define the rectangular bounding box of the oval. To draw a filled circle, make the width and height equal to each other.

EXAMPLE of OVAL Statement:

```
10 SCREEN $80
20 FORI=1 TO 20:OVAL RND(1)*320,RND(1)*200,RND(1)*320,RND(1)*200,RND(1)*128:NEXT
30 GOTO 20
```

POINTER

TYPE: Function
FORMAT: POINTER(<variable>)

Action: Returns the memory address of the internal structure representing a BASIC variable.

EXAMPLE of POINTER function:

```
10 A$="MOO"
20 PRINT HEX$(POINTER(A$))
RUN
0823
```

POWEROFF

TYPE: Command
FORMAT: POWEROFF

Action: This command instructs the SMC to power down the system. This is equivalent to pressing the physical power switch.

EXAMPLE of POWEROFF Statement:

```
POWEROFF
```

PSET

TYPE: Command
FORMAT: PSET <x>,<y>,<color>

Action: This command sets a pixel on the graphics screen to a given color.

EXAMPLE of PSET Statement:

```
10 SCREEN$80
20 FORI=1TO20:PSETRND(1)*320,RND(1)*200,RND(1)*256:NEXT
30 GOTO20
```

PSGCHORD

TYPE: Command
FORMAT: PSGCHORD <first voice>,<string>

Action: This command uses the same syntax as `PSGPLAY`, but instead of playing a series of notes, it will start all of the notes in the string simultaneously on one or more voices. The first parameter to `PSGCHORD` is the first voice to use, and will be used for the first note in the string, and subsequent notes in the string will be started on subsequent voices, with the voice after 15 being voice 0.

All macros are supported, even the ones that only affect `PSGPLAY` and `FMPLAY`.

The full set of macros is documented here.

EXAMPLE of PSGCHORD statement:

```
10 PSGINIT
20 PSGCHORD 15,"O3G>CE" : REM STARTS PLAYING A CHORD ON VOICES 15, 0, AND 1
30 PSGPLAY 14,">C<DGB>CDE" : REM PLAYS A SERIES OF NOTES ON VOICE 14
40 PSGCHORD 15,"RRR" : REM RELEASES CHORD ON VOICES 15, 0, AND 1
50 PSGPLAY 14,"O4CAG>C<A" : REM PLAYS A SERIES OF NOTES ON VOICE 14
60 PSGCHORD 0,"O3A>CF" : REM STARTS PLAYING A CHORD ON VOICES 0, 1, AND 2
70 PSGPLAY 14,"L16FGAB->CDEF4" : REM PLAYS A SERIES OF NOTES ON VOICE
80 PSGCHORD 0,"RRR" : REM RELEASES CHORD ON VOICES 0, 1, AND 2
```

PSGFREQ

TYPE: Command
FORMAT: PSGFREQ <voice>,<frequency>

Action: Play a note by frequency on the VERA PSG. The accepted range is in Hz from 1 to 24319. PSGFREQ also accepts a frequency of 0 to release the note.

EXAMPLE of PSGFREQ statement:

```
10 PSGINIT : REM RESET ALL VOICES TO SQUARE WAVEFORM
20 PSGFREQ 0,350 : REM PLAY A SQUARE WAVE AT 350 HZ
30 PSGFREQ 1,440 : REM PLAY A SQUARE WAVE AT 440 HZ ON ANOTHER VOICE
40 FOR X=1 TO 10000 : NEXT X : REM DELAY A BIT
50 PSGFREQ 0,0 : PSGFREQ 1,0 : REM RELEASE BOTH VOICES
```

The above BASIC program plays a sound similar to a North American dial tone for a few seconds.

PSGINIT

TYPE: Command
FORMAT: PSGINIT

Action: Initialize VERA PSG, silence all voices, set volume to 63 on all voices, and set the waveform to pulse and the duty cycle to 63 (50%) for all 16 voices.

PSGNOTE

TYPE: Command
FORMAT: PSGNOTE <voice>,<note>

Action: Play a note on the VERA PSG. The note value is constructed as follows. Using hexadecimal notation, the first nybble is the octave, 0-7, and the second nybble is the note within the octave as follows:

$x0	$x1	$x2	$x3	$x4	$x5	$x6	$x7	$x8	$x9	$xA	$xB	$xC	$xD-$xF
Release	C	C♯/D♭	D	D♯/E♭	E	F	F♯/G♭	G	G♯/A♭	A	A♯/B♭	B	no-op

EXAMPLE of PSGNOTE statement:

```
10 PSGNOTE 1,$4A : REM PLAYS CONCERT A
20 FOR X=1 TO 5000 : NEXT X : REM DELAYS FOR A BIT
30 PSGNOTE 1,0 : REM RELEASES THE NOTE
40 FOR X=1 TO 2500 : NEXT X : REM SHORT DELAY
50 PSGNOTE 1,$3A : REM PLAYS A IN THE 3RD OCTAVE
60 FOR X=1 TO 2500 : NEXT X : REM SHORT DELAY
70 PSGNOTE 1,0 : REM RELEASES THE NOTE
```

PSGPAN

TYPE: Command
FORMAT: PSGPAN <voice>,<panning>

Action: Sets the simple stereo panning on a VERA PSG voice. Valid values are as follows:

- 1 = left

- 2 = right
- 3 = both

PSGPLAY

TYPE: Command
FORMAT: PSGPLAY <voice>,<string>

Action: This command is very similar to `PLAY` on other BASICs such as GWBASIC. It takes a string of notes, rests, tempo changes, note lengths, and other macros, and plays all of the notes synchronously. That is, the PSGPLAY command will not return control until all of the notes and rests in the string have been fully played.

The full set of macros is documented here .

EXAMPLE of PSGPLAY statement:

```
10 PSGWAV 0,31 : REM PULSE, 25% DUTY
20 PSGPLAY 0,"T180 S0 O5 L32" : REM TEMPO 180 BPM, LEGATO, OCTAVE 5, 32ND NOTES
30 PSGPLAY 0,"C<G>CEG>C<G<A-"
40 PSGPLAY 0,">CE-A-E-A->CE-A-"
50 PSGPLAY 0,"E-<<B->DFB-FB->DFB-F" : REM GRAB YOURSELF A MUSHROOM
```

PSGVOL

TYPE: Command
FORMAT: PSGVOL <voice>,<volume>

Action: This command sets the voice's volume. The volume remains at the requested level until another `PSGVOL` command for that voice or `PSGINIT` is called. Valid range is from 0 (completely silent) to 63 (full volume).

PSGWAV

TYPE: Command
FORMAT: PSGWAV <voice>,<w>

Action: Sets the waveform and duty cycle for a PSG voice.

- w = 0-63 -> Pulse: Duty cycle is `(w+1)/128` . A value of 63 means 50% duty.
- w = 64-127 -> Sawtooth (all values have identical effect)
- w = 128-191 -> Triangle (all values have identical effect)
- w = 192-255 -> Noise (all values have identical effect)

EXAMPLE of PSGWAV Statement:

```
10 FOR O=$20 TO $50 STEP $10:REM OCTAVE LOOP
20 FOR N=1 TO 11 STEP 2:REM NOTE LOOP, EVERY OTHER NOTE
30 PSGNOTE 0,O+N:REM START PLAYBACK OF THE NOTE
40 FOR P=0 TO 30:REM PULSE WIDTH MODULATION LOOP (INCREASING DUTY)
50 PSGWAV 0,P:REM SET PW
60 FOR D=1 TO 30:NEXT D:REM DELAY LOOP
70 NEXT P
80 PSGNOTE 0,O+N+1:REM START PLAYBACK OF THE NOTE + A SEMITONE
90 FOR P=31 TO 1 STEP -1:REM PWM LOOP (DECREASING DUTY)
100 PSGWAV 0,P:REM SET PW
110 FOR D=1 TO 30:NEXT D:REM DELAY LOOP
120 NEXT P
130 NEXT N
140 NEXT O
150 PSGNOTE 0,0:REM STOP SOUND
```

This example plays a chromatic scale while applying pulse-width modulation on the voice.

RING

TYPE: Command
FORMAT: RING <x1>,<y1>,<x2>,<y2>,<color>

Action: This command draws an oval outline on the graphics screen in a given color.

The coordinate arguments define the rectangular bounding box of the oval. To draw a circle outline, make the width and height equal to each other.

EXAMPLE of RING Statement:

```
10 SCREEN $80
20 FORI=1 TO 20:RING RND(1)*320,RND(1)*200,RND(1)*320,RND(1)*200,RND(1)*128:NEXT
30 GOTO 20
```

RECT

TYPE: Command
FORMAT: RECT <x1>,<y1>,<x2>,<y2>,<color>

Action: This command draws a solid rectangle on the graphics screen in a given color.

EXAMPLE of RECT Statement:

```
10 SCREEN$80
20 FORI=1TO20:RECTRND(1)*320,RND(1)*200,RND(1)*320,RND(1)*200,RND(1)*256:NEXT
30 GOTO20
```

REBOOT

TYPE: Command
FORMAT: REBOOT

Action: Performs a software reset of the system by calling the ROM reset vector.

EXAMPLE of REBOOT Statement:

```
REBOOT
```

REN

TYPE: Command
FORMAT: REN [<new line num>[, <increment>[, <first old line num>]]]

Action: Renumbers a BASIC program while updating the line number arguments of GOSUB, GOTO, RESTORE, RUN, and THEN.

Optional arguments:

- The line number of the first line after renumbering, default: **10**
- The value of the increment for subsequent lines, default **10**
- The earliest old line to start renumbering at, default: **0**

THIS STATEMENT IS EXPERIMENTAL. Please ensure your have saved your program before using this command to renumber.

KNOWN BUG: In release R43, due to improper parsing of escape tokens, REN will improperly treat arguments to these statements as line numbers:

- `FRAME`
- `RECT`
- `MOUSE`
- `COLOR`
- `PSGWAV`

This behavior has been fixed in R44.

EXAMPLE of REN Statement:

```
10 PRINT "HELLO"
20 DATA 1,2,3
30 DATA 4,5,6
40 READ X
```

```
50 PRINT X
60 RESTORE 30
70 READ X
80 PRINT X
90 GOTO 10

REN 100,5

LIST
100 PRINT "HELLO"
105 DATA 1,2,3
110 DATA 4,5,6
115 READ X
120 PRINT X
125 RESTORE 110
130 READ X
135 PRINT X
140 GOTO 100
READY.
```

RESET

TYPE: Command
FORMAT: RESET

Action: This command instructs the SMC to assert the reset line on the system, which performs a hard reset. This is equivalent to pressing the physical reset switch.

EXAMPLE of RESET Statement:

```
RESET
```

RESTORE

TYPE: Command
FORMAT: RESTORE [<linenum>]

Action: This command resets the pointer for the `READ` command. Without arguments, it will reset the pointer to the first `DATA` constant in the program. With a parameter `linenum`, the command will reset the pointer to the first `DATA` constant at or after that line number.

EXAMPLE of RESTORE Statement:

```
10 DATA 1,2,3
20 DATA 4,5,6
30 READ Y
40 PRINT Y
50 RESTORE 20
60 READ Y
70 PRINT Y
```

This program will output the number 1 followed by the number 4.

RPT$

TYPE: Function
FORMAT: RPT$(<byte>,<count>)

Action: Returns a string of <count> instances of the PETSCII character represented by the numeric value <byte>. This function is similar in behavior to `CHR$()` but takes a second argument as a repeat count.

`RPT$(A,1)` is functionally equivalent to `CHR$(A)`.

EXAMPLE of RPT$ function:

```
10 REM TEN EXCLAMATION MARKS
20 PRINT RPT$(33,10)
READY.
RUN
!!!!!!!!!!

READY.
```

SAVE

TYPE: Command **FORMAT: SAVE <filename> [, <device>**]

Action: Saves a BASIC program to a file.

This saves the currently loaded BASIC program to a file. If the device number is not supplied, SAVE will use the default drive. This is usually the SD card.

Note that SAVE will not overwrite an existing file by default. To do this, you must prefix the filename with @:, like this: `SAVE "@:filename"`

EXAMPLES of SAVE:

```
SAVE "HELLO.PRG"
```

The above example saves your Hello World program to the SD card.

```
SAVE "@:HELLO.PRG",9
```

The above example overwrites an existing file on drive 9, which would be a Commodore style disk drive plugged into the IEC port.

SCREEN

TYPE: Command
FORMAT: SCREEN <mode>

Action: This command switches screen modes.

For a list of supported modes, see Chapter 3: Editor. The value of -1 toggles between modes $00 and $03.

EXAMPLE of SCREEN Statement:

```
SCREEN 3 : REM SWITCH TO 40 CHARACTER MODE
SCREEN 0 : REM SWITCH TO 80 CHARACTER MODE
SCREEN -1 : REM SWITCH BETWEEN 40 and 80 CHARACTER MODE
```

SLEEP

TYPE: Command
FORMAT: SLEEP [<jiffies>]

Action: With the default interrupt source configured and enabled, this command waits for `jiffies` +1 VSYNC events and then resumes program execution. In other words, `SLEEP` with no arguments is equivalent to `SLEEP 0`, which waits until the beginning of the next frame. Another useful example, `SLEEP 60`, pauses for approximately 1 second.

Allowed values for `jiffies` is from 0 to 65535, inclusive.

EXAMPLE of SLEEP Statement:

```
10 FOR I=1 TO 10
20 PRINT I
30 SLEEP 60
40 NEXT
```

SPRITE

TYPE: Command
FORMAT: SPRITE <sprite idx>,<priority>[,<palette offset>[,<flip>[,<x-width>[,<y-width>[,<color depth>]]]]]

Action: This command configures a sprite's geometry, palette, and visibility.

The first two arguments are required, but the remainder are optional.

- `sprite idx` is a value between 0-127 inclusive.
- `priority` , also known as z-depth changes the visibility of the sprite and above which layer it is rendered. Range is 0-3 inclusive. 0 = off, 1 = below layer 0, 2 = in between layers 0 and 1, 3 = above layer 1
- `palette offset` is the palette offset for the sprite. Range is 0-15 inclusive. This value is multiplied by 16 to determine the starting palette index.
- `flip` controls the X and Y flipping of the sprite. Range is 0-3 inclusive. 0 = unflipped, 1 = X is flipped, 2 = Y is flipped, 3 = both X and Y are flipped.
- `x-width` and `y-width` represent the dimensions of the sprite. Range is 0-3 inclusive. 0 = 8px, 1 = 16px, 2 = 32px, 3 = 64px.
- `color depth` selects either 4 or 8-bit color depth for the sprite. 0 = 4-bit, 1 = 8-bit. This attribute can also be set by the `SPRMEM` command.

Note: If VERA's sprite layer is disabled when the `SPRITE` command is called, the sprite layer will be enabled, regardless of the arguments to `SPRITE` .

EXAMPLE of SPRITE Statement:

```
10 BVLOAD "MYSPRITE.BIN",8,1,$3000
20 SPRMEM 1,1,$3000,1
30 SPRITE 1,3,0,0,3,3
40 MOVSPR 1,320,200
```

SPRMEM

TYPE: Command
FORMAT: SPRMEM <sprite idx>,<VRAM bank>,<VRAM address>[,<color depth>]

Action: This command configures the address of where the sprite's pixel data is to be found. It also can change or set the color depth of the sprite.

The first three arguments are required, but the last one is optional.

- `sprite idx` is a value between 0-127 inclusive.
- `VRAM bank` is a value, `0` or `1` , which represents which of the two 64k regions of VRAM to select.
- `VRAM address` is a 16-bit value, $0000-$FFFF, is the address within the VRAM bank to point the sprite to. The lowest 5 bits are ignored.
- `color depth` selects either 4 or 8-bit color depth for the sprite. 0 = 4-bit, 1 = 8-bit. This attribute can also be set by the `SPRITE` command.

EXAMPLE of SPRITE Statement:

```
10 BVLOAD "MYSPRITE.BIN",8,1,$3000
20 SPRMEM 1,1,$3000,1
30 SPRITE 1,3,0,0,3,3
40 MOVSPR 1,320,200
```

STRPTR

TYPE: Function
FORMAT: STRPTR(<variable>)

Action: Returns the memory address of the first character of a string contained within a string variable. If the string variable has zero length, this function will likely still return a non-zero value pointing either to the close quotation mark in the literal assignment, or to somewhere undefined in string memory. Programs should check the `LEN()` of string variables before using the pointer returned from `STRPTR` .

EXAMPLE of STRPTR function:

```
10 A$="MOO"
20 P=STRPTR(A$)
30 FOR I=0 TO LEN(A$)-1
```

```
40 PRINT CHR$(PEEK(P+I));
50 NEXT
60 A$=""
70 P=STRPTR(A$)
80 FOR I=0 TO LEN(A$)-1 : REM THIS LOOP WILL STILL ALWAYS HAPPEN ONCE
90 PRINT CHR$(PEEK(P+I));
100 NEXT
RUN
MOO"
READY.
```

In this case, the pointer returned on line 70 pointed to the first character after the open quote on line 60. Since it was an empty string, the pointer ended up pointing to the close quote. To avoid this scenario, we should have checked the `LEN(A$)` before line 80 and skipped over the loop.

SYS

TYPE: Command
FORMAT: SYS <address>

Action: The SYS command executes a machine language subroutine located at <address>. Execution continues until an RTS is executed, and control returns to the BASIC program.

In order to communicate with the routine, you can pre-load the CPU registers by using POKE to write to the following memory locations:

- `$030C` : Accumulator
- `$030D` : X Register
- `$030E` : Y Register
- `$030F` : Status Register/Flags

When the routine is over, the CPU registers will be loaded back in to these locations. So you can read the results of a machine language routine by PEEKing these locations.

EXAMPLE of SYS statemet:

Push a <CR> into the keyboard buffer.

```
POKE $30C,13
SYS $FEC3
```

Run the Machine Language Monitor (Supermon)

```
SYS  $FECC
```

TILE

TYPE: Command
FORMAT: TILE <x>,<y>,<tile/screen code>[,<attribute>]

Action: The `TILE` command sets the tile or text character at the given x/y tile/character coordinate to the given screen code or tile index, optionally resetting the attribute byte. It works for tiles or text on Layer 1.

In the default text mode, this can be used to quickly change a character on the screen and optionally its fg/bg color without needing to calculate the VRAM address for VPOKE.

However, it can also be used if VERA Layer 1's map base value is changed or the map size is changed.

EXAMPLE of TILE command:

```
10 REM VERY SLOWLY CLEAR THE SCREEN IN STYLE
20 FOR Y=59 TO 0 STEP -1
30 FOR X=79 TO 0 STEP -1
40 FOR I=255 TO 32 STEP -1
50 TILE X,Y,I
60 NEXT:NEXT:NEXT
```

TATTR

TYPE: Function
FORMAT: TATTR(<x coordinate>,<y coordinate>)

Action: The `TATTR` function retrieves the text/tile attribute at the given x/y coordinate. It works for tiles or text on Layer 1.

In the default text modes, this can be used to retrieve the color attribute (fg/bg) of a specific coordinate without needing to calculate the VRAM address for VPEEK.

EXAMPLE of TATTR command:

```
10 REM COPY BUTTERFLY LOGO WITH COLORS TO CENTER OF 80X60 SCREEN
20 XO = 37 : YO = 27
30 FOR X = 0 TO 6
40 FOR Y = 0 TO 6
50 TD = TDATA(X, Y)
60 TA = TATTR(X, Y)
70 TILE XO+X, YO+Y, TD, TA
80 NEXT:NEXT
```

TDATA

TYPE: Function
FORMAT: TDATA(<x coordinate>,<y coordinate>)

Action: The `TDATA` function retrieves the text/tile at the given x/y coordinate. It works for tiles or text on Layer 1.

In the default text modes, this can be used to retrieve the character a specific coordinate without needing to calculate the VRAM address for VPEEK.

EXAMPLE of TATTR command:

```
10 REM COPY BUTTERFLY LOGO TO CENTER OF 80X60 SCREEN
20 XO = 37 : YO = 27
30 FOR X = 0 TO 6
40 FOR Y = 0 TO 6
50 TD = TDATA(X, Y)
60 TILE XO+X, YO+Y, TD
70 NEXT:NEXT
```

VPEEK

TYPE: Integer Function
FORMAT: VPEEK (<bank>, <address>)

Action: Return a byte from the video address space. The video address space has 17 bit addresses, which is exposed as 2 banks of 65536 addresses each.

In addition, VPEEK can reach add-on VERA cards with higher bank numbers.

BANK 2-3 is for IO3 (VERA at $9F60-$9F7F)
BANK 4-5 is for IO4 (VERA at $9F80-$9F9F)

EXAMPLE of VPEEK Function:

```
PRINT VPEEK(1,$B000) : REM SCREEN CODE OF CHARACTER AT 0/0 ON SCREEN
```

VPOKE

TYPE: Command
FORMAT: VPOKE <bank>, <address>, <value>

Action: Set a byte in the video address space. The video address space has 17 bit addresses, which is exposed as 2 banks of 65536 addresses each.

In addition, VPOKE can reach add-on VERA cards with higher bank numbers.

BANK 2-3 is for IO3 (VERA at $9F60-$9F7F)
BANK 4-5 is for IO4 (VERA at $9F80-$9F9F)

EXAMPLE of VPOKE Statement:

```
VPOKE 1,$B000+1,1 * 16 + 2 : REM SETS THE COLORS OF THE CHARACTER
                             REM AT 0/0 TO RED ON WHITE
```

VLOAD

TYPE: Command
FORMAT: VLOAD <filename>, <device>, <VERA_high_address>, <VERA_low_address>

Action: Loads a file directly into VERA RAM, skipping the two-byte header that is presumed to be in the file.

EXAMPLES of VLOAD:

```
VLOAD "MYFILE.PRG", 8, 0, $4000  :REM LOADS MYFILE.PRG FROM DEVICE 8 TO VRAM $4000
                                  REM WHILE SKIPPING THE FIRST TWO BYTES OF THE FILE.
```

To load a raw binary file without skipping the first two bytes, use `BVLOAD`

Other New Features

Hexadecimal and Binary Literals

The numeric constants parser supports both hex (`$`) and binary (`%`) literals, like this:

```
PRINT $EA31 + %1010
```

The size of hex and binary values is only restricted by the range that can be represented by BASIC's internal floating point representation.

LOAD into VRAM

In BASIC, the contents of files can be directly loaded into VRAM with the `LOAD` statement. When a secondary address greater than one is used, the KERNAL will now load the file into the VERA's VRAM address space. The first two bytes of the file are used as lower 16 bits of the address. The upper 4 bits are `(SA-2) & 0x0ff` where `SA` is the secondary address.

Examples:

```
10 REM LOAD VERA SETTINGS
20 LOAD"VERA.BIN",1,17 : REM SET ADDRESS TO $FXXXX
30 REM LOAD TILES
40 LOAD"TILES.BIN",1,3 : REM SET ADDRESS TO $1XXXX
50 REM LOAD MAP
60 LOAD"MAP.BIN",1,2 : REM SET ADDRESS TO $0XXXX
```

Default Device Numbers

In BASIC, the LOAD, SAVE and OPEN statements default to the last-used IEEE device (device numbers 8 and above), or 8.

Internal Representation

Like on the C64, BASIC keywords are tokenized.

- The C64 BASIC V2 keywords occupy the range of $80 (`END`) to $CB (`GO`).
- BASIC V3.5 also used $CE (`RGR`) to $FD (`WHILE`).
- BASIC V7 introduced the $CE escape code for function tokens $CE-$02 (`POT`) to $CE-$0A (`POINTER`), and the $FE escape code for statement tokens $FE-$02 (`BANK`) to $FE-$38 (`SLOW`).
- The unreleased BASIC V10 extended the escaped tokens up to $CE-$0D (`RPALETTE`) and $FE-$45 (`EDIT`).

The X16 BASIC aims to be as compatible as possible with this encoding. Keywords added to X16 BASIC that also exist in other versions of BASIC match the token, and new keywords are encoded in the ranges $CE-$80+ and $FE-$80+.

Auto-Boot

When BASIC starts, it automatically executes the `BOOT` command, which tries to load a PRG file named `AUTOBOOT.X16` from device 8 and, if successful, runs it. Here are some use cases for this:

- An SD card with a game can auto-boot this way.
- An SD card with a collection of applications can show a menu that allows selecting an application to load.
- The user's "work" SD card can contain a small auto-boot BASIC program that sets the keyboard layout and changes the screen colors, for example.

Chapter 5: KERNAL

The Commander X16 contains a version of KERNAL as its operating system in ROM. It contains

- "Channel I/O" API for abstracting devices
- a variable size screen editor
- a color bitmap graphics API with proportional fonts
- simple memory management
- timekeeping
- drivers
  - PS/2 keyboard and mouse
  - NES/SNES controller
  - Commodore Serial Bus ("IEC")
  - I2C bus

KERNAL Version

The KERNAL version can be read from location $FF80 in ROM. A value of $FF indicates a custom build. All other values encode the build number. Positive numbers are release versions ($02 = release version 2), two's complement negative numbers are prerelease versions ($FE = $100 - 2 = prerelease version 2).

Compatibility Considerations

For applications to remain compatible between different versions of the ROM, they can rely upon:

- the KERNAL API calls at $FF81-$FFF3
- the KERNAL vectors at $0314-$0333

The following features must not be relied upon:

- the zero page and $0200+ memory layout
- direct function offsets in the ROM

Commodore 64 API Compatibility

The KERNAL fully supports the C64 KERNAL API.

These routines have been stable ever since the C64 came out and are extensively documented in various resources dedicated to the C64. Currently, they are not documented *here* so if you need to look them up, here is a very thorough reference of these standard kernal routines (hosted on M. Steil's website). It integrates a dozen or so different sources for documentation about these routines.

Commodore 128 API Compatibility

In addition, the X16 supports a subset of the C128 API.

The following C128 APIs have equivalent functionality on the X16 but are not compatible:

Address	C128 Name	X16 Name
$FF5F	SWAPPER	screen_mode
$FF62	DLCHR	screen_set_charset
$FF74	FETCH	fetch
$FF77	STASH	stash

New API for the Commander X16

There are lots of new APIs. Please note that their addresses and their behavior is still preliminary and can change between revisions.

Some new APIs use the "16 bit" ABI, which uses virtual 16 bit registers r0 through r15, which are located in zero page locations $02 through $21: r0 = r0L = $02, r0H = $03, r1 = r1L = $04 etc.

The 16 bit ABI generally follows the following conventions:

- arguments
  - word-sized arguments: passed in r0-r5
  - byte-sized arguments: if three or less, passed in .A, .X, .Y; otherwise in 16 bit registers
  - boolean arguments: c, n
- return values
  - basic rules as above
  - function takes no arguments: r0-r5, else indirect through passed-in pointer
  - arguments in r0-r5 can be "inout", i.e. they can be updated
- saved/scratch registers
  - r0-r5: arguments (saved)
  - r6-r10: saved
  - r11-r15: scratch
  - .A, .X, .Y, c, n: scratch (unless used otherwise)

KERNAL API functions

Label	Address	Class	Description	Inputs	Affects	Origin
ACPTR	$FFA5	CPB	Read byte from peripheral bus		A X	C64
BASIN	$FFCF	ChIO	Get character		A X	C64
BSAVE	$FEBA	ChIO	Like SAVE but omits the 2-byte header	A X Y	A X Y	X16
BSOUT	$FFD2	ChIO	Write byte in A to default output.	A	P	C64
CIOUT	$FFA8	CPB	Send byte to peripheral bus	A	A X	C64
CLALL	$FFE7	ChIO	Close all channels		A X	C64
CLOSE	$FFC3	ChIO	Close a channel	A	A X Y P	C64
CHKIN	$FFC6	ChIO	Set channel for character input	X	A X	C64
clock_get_date_time	$FF50	Time	Get the date and time	none	r0 r1 r2 r3 A X Y P	X16
clock_set_date_time	$FF4D	Time	Set the date and time	r0 r1 r2 r3	A X Y P	X16
CHRIN	$FFCF	ChIO	Alias for BASIN		A X	C64
CHROUT	$FFD2	ChIO	Alias for BSOUT	A	P	C64
CLOSE_ALL	$FF4A	ChIO	Close all files on a device			C128
CLRCHN	$FFCC	ChIO	Restore character I/O to screen/keyboard		A X	C64
console_init	$FEDB	Video	Initialize console mode	none	r0 A P	X16
console_get_char	$FEE1	Video	Get character from console	A	r0 r1 r2 r3 r4 r5 r6 r12 r13 r14 r15 A X Y P	X16
console_put_char	$FEDE	Video	Print character to console	A C	r0 r1 r2 r3 r4 r5 r6 r12 r13 r14 r15 A X Y P	X16
console_put_image	$FED8	Video	Draw image as if it was a character	r0 r1 r2	r0 r1 r2 r3 r4 r5 r14 r15 A X Y P	X16
console_set_paging_message	$FED5	Video	Set paging message or disable paging	r0	A P	X16
enter_basic	$FF47	Misc	Enter BASIC	C	A X Y P	X16
entropy_get	$FECF	Misc	get 24 random bits	none	A X Y P	X16

extapi	$FEAB	Misc	Extended API	A X Y P	A X Y P	X16
extapi16	$FEA8	Misc	Extended 65C816 API	A X Y P	A X Y P	X16
fetch	$FF74	Mem	Read a byte from any RAM or ROM bank	(A) X Y	A X P	X16
FB_cursor_next_line †	$FF02	Video	Move direct-access cursor to next line	r0†	A P	X16
FB_cursor_position	$FEFF	Video	Position the direct-access cursor	r0 r1	A P	X16
FB_fill_pixels	$FF17	Video	Fill pixels with constant color, update cursor	r0 r1 A	A X Y P	X16
FB_filter_pixels	$FF1A	Video	Apply transform to pixels, update cursor	r0 r1	r14H r15 A X Y P	X16
FB_get_info	$FEF9	Video	Get screen size and color depth	none	r0 r1 A P	X16
FB_get_pixel	$FF05	Video	Read one pixel, update cursor	none	A	X16
FB_get_pixels	$FF08	Video	Copy pixels into RAM, update cursor	r0 r1	(r0) A X Y P	X16
FB_init	$FEF6	Video	Enable graphics mode	none	A P	X16
FB_move_pixels	$FF1D	Video	Copy horizontally consecutive pixels to a different position	r0 r1 r2 r3 r4	A X Y P	X16
FB_set_8_pixels	$FF11	Video	Set 8 pixels from bit mask (transparent), update cursor	A X	A P	X16
FB_set_8_pixels_opaque	$FF14	Video	Set 8 pixels from bit mask (opaque), update cursor	r0L A X Y	r0L A P	X16
FB_set_palette	$FEFC	Video	Set (parts of) the palette	A X r0	A X Y P	X16
FB_set_pixel	$FF0B	Video	Set one pixel, update cursor	A	none	X16
FB_set_pixels	$FF0E	Video	Copy pixels from RAM, update cursor	r0 r1	A X P	X16
GETIN	$FFE4	Kbd	Get character from keyboard		A X	C64
GRAPH_clear	$FF23	Video	Clear screen	none	r0 r1 r2 r3 A X Y P	X16
GRAPH_draw_image	$FF38	Video	Draw a rectangular image	r0 r1 r2 r3 r4	A P	X16
GRAPH_draw_line	$FF2C	Video	Draw a line	r0 r1 r2 r3	r0 r1 r2 r3 r7 r8 r9 r10 r12 r13 A X Y P	X16
GRAPH_draw_oval	$FF35	Video	Draw an oval or circle (optionally filled)	r0 r1 r2 r3 r4 C	A X Y P	X16
GRAPH_draw_rect †	$FF2F	Video	Draw a rectangle (optionally filled)	r0 r1 r2 r3 r4 C	A P	X16
GRAPH_get_char_size	$FF3E	Video	Get size and baseline of a character	A X	A X Y P	X16
GRAPH_init	$FF20	Video	Initialize graphics	r0	r0 r1 r2 r3 A X Y P	X16
GRAPH_move_rect †	$FF32	Video	Move pixels	r0 r1 r2 r3 r4 r5	r1 r3 r5 A X Y P	X16
GRAPH_put_char †	$FF41	Video	Print a character	r0 r1 A	r0 r1 A X Y P	X16

GRAPH_set_colors	$FF29	Video	Set stroke, fill and background colors	A X Y	none	X16
GRAPH_set_font	$FF3B	Video	Set the current font	r0	r0 A Y P	X16
GRAPH_set_window †	$FF26	Video	Set clipping region	r0 r1 r2 r3	A P	X16
i2c_batch_read	$FEB4	I2C	Read multiple bytes from an I2C device	X r0 r1 C	A Y C	X16
i2c_batch_write	$FEB7	I2C	Write multiple bytes to an I2C device	X r0 r1 C	A Y r2 C	X16
i2c_read_byte	$FEC6	I2C	Read a byte from an I2C device	A X Y	A C	X16
i2c_write_byte	$FEC9	I2C	Write a byte to an I2C device	A X Y	A C	X16
IOBASE	$FFF3	Misc	Return start of I/O area		X Y	C64
JSRFAR	$FF6E	Misc	Execute a routine on another RAM or ROM bank	PC+3 PC+5	none	X16
joystick_get	$FF56	Joy	Get one of the saved controller states	A	A X Y P	X16
joystick_scan	$FF53	Joy	Poll controller states and save them	none	A X Y P	X16
kbd_scan	$FF9F	Kbd	Process a keystroke and place it in the buffer	none	A X Y P	C64
kbdbuf_get_modifiers	$FEC0	Kbd	Get currently pressed modifiers	A	A X P	X16
kbdbuf_peek	$FEBD	Kbd	Get next char and keyboard queue length	A X	A X P	X16
kbdbuf_put	$FEC3	Kbd	Append a character to the keyboard queue	A	X	X16
keymap	$FED2	Kbd	Set or get the current keyboard layout Call address	X Y C	A X Y C	X16
LISTEN	$FFB1	CPB	Send LISTEN command	A	A X	C64
LKUPLA	$FF59	ChIO	Search tables for given LA			C128
LKUPSA	$FF5C	ChIO	Search tables for given SA			C128
LOAD	$FFD5	ChIO	Load a file into main memory or VRAM	A X Y	A X Y	C64
MACPTR	$FF44	CPB	Read multiple bytes from the peripheral bus	A X Y C	A X Y P	X16
MCIOUT	$FEB1	CPB	Write multiple bytes to the peripheral bus	A X Y C	A X Y P	X16
MEMBOT	$FF9C	Mem	Get address of start of usable RAM			C64
MEMTOP	$FF99	Mem	Get/set number of banks and address of the end of usable RAM		A X Y	C64
memory_copy	$FEE7	Mem	Copy a memory region to a different region	r0 r1 r2	r2 A X Y P	X16
memory_crc	$FEEA	Mem	Calculate the CRC16 of a memory region	r0 r1	r2 A X Y P	X16
memory_decompress	$FEED	Mem	Decompress an LZSA2 block	r0 r1	r1 A X Y P	X16

memory_fill	$FEE4	Mem	Fill a memory region with a byte value	A r0 r1	r1 X Y P	X16
monitor	$FECC	Misc	Enter machine language monitor	none	A X Y P	X16
mouse_config	$FF68	Mouse	Configure mouse pointer	A X Y	A X Y P	X16
mouse_get	$FF6B	Mouse	Get saved mouse sate	X	A (X) P	X16
mouse_scan	$FF71	Mouse	Poll mouse state and save it	none	A X Y P	X16
OPEN	$FFC0	ChIO	Open a channel/file.		A X Y	C64
PLOT	$FFF0	Video	Read/write cursor position	A X Y	A X Y	C64
PRIMM	$FF7D	Misc	Print string following the caller's code			C128
RDTIM	$FFDE	Time	Read system clock		A X Y	C64
READST	$FFB7	ChIO	Return status byte		A	C64
SAVE	$FFD8	ChIO	Save a file from memory	A X Y	A X Y C	C64
SCNKEY	$FF9F	Kbd	Alias for kbd_scan	none	A X Y P	C64
SCREEN	$FFED	Video	Get the text resolution of the screen		X Y	C64
screen_mode	$FF5F	Video	Get/set screen mode	A C	A X Y P	X16
screen_set_charset	$FF62	Video	Activate 8x8 text mode charset	A X Y	A X Y P	X16
SECOND	$FF93	CPB	Send LISTEN secondary address	A	A	C64
SETLFS	$FFBA	ChIO	Set file parameters (LA, FA, and SA).	A X Y		C64
SETMSG	$FF90	ChIO	Set verbosity	A		C64
SETNAM	$FFBD	ChIO	Set file name.	A X Y		C64
SETTIM	$FFDB	Time	Write system clock	A X Y	A X Y	C64
SETTMO	$FFA2	CPB	Set timeout			C64
sprite_set_image †	$FEF0	Video	Set the image of a sprite	r0 r1 r2L A X Y C	A P	X16
sprite_set_position	$FEF3	Video	Set the position of a sprite	r0 r1 A	A X P	X16
stash	$FF77	Mem	Write a byte to any RAM bank	stavec A X Y	(stavec) X P	X16
STOP	$FFE1	Kbd	Test for STOP key		A X P	C64
TALK	$FFB4	CPB	Send TALK command	A	A	C64
TKSA	$FF96	CPB	Send TALK secondary address	A	A	C64
UDTIM	$FFEA	Time	Increment the jiffies clock		A X	C64
UNLSN	$FFAE	CPB	Send UNLISTEN command		A	C64
UNTLK	$FFAB	CPB	Send UNTALK command		A	C64

🚫 = Currently unimplemented
† = Partially implemented

Some notes:

- For device #8, the Commodore Peripheral Bus calls first talk to the "Computer DOS" built into the ROM to detect an SD card, before falling back to the Commodore Serial Bus.
- The `IOBASE` call returns $9F00, the location of the first VIA controller.
- The `SETTMO` call has been a no-op since the Commodore VIC-20, and has no function on the X16 either.
- The layout of the zero page ($0000-$00FF) and the KERNAL/BASIC variable space ($0200+) are generally **not** compatible with the C64.

KERNAL Vectors

The KERNAL indirect vectors ($0314-$0333) are fully compatible with the C64:

$0314-$0315: `CINV` – IRQ Interrupt Routine
$0316-$0317: `CBINV` – BRK Instruction Interrupt
$0318-$0319: `NMINV` – Non-Maskable Interrupt
$031A-$031B: `IOPEN` – Kernal OPEN Routine
$031C-$031D: `ICLOSE` – Kernal CLOSE Routine
$031E-$031F: `ICHKIN` – Kernal CHKIN Routine
$0320-$0321: `ICKOUT` – Kernal CKOUT Routine
$0322-$0323: `ICLRCH` – Kernal CLRCHN Routine
$0324-$0325: `IBASIN` – Kernal CHRIN Routine
$0326-$0327: `IBSOUT` – Kernal CHROUT Routine
$0328-$0329: `ISTOP` – Kernal STOP Routine
$032A-$032B: `IGETIN` – Kernal GETIN Routine
$032C-$032D: `ICLALL` – Kernal CLALL Routine
$0330-$0331: `ILOAD` – Kernal LOAD Routine
$0332-$0333: `ISAVE` – Kernal SAVE Routine

Additional KERNAL indirect vectors have been added as part of the KERNAL's 65C816 support

$0334-$0335: `IECOP` - COP Instruction Interrupt Routine (emulation mode)
$0336-$0337: `IEABORT` - ABORT Routine (emulation mode)
$0338-$0339: `INIRQ` - IRQ Interrupt Routine (native mode)
$033A-$033B: `INBRK` - BRK Instruction Interrupt Routine (native mode)
$033C-$033D: `INNMI` - Non-Maskable Interrupt Routine (native mode)
$033E-$033F: `INCOP` - COP Instruction Interrupt Routine (native mode)
$0340-$0341: `INABORT` - ABORT Routine (native mode)

Handling NMI

If the NMI vector is replaced with a user function and that function does not call back to the replaced NMI routine, some cleanup will need to be done. Before the user NMI function is called, the KERNAL pushes `a` and the rom bank onto the stack. These values will need to be popped before returning from the NMI:

```
.proc my_awesome_nmi
        ...

    pla
    sta $01
    pla
    rti
.endproc
```

Commodore Peripheral Bus

The X16 adds two new functions for dealing with the Commodore Peripheral Bus ("IEEE"):

$FEB1: `MCIOUT` - write multiple bytes to peripheral bus $FF44: `MACPTR` - read multiple bytes from peripheral bus

---

Function Name: ACPTR

Purpose: Read a byte from the peripheral bus
Call address: $FFA5
Communication registers: .A
Preparatory routines: `SETNAM` , `SETLFS` , `OPEN` , `CHKIN`
Error returns: None
Registers affected: .A .X .Y .P

Description: This routine gets a byte of data off the peripheral bus. The data is returned in the accumulator. Errors are returned in the status word which can be read via the `READST` API call.

Function Name: MACPTR

Purpose: Read multiple bytes from the peripheral bus
Call address: $FF44
Communication registers: .A .X .Y c
Preparatory routines: `SETNAM`, `SETLFS`, `OPEN`, `CHKIN`
Error returns: None
Registers affected: .A .X .Y

Description: The routine `MACPTR` is the multi-byte variant of the `ACPTR` KERNAL routine. Instead of returning a single byte in .A, it can read multiple bytes in one call and write them directly to memory.

The number of bytes to be read is passed in the .A register; a value of 0 indicates that it is up to the KERNAL to decide how many bytes to read - up to a maximum of 512 bytes (this corresponds to 1 sector on the SD card). A pointer to where the data is supposed to be written is passed in the .X (lo) and .Y (hi) registers. If carry flag is clear, the destination address will advance with each byte read. If the carry flag is set, the destination address will not advance as data is read. This is useful for reading data directly into VRAM, PCM FIFO, etc.

For reading into Hi RAM, you must set the desired bank prior to calling `MACPTR`. During the read, `MACPTR` will automatically wrap to the next bank as required, leaving the new bank active when finished.

Upon return, a set c flag indicates that the device or file does not support `MACPTR`, and the program needs to read the data byte-by-byte using the `ACPTR` call instead.

If `MACPTR` is supported, c is clear and .X (lo) and .Y (hi) contain the number of bytes read. *It is possible that this is less than the number of bytes requested to be read! (But is always greater than 0)*

Like with `ACPTR`, the status of the operation can be retrieved using the `READST` KERNAL call.

Function Name: MCIOUT

Purpose: Write multiple bytes to the peripheral bus
Call address: $FEB1
Communication registers: .A .X .Y c
Preparatory routines: `SETNAM`, `SETLFS`, `OPEN`, `CHKOUT`
Error returns: None
Registers affected: .A .X .Y

Description: The routine `MCIOUT` is the multi-byte variant of the `CIOUT` KERNAL routine. Instead of writing a single byte, it can write multiple bytes from memory in one call.

The number of bytes to be written is passed in the .A register; a value of 0 indicates 256 bytes. A pointer to the data to be read from is passed in the .X (lo) and .Y (hi) registers. If carry flag is clear, the source address will advance with each byte read out. If the carry flag is set, the source address will not advance as data is read out. This is useful for saving data directly from VRAM.

For reading from Hi RAM, you must set the desired bank prior to calling `MCIOUT`. During the operation, `MCIOUT` will automatically wrap to the next bank as required, leaving the new bank active when finished.

Upon return, a set c flag indicates that the device or file does not support `MCIOUT`, and the program needs to write the data byte-by-byte using the `CIOUT` call instead.

If `MCIOUT` is supported, c is clear and .X (lo) and .Y (hi) contain the number of bytes written. *It is possible that this is less than the number of bytes requested to be written! (But is always greater than 0)*

Like with `CIOUT`, the status of the operation can be retrieved using the `READST` KERNAL call. If an error occurred, `READST` should return nonzero.

Channel I/O

Function Name: `BSAVE`

Purpose: Save an area of memory to a file without writing an address header.
Call Address: $FEBA
Communication Registers: .A .X .Y
Preparatory routines: SETNAM, SETLFS

Error returns: c = 0 if no error, c = 1 in case of error and A will contain kernel error code
Registers affected: .A .X .Y .P

Description: Save the contents of a memory range to a file. Unlike `SAVE`, this call does not write the start address to the beginning of the output file.

`SETLFS` and `SETNAM` must be called beforehand.
A is address of zero page pointer to the start address.
X and Y contain the *exclusive* end address to save. That is, these should contain the address immediately after the final byte: X = low byte, Y = high byte.
Upon return, if C is clear, there were no errors. C being set indicates an error in which case A will have the error number.

Function Name: `BSOUT`

(This routine is also referred to as `CHROUT`)

Purpose: Write a character to the default output device.
Call Address: $FFD2
Communication Register: .A
Preparatory routines: OPEN, CHKOUT (Both are only needed when sending to files/other non-screen devices)
Error returns: c = 0 if no error, c = 1 in case of error
Registers affected: .P

Description: Writes the character in A to the currently-selected output device. By default, this is the user's screen. By calling `CHKOUT`, however, the default device can be changed and characters can be sent to other devices - a file on an SD card, for example. In order to send output to a file, call `OPEN` first to open the file, then `CHKOUT` to set it as the default output device, then finally `BSOUT` to write the data.

Upon return, if C is clear, there were no errors. Otherwise, C will be set.

Note: Before returning, this routine uses a `CLI` processor instruction, which will allow IRQ interrupts to be triggered. This makes the `BSOUT` routine inappropriate for use within interrupt handler functions. One possible workaround could be to output text information directly, by writing to the appropriate VERA registers. Care must be taken to save and restore the VERA's state, however, in order to prevent affecting other software running on the system (to include BASIC or the KERNAL itself).

Function Name: `CLOSE`

Purpose: Close a logical file
Call address: $FFC3
Communication registers: .A
Preparatory routines: None
Error returns: None
Registers affected: .A .X .Y .P

Description: `CLOSE` releases resources associated with a logical file number. If the associated device is a serial device on the IEC bus or is a simulated serial device such as CMDR-DOS backed by the X16 SD card, and the file was opened with a secondary address, a close command is sent to the device or to CMDR-DOS.

Function Name: `CHKIN`

Purpose: Set file to be used for character input Call address: $FFC6 Communication registers: .X Preparatory routines: OPEN
Error returns: None
Registers affected: .A .X

Description: `CHKIN` sets a file to be used as default input allowing for subsequent calls to `CHRIN` or other file read functions. The `x` register should contain the logical file number. `OPEN` will need to have been called prior to using `CHKIN`.

Function Name: `LOAD`

Purpose: Load the contents of a file from disk to memory
Call address: $FFD5
Communication registers: .A .X .Y
Preparatory routines: SETNAM, SETLFS
Error returns: Carry (Set on Error), .A
Registers affected: .A .X .Y .P

Description: Loads a file from disk to memory.

The behavior of `LOAD` can be modified by parameters passed to prior call to `SETLFS`. In particular, the .Y register, which usually denotes the *secondary address*, has a specific meaning as follows:

- .Y = 0: load to the address given in .X/.Y to the `LOAD` call, skipping the first two bytes of the file. (like `LOAD "FILE",8` in BASIC)
- .Y = 1: load to the address given by the first two bytes of the file. The address in .X/.Y is ignored. (like `LOAD "FILE",8,1` in BASIC)
- .Y = 2: load the entire file to the address given in .X/.Y to the `LOAD` call. This is also known as a *headerless* load. (like `BLOAD "FILE",8,1,$A000` in BASIC)

For the `LOAD` call itself, .X and .Y is the memory address to load the file into. .A controls where the file is to be loaded. On the X16, `LOAD` has an additional feature to load the contents of a file directly into VRAM.

- If the A register is zero, the kernal loads into system memory.
- If the A register is 1, the kernal performs a verify.
- If the A register is 2, the kernal loads into VRAM, starting from $00000 + the specified starting address.
- If the A register is 3, the kernal loads into VRAM, starting from $10000 + the specified starting address.

(On the C64, if A is greater than or equal to 1, the kernal performs a verify)

For loads into the banked RAM area. The current RAM bank (in location `$00`) is used as the start point for the load along with the supplied address. If the load is large enough to advance to the end of banked RAM (`$BFFF`), the RAM bank is automatically advanced, and the load continues into the next bank starting at `$A000`.

After the load, if c is set, an error occurred and .A will contain the error code. If c is clear, .X/.Y will point to the address of final byte loaded + 1.

Note: One does not need to call `CLOSE` after `LOAD`.

Function Name: `OPEN`

Purpose: Opens a channel/file
Call address: $FFC0
Communication registers: None
Preparatory routines: SETNAM, SETLFS
Error returns: None
Registers affected: .A .X .Y

Description: Opens a file or channel.
The most common pattern is to then redirect the standard input or output to the file using `CHKIN` or `CHKOUT` respectively. Afterwards, I/O from or to the file or channel is done using `BASIN` (`CHRIN`) and `BSOUT` (`CHROUT`) respectively.

For file I/O, the lower level calls `ACPTR` and `MACPTR` can be used in place of `CHRIN`, since `CHKIN` does the low-level setup for this. Likewise `CIOUT` and `MCIOUT` can be used after `CHKOUT` for the same reason.

Function Name: `SAVE`

Purpose: Save an area of memory to a file.
Call Address: $FFD8
Communication Registers: .A .X .Y
Preparatory routines: SETNAM, SETLFS
Error returns: c = 0 if no error, c = 1 in case of error and A will contain kernel error code
Registers affected: .A .X .Y .P

Description: Save the contents of a memory range to a file. The (little-endian) start address is written to the file as the first two bytes of output, followed by the requested data.

`SETLFS` and `SETNAM` must be called beforehand.
A is address of zero page pointer to start address.
X = low byte of end address + 1, Y = high byte of end address.
If C is zero there were no errors; 1 is an error in which case A will have the error

---

Function Name: `SETLFS`

Purpose: Set file parameters
Call Address: $FFBA
Communication Registers: .A .X .Y
Preparatory routines: SETNAM
Error returns: None
Registers affected: .A .X .Y

Description: Set file parameters typically after calling SETNAM

A is the logical file number, X is the device number, and Y is the secondary address.

Since multiple files can be open (with some exceptions), the value of A specifies the file number. If only one file is being opened at a time, $01 can be used.

The device number corresponds to the hardware device where the file lives. On the X16, $08 would be the SD card.

The secondary address has some special meanings:

When used with `OPEN` on disk type devices, the following applies:

- 0 = Load (open for read)
- 1 = Save (open for write)
- 2-14 = Read mode, by default. Write, Append, and Modify modes can be specified in the SETNAM filename string as the third argument, e.g. `"FILE.DAT,S,W"` for write mode. The seek command "P" is available in any mode.
- 15 = Command Channel (for sending special commands to CMDR-DOS or the disk device)

When used with `LOAD` the following applies:

- 0 = Load the data to address specified in the X and Y register of the LOAD call, regardless of the address header. The two-byte header itself is not loaded into RAM.
- 1 = Load to the address specified in the file's header. The two-byte header itself is not loaded into RAM.
- 2 = Load the data to address specified in the X and Y register of the LOAD call. The entire file is loaded ("headerless").

For more information see Chapter 13: Working with CMDR-DOS

Function Name: `SETNAM`

Purpose: Set file name
Call Address: $FFBD
Communication Registers: .A .X .Y
Preparatory routines: SETLFS
Error returns: None
Registers affected: .A .X .Y

Description: Inform the kernal the name of the file that is to later be opened. A is filename length, X is low byte of filename pointer, Y is high byte of filename pointer.

For example:

```
lda #$08
ldx #<filename
ldy #>filename
jsr SETNAM
```

`SETLFS` and `SETNAM` both need to be called prior other file comamnds, such as `OPEN` or `SAVE`.

Memory

$FEE4: `memory_fill` - fill memory region with a byte value
$FEE7: `memory_copy` - copy memory region
$FEEA: `memory_crc` - calculate CRC16 of memory region
$FEED: `memory_decompress` - decompress LZSA2 block
$FF74: `fetch` - read a byte from any RAM or ROM bank
$FF77: `stash` - write a byte to any RAM bank $FF99: `MEMTOP` - get number of banks and address of end of usable RAM

Function Name: memory_fill

Signature: void memory_fill(word address: r0, word num_bytes: r1, byte value: .A);
Purpose: Fill a memory region with a byte value.
Call address: $FEE4

Description: This function fills the memory region specified by an address (r0) and a size in bytes (r1) with the constant byte value passed in .A. r0 and .A are preserved, r1 is destroyed.

If the target address is in the $9F00-$9FFF range, all bytes will be written to the same address (r0), i.e. the address will not be incremented. This is useful for filling VERA memory ($9F23 or $9F24), for example.

Function Name: memory_copy

Signature: void memory_copy(word source: r0, word target: r1, word num_bytes: r2);
Purpose: Copy a memory region to a different region.
Call address: $FEE7

Description: This function copies one memory region specified by an address (r0) and a size in bytes (r2) to a different region specified by its start address (r1). The two regions may overlap. r0 and r1 are preserved, r2 is destroyed.

Like with `memory_fill`, source and destination addresses in the $9F00-$9FFF range will not be incremented during the copy. This allows, for instance, uploading data from RAM to VERA (destination of $9F23 or $9F24), downloading data from VERA (source $9F23 or $9F24) or copying data inside VERA (source $9F23, destination $9F24). This functionality can also be used to upload, download or transfer data with other I/O devices that have an 8 bit data port.

Function Name: memory_crc

Signature: (word result: r2) memory_crc(word address: r0, word num_bytes: r1);
Purpose: Calculate the CRC16 of a memory region.
Call address: $FEEA

Description: This function calculates the CRC16 checksum of the memory region specified by an address (r0) and a size in bytes (r1). The result is returned in r2. r0 is preserved, r1 is destroyed.

Like `memory_fill`, this function does not increment the address if it is in the range of $9F00-$9FFF, which allows checksumming VERA memory or data streamed from any other I/O device.

Function Name: memory_decompress

Signature: void memory_decompress(word input: r0, inout word output: r1);
Purpose: Decompress an LZSA2 block
Call address: $FEED

Description: This function decompresses an LZSA2-compressed data block from the location passed in r0 and outputs the decompressed data at the location passed in r1. After the call, r1 will be updated with the location of the last output byte plus one.

If the target address is in the $9F00-$9FFF range, all bytes will be written to the same address (r0), i.e. the address will not be incremented. This is useful for decompressing directly into VERA memory ($9F23 or $9F24), for example. Note that decompressing *from* I/O is not supported.

Notes:

- To create compressed data, use the `lzsa` tool ^1 like this: `lzsa -r -f2 <original_file> <compressed_file>`
- If using the LZSA library to compress data, make sure to use format 2 and include the raw blocks flag, which is what the above command does.
- This function cannot be used to decompress data in-place, as the output data would overwrite the input data before it is consumed. Therefore, make sure to load the input data to a different location.
- It is possible to have the input data stored in banked RAM, with the obvious 8 KB size restriction.

Function Name: fetch

Purpose: Read a byte from any RAM or ROM bank
Call address: $FF74
Communication registers: .A .X .Y .P

Description: This function performs an `LDA (ZP),Y` from any RAM or ROM bank. The the zero page address containing the base address is passed in .A, the bank in .X and the offset from the vector in .Y. The data byte is returned in .A. The flags are set according to .A, .X is destroyed, but .Y is preserved.

Function Name: stash

Purpose: Write a byte to any RAM bank
Call address: $FF77
Communication registers: .A .X .Y

Description: This function performs an `STA (ZP),Y` to any RAM bank. The the zero page address containing the base address is passed in `stavec` ($03B2), the bank in .X and the offset from the vector in .Y. After the call, .X is destroyed, but .A and .Y are preserved.

Function Name: MEMTOP

Purpose: Get/Set top of RAM, number of usable RAM banks.
Call address: $FF99
Communication registers: .A .X .Y .P (Carry)
Registers affected: .A .X .Y

Description: Original C64 function which gets or sets the top of the usable address in RAM. On the X16, it additionally provides the number of RAM banks available on the system and can even be used to set this value after boot if desired.

To set the top of RAM, and the number of available banks, clear the carry flag.

To get the top of RAM and the number of available banks, set carry flag.

Note that the number of RAM banks is for informational purposes or for use by other programs. The KERNAL does not use this value itself.

Getting the number of usable RAM banks:

On the X16, calling MEMTOP with the carry flag set will return the number of available RAM banks on the system in A. For example:

```
sec
jsr MEMTOP
sta zp_NUM_BANKS
```

If the system has 512k of banked RAM, zp_NUM_BANKS will contain $40 (64). For 1024k, $80; for 1536k, $C0. For 2048k, the result will be $00 (which can be thought of as $100, or 256). It is possible to have other values (e.g. $42), such as if the system has bad banked RAM.

Setting the top of BASIC RAM

This routine changes the top of memory, allowing you to save a small machine language routine at the top of BASIC RAM, just below the I/O space:

```
10 POKE$30F,1:SYS$FF99
20 Y=$8C:X=$00
30 POKE$30D,X:POKE$30E,Y:POKE$30F,0:SYS$FF99
40 CLR
```

Analysis:

The SYS command uses memory locations $30C-$30F to pre-load the CPU registers, it then dumps the registers back to these locations after the SYS call is complete. $30D is the X register, $30E is .Y, and $30F is the flags. The Carry flag is bit 0, so setting $30F to 1 before calling MEMTOP indicates that this is a *read* of the values.

1. Line 10 reads the current values. Do this to preserve the extended RAM bank count.
2. Line 20 uses the X and Y variables to make the code easier to read. Set Y to the high byte of the address and X to the low byte.
3. Line 30 POKEs those values in, clears the Carry bit ($30F is now 0), and calls MEMTOP again.
4. Finally, use CLR to lock in the new values. Since this clears all the variables, you should *probably* do this at the top of your program.

The address entered is actually the first byte of free space *after* your BASIC program space, so if you set MEMTOP to $9C00, then you can start your assembly program at $9C00 with `* = $9C00` or `org $9c00`.

To reserve 256 bytes, set X to $9E. To reserve 1KB, set X to $9C. To return to the default values, set Y=$9F and X=0.

Clock

$FF4D: `clock_set_date_time` - set date and time
$FF50: `clock_get_date_time` - get date and time

Function Name: clock_set_date_time

Purpose: Set the date and time
Call address: $FF4D
Communication registers: r0 r1 r2 r3
Preparatory routines: None
Error returns: None
Registers affected: .A .X .Y

Description: The routine `clock_set_date_time` sets the system's real-time-clock.

Register	Contents
r0L	year (1900-based)
r0H	month (1-12)
r1L	day (1-31)
r1H	hours (0-23)
r2L	minutes (0-59)
r2H	seconds (0-59)
r3L	jiffies (0-59)
r3H	weekday (1-7)

Jiffies are 1/60th seconds.

Function Name: clock_get_date_time

Purpose: Get the date and time
Call address: $FF50
Communication registers: r0 r1 r2 r3
Preparatory routines: None
Error returns: None
Registers affected: .A .X .Y

Description: The routine `clock_get_date_time` returns the state of the system's real-time-clock. The register assignment is identical to `clock_set_date_time`.

On the Commander X16, the *jiffies* field is unsupported and will always read back as 0.

Function Name: RDTIM

Purpose: Read system clock
Call address: $FFDE
Communication registers: .A .X .Y
Preparatory routines: None
Error returns: None
Registers affected: .A .X .Y

Description: Original C64 function which reads the system clock. The clock's resolution is a 60th of a second. Three bytes are returned by the routine. The accumulator contains the least significant byte, the X index register contains the next most significant byte, and the Y index register contains the the most significant byte.

The behavior of this Kernal routine is the same on the X16 and C64 despite errors in the *Commodore 64 Programmer's Reference Guide* and some other period books which incorrectly describe the order/significance of the resulting bytes in the registers.

EXAMPLE:

```
jsr RDTIM
sta STARTTIME    ; least significant byte
stx STARTTIME+1
sty STARTTIME+2  ; most significant byte
```

Keyboard

$FEBD: `kbdbuf_peek` - get first char in keyboard queue and queue length
$FEC0: `kbdbuf_get_modifiers` - get currently pressed modifiers
$FEC3: `kbdbuf_put` - append a char to the keyboard queue
$FED2: `keymap` - set or get the current keyboard layout

Function Name: kbdbuf_peek

Purpose: Get next char and keyboard queue length
Call address: $FEBD
Communication registers: .A .X
Preparatory routines: None
Error returns: None
Registers affected: -

Description: The routine `kbdbuf_peek` returns the next character in the keyboard queue in .A, without removing it from the queue, and the current length of the queue in .X. If .X is 0, the Z flag will be set, and the value of .A is undefined.

Function Name: kbdbuf_get_modifiers

Purpose: Get currently pressed modifiers
Call address: $FEC0
Communication registers: .A
Preparatory routines: None
Error returns: None
Registers affected: -

Description: The routine `kbdbuf_get_modifiers` returns a bitmask that represents the currently pressed modifier keys in .A:

Bit	Value	Description	Comment
0	1	Shift	
1	2	Alt	C64: Commodore
2	4	Control	
3	8	Logo/Windows	C128: Alt
4	16	Caps	

This allows detecting combinations of a regular key and a modifier key in cases where there is no dedicated PETSCII code for the combination, e.g. Ctrl+Esc or Alt+F1.

Function Name: kbdbuf_put

Purpose: Append a char to the keyboard queue
Call address: $FEC3
Communication registers: .A
Preparatory routines: None
Error returns: None
Registers affected: .X

Description: The routine `kbdbuf_put` appends the char in .A to the keyboard queue.

Function Name: keymap

Purpose: Set or get the current keyboard layout Call address: $FED2
Communication registers: .X .Y
Preparatory routines: None
Error returns: c = 1 in case of error
Registers affected: -

Description: If c is set, the routine `keymap` returns a pointer to a zero-terminated string with the current keyboard layout identifier in .X/.Y. If c is clear, it sets the keyboard layout to the zero-terminated identifier pointed to by .X/.Y. On return, c is set in case the keyboard layout is unsupported.

Keyboard layout identifiers are in the form "DE", "DE-CH" etc.

Function Name: kbd_scan

Also Known As: SCNKEY
Purpose: Read a keycode previously fetched from the SMC, apply keymap localization, and add it to the X16's buffer.

Call address: $FF9F
Communication registers: None
Preparatory routines: `ps2data_fetch`
Error returns: None
Registers affected: .A .X .Y

Description:

This routine is called by the default KERNAL IRQ hancler in order to process a keystroke previously fetched by `ps2data_fetch`, translate it to the appropriate localized PETSCII or ISO code based on the configured layout, and place it in the KERNAL's keyboard buffer.

Unless the KERNAL IRQ handler is being bypassed or supplemented, it is not normally necessary to call this routine from user code, as both `ps2data_fetch` and `kbd_scan` are both run inside the default IRQ handler.

Mouse

$FF68: `mouse_config` - configure mouse pointer
$FF71: `mouse_scan` - query mouse
$FF6B: `mouse_get` - get state of mouse

Function Name: mouse_config

Purpose: Configure the mouse pointer
Call address: $FF68
Communication registers: .A .X .Y
Preparatory routines: None
Error returns: None
Registers affected: .A .X .Y

Description: The routine `mouse_config` configures the mouse pointer.

The argument in .A specifies whether the mouse pointer should be visible or not, and what shape it should have. For a list of possible values, see the basic statement `MOUSE`.

The arguments in .X and .Y specify the screen resolution in 8 pixel increments. The values .X = 0 and .Y = 0 keep the current resolution.

EXAMPLE:

SEC JSR screen_mode ; get current screen size (in 8px) into .X and .Y LDA #1 JSR mouse_config ; show the default mouse pointer

---

Function Name: mouse_scan

Purpose: Query the mouse and save its state
Call address: $FF71
Communication registers: None
Preparatory routines: None
Error returns: None
Registers affected: .A .X .Y

Description: The routine `mouse_scan` retrieves all state from the mouse and saves it. It can then be retrieved using `mouse_get`. The default interrupt handler already takes care of this, so this routine should only be called if the interrupt handler has been completely replaced.

Function Name: mouse_get

Purpose: Get the mouse state
Call address: $FF6B
Communication registers: .X
Preparatory routines: `mouse_config`
Error returns: None
Registers affected: .A .X

Description: The routine `mouse_get` returns the state of the mouse. The caller passes the offset of a zero-page location in .X, which the routine will populate with the mouse position in 4 consecutive bytes:

Offset	Size	Description
0	2	X Position

2	2	Y Position

The state of the mouse buttons is returned in the .A register:

Bit	Description
0	Left Button
1	Right Button
2	Middle Button
3	Unused
4	Button 4
5	Button 5

If a button is pressed, the corresponding bit is set. Buttons 4 and 5 are extended buttons not supported by all mice.

If available, the movement of the scroll wheel since the last call to this function is returned in the .X register as an 8-bit signed value. Moving the scroll wheel away from the user is represented by a negative value, and moving it towards the user is represented by a positive value. If the connected mouse has no scroll wheel, the value 0 is returned in the .X register.

EXAMPLE:

```
LDX #$70
JSR mouse_get ; get mouse position in $70/$71 (X) and $72/$73 (Y)
AND #1
BNE BUTTON_PRESSED
```

Joystick

$FF53: `joystick_scan` - query joysticks
$FF56: `joystick_get` - get state of one joystick

Function Name: joystick_scan

Purpose: Query the joysticks and save their state
Call address: $FF53
Communication registers: None
Preparatory routines: None
Error returns: None
Registers affected: .A .X .Y

Description: The routine `joystick_scan` retrieves all state from the four joysticks and saves it. It can then be retrieved using `joystick_get`. The default interrupt handler already takes care of this, so this routine should only be called if the interrupt handler has been completely replaced.

Function Name: joystick_get

Purpose: Get the state of one of the joysticks
Call address: $FF56
Communication registers: .A
Preparatory routines: `joystick_scan`
Error returns: None
Registers affected: .A .X .Y

Description: The routine `joystick_get` retrieves all state from one of the joysticks. The number of the joystick is passed in .A (0 for the keyboard joystick and 1 through 4 for SNES controllers), and the state is returned in .A, .X and .Y.

```
      .A, byte 0:      | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
                  SNES | B | Y |SEL|STA|UP |DN |LT |RT |

      .X, byte 1:      | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
```

```
                SNES | A | X | L | R | 1 | 1 | 1 | 1 |
      .Y, byte 2:
                $00 = joystick present
                $FF = joystick not present
```

If a button is pressed, the corresponding bit is zero.

(With a dedicated handler, the API can also be used for other devices with an SNES controller connector. The data returned in .A/.X/Y is just the raw 24 bits returned by the device.)

The keyboard joystick uses the standard SNES9X/ZSNES mapping:

SNES Button	Keyboard Key	Alt. Keyboard Key
A	X	Left Ctrl
B	Z	Left Alt
X	S	
Y	A	
L	D	
R	C	
START	Enter	
SELECT	Left Shift	
D-Pad	Cursor Keys	

Note that the keyboard joystick will allow LEFT and RIGHT as well as UP and DOWN to be pressed at the same time, while controllers usually prevent this mechanically.

How to Use:

If the default interrupt handler is used:

1. Call this routine.

If the default interrupt handler is disabled or replaced:

1. Call `joystick_scan` to have the system query the joysticks.
2. Call this routine.

EXAMPLE:

```
      JSR joystick_scan
      LDA #0
      JSR joystick_get
      TXA
      AND #128
      BEQ A_PRESSED
```

I2C

$FEB4: `i2c_batch_read` - read multiple bytes from an I2C device
$FEB7: `i2c_batch_write` - write multiple bytes to an I2C device
$FEC6: `i2c_read_byte` - read a byte from an I2C device
$FEC9: `i2c_write_byte` - write a byte to an I2C device

Function Name: i2c_batch_read

Purpose: Read bytes from a given I2C device into a RAM location
Call address: $FEB4
Communication registers: .X r0 r1 c
Preparatory routines: None

Error returns: c = 1 in case of error
Registers affected: .A .Y .P

Description: The routine `i2c_batch_read` reads a fixed number of bytes from an I2C device into RAM. To call, put I2C device (address) in .X, the pointer to the RAM location to which to place the data into r0, and the number of bytes to read into r1. If carry is set, the RAM location isn't advanced. This might be useful if you're reading from an I2C device and writing directly into VRAM.

If the routine encountered an error, carry will be set upon return.

EXAMPLE:

```
ldx #$50 ; One of the cartridge I2C flash devices
lda #<$0400
sta r0
lda #>$0400
sta r0+1
lda #<500
sta r1
lda #>500
sta r1+1
clc
jsr i2c_batch_read ; read 500 bytes from I2C device $50 into RAM starting at $0400
```

Function Name: i2c_batch_write

Purpose: Write bytes to a given I2C device with data in RAM
Call address: $FEB7
Communication registers: .X r0 r1 r2 c
Preparatory routines: None
Error returns: c = 1 in case of error
Registers affected: .A .Y .P r2

Description: The routine `i2c_batch_write` writes a fixed number of bytes from RAM to an I2C device. To call, put I2C device (address) in .X, the pointer to the RAM location from which to read into r0, and the number of bytes to write into r1. If carry is set, the RAM location isn't advanced. This might be useful if you're reading from an I/O device and writing that data to an I2C device.

The number of bytes written is returned in r2. If the routine encountered an error, carry will be set upon return.

EXAMPLE:

```
ldx #$50 ; One of the cartridge I2C flash devices
lda #<$0400
sta r0
lda #>$0400
sta r0+1
lda #<500
sta r1
lda #>500
sta r1+1
clc
jsr i2c_batch_write ; write 500 bytes to I2C device $50 from RAM
                    ; starting at $0400
                    ; for this example, the first two bytes in
                    ; the $0400 buffer would be the target address
                    ; in the I2C flash. This, of course, varies
                    ; between various I2C device types.
```

Function Name: i2c_read_byte

Purpose: Read a byte at a given offset from a given I2C device
Call address: $FEC6
Communication registers: .A .X .Y
Preparatory routines: None

Error returns: c = 1 in case of error
Registers affected: .A

Description: The routine `i2c_read_byte` reads a single byte at offset .Y from I2C device .X and returns the result in .A. c is 0 if the read was successful, and 1 if no such device exists.

EXAMPLE:

```
LDX #$6F ; RTC device
LDY #$20 ; start of NVRAM inside RTC
JSR i2c_read_byte ; read first byte of NVRAM
```

Function Name: i2c_write_byte

Purpose: Write a byte at a given offset to a given I2C device
Call address: $FEC9
Communication registers: .A .X .Y
Preparatory routines: None
Error returns: c = 1 in case of error
Registers affected: .A .P

Description: The routine `i2c_write_byte` writes the byte in .A at offset .Y of I2C device .X. c is 0 if the write was successful, and 1 if no such device exists.

EXAMPLES:

```
LDX #$6F ; RTC device
LDY #$20 ; start of NVRAM inside RTC
LDA #'X'
JSR i2c_write_byte ; write first byte of NVRAM

LDX #$42 ; System Management Controller
LDY #$01 ; magic location for system poweroff
LDA #$00 ; magic value for system poweroff
JSR i2c_write_byte ; power off the system

; Reset system at the end of your program
LDX #$42  ; System Management Controller
LDY #$02  ; magic location for system reset
LDA #$00  ; magic value for system poweroff/reset
JSR $FEC9 ; reset the computer
```

Sprites

$FEF0: `sprite_set_image` - set the image of a sprite
$FEF3: `sprite_set_position` - set the position of a sprite

Function Name: sprite_set_image

Purpose: Set the image of a sprite
Call address: $FEF0
Signature: bool sprite_set_image(byte number: .A, width: .X, height: .Y, apply_mask: c, word pixels: r0, word mask: r1, byte bpp: r2L);
Error returns: c = 1 in case of error

Description: This function sets the image of a sprite. The number of the sprite is given in .A, The bits per pixel (bpp) in r2L, and the width and height in .X and .Y. The pixel data at r0 is interpreted accordingly and converted into the graphics hardware's native format. If the c flag is set, the transparency mask pointed to by r1 is applied during the conversion. The function returns c = 0 if converting the data was successful, and c = 1 otherwise. Note that this does not change the visibility of the sprite.

Note: There are certain limitations on the possible values of width, height, bpp and apply_mask:

- width and height may not exceed the hardware's capabilities.
- Legal values for bpp are 1, 4 and 8. If the hardware only supports lower depths, the image data is converted down.
- apply_mask is only valid for 1 bpp data.

Function Name: sprite_set_position

Purpose: Set the position of a sprite or hide it.
Call address: $FEF3
Signature: void sprite_set_position(byte number: .A, word x: r0, word y: r1);
Error returns: None

Description: This function shows a given sprite (.A) at a certain position or hides it. The position is passed in r0 and r1. If the x position is negative (>$8000), the sprite will be hidden.

Note: This routine only supports setting the position for sprite numbers 0-31.

Framebuffer

The framebuffer API is a low-level graphics API that completely abstracts the framebuffer by exposing a minimal set of high-performance functions. It is useful as an abstraction and as a convenience library for applications that need high performance framebuffer access.

```
$FEF6: `FB_init` - enable graphics mode
$FEF9: `FB_get_info` - get screen size and color depth
$FEFC: `FB_set_palette` - set (parts of) the palette
$FEFF: `FB_cursor_position` - position the direct-access cursor
$FF02: `FB_cursor_next_line` - move direct-access cursor to next line
$FF05: `FB_get_pixel` - read one pixel, update cursor
$FF08: `FB_get_pixels` - copy pixels into RAM, update cursor
$FF0B: `FB_set_pixel` - set one pixel, update cursor
$FF0E: `FB_set_pixels` - copy pixels from RAM, update cursor
$FF11: `FB_set_8_pixels` - set 8 pixels from bit mask (transparent), update cursor
$FF14: `FB_set_8_pixels_opaque` - set 8 pixels from bit mask (opaque), update cursor
$FF17: `FB_fill_pixels` - fill pixels with constant color, update cursor
$FF1A: `FB_filter_pixels` - apply transform to pixels, update cursor
$FF1D: `FB_move_pixels` - copy horizontally consecutive pixels to a different position
```

All calls are vectored, which allows installing a replacement framebuffer driver.

```
$02E4: I_FB_init
$02E6: I_FB_get_info
$02E8: I_FB_set_palette
$02EA: I_FB_cursor_position
$02EC: I_FB_cursor_next_line
$02EE: I_FB_get_pixel
$02F0: I_FB_get_pixels
$02F2: I_FB_set_pixel
$02F4: I_FB_set_pixels
$02F6: I_FB_set_8_pixels
$02F8: I_FB_set_8_pixels_opaque
$02FA: I_FB_fill_pixels
$02FC: I_FB_filter_pixels
$02FE: I_FB_move_pixels
```

The model of this API is based on the direct-access cursor. In order to read and write pixels, the cursor has to be set to a specific x/y-location, and all subsequent calls will access consecutive pixels at the cursor position and update the cursor.

The default driver supports the VERA framebuffer at a resolution of 320x200 pixels and 256 colors. Using `screen_mode` to set mode $80 will enable this driver.

Function Name: FB_init

Signature: void FB_init();
Purpose: Enter graphics mode.

Function Name: FB_get_info

Signature: void FB_get_info(out word width: r0, out word height: r1, out byte color_depth: .A);
Purpose: Return the resolution and color depth

Function Name: FB_set_palette

Signature: void FB_set_palette(word pointer: r0, index: .A, color count: .X);
Purpose: Set (parts of) the palette

Description: `FB_set_palette` copies color data from the address pointed to by r0, updates the color in VERA palette RAM starting at the index A, with the length of the update (in words) in X. If X is 0, all 256 colors are copied (512 bytes)

Function Name: FB_cursor_position

Signature: void FB_cursor_position(word x: r0, word y: r1);
Purpose: Position the direct-access cursor

Description: `FB_cursor_position` sets the direct-access cursor to the given screen coordinate. Future operations will access pixels at the cursor location and update the cursor.

Function Name: FB_cursor_next_line

Signature: void FB_cursor_next_line(word x: r0);
Purpose: Move the direct-access cursor to next line

Description: `FB_cursor_next_line` increments the y position of the direct-access cursor, and sets the x position to the same one that was passed to the previous `FB_cursor_position` call. This is useful for drawing rectangular shapes, and faster than explicitly positioning the cursor.

Function Name: FB_get_pixel

Signature: byte FB_get_pixel();
Purpose: Read one pixel, update cursor

Function Name: FB_get_pixels

Signature: void FB_get_pixels(word ptr: r0, word count: r1);
Purpose: Copy pixels into RAM, update cursor

Description: This function copies pixels into an array in RAM. The array consists of one byte per pixel.

Function Name: FB_set_pixel

Signature: void FB_set_pixel(byte color: .A);
Purpose: Set one pixel, update cursor

Function Name: FB_set_pixels

Signature: void FB_set_pixels(word ptr: r0, word count: r1);
Purpose: Copy pixels from RAM, update cursor

Description: This function sets pixels from an array of pixels in RAM. The array consists of one byte per pixel.

Function Name: FB_set_8_pixels

Signature: void FB_set_8_pixels(byte pattern: .A, byte color: .X);
Purpose: Set 8 pixels from bit mask (transparent), update cursor

Description: This function sets all 1-bits of the pattern to a given color and skips a pixel for every 0 bit. The order is MSB to LSB. The cursor will be moved by 8 pixels.

Function Name: FB_set_8_pixels_opaque

Signature: void FB_set_8_pixels_opaque(byte pattern: .A, byte mask: r0L, byte color1: .X, byte color2: .Y);
Purpose: Set 8 pixels from bit mask (opaque), update cursor

Description: For every 1-bit in the mask, this function sets the pixel to color1 if the corresponding bit in the pattern is 1, and to color2 otherwise. For every 0-bit in the mask, it skips a pixel. The order is MSB to LSB. The cursor will be moved by 8 pixels.

Function Name: FB_fill_pixels

Signature: void FB_fill_pixels(word count: r0, word step: r1, byte color: .A);
Purpose: Fill pixels with constant color, update cursor

Description: `FB_fill_pixels` sets pixels with a constant color. The argument `step` specifies the increment between pixels. A value of 0 or 1 will cause consecutive pixels to be set. Passing a `step` value of the screen width will set vertically adjacent pixels going top down. Smaller values allow drawing dotted horizontal lines, and multiples of the screen width allow drawing dotted vertical lines.

Function Name: FB_filter_pixels

Signature: void FB_filter_pixels(word ptr: r0, word count: r1);
Purpose: Apply transform to pixels, update cursor

Description: This function allows modifying consecutive pixels. The function pointer will be called for every pixel, with the color in .A, and it needs to return the new color in .A.

Function Name: FB_move_pixels

Signature: void FB_move_pixels(word sx: r0, word sy: r1, word tx: r2, word ty: r3, word count: r4);
Purpose: Copy horizontally consecutive pixels to a different position

[Note: Overlapping regions are not yet supported.]

Graphics

The high-level graphics API exposes a set of standard functions. It allows applications to easily perform some common high-level actions like drawing lines, rectangles and images, as well as moving parts of the screen. All commands are completely implemented on top of the framebuffer API, that is, they will continue working after replacing the framebuffer driver with one that supports a different resolution, color depth or even graphics device.

$FF20: `GRAPH_init` - initialize graphics
$FF23: `GRAPH_clear` - clear screen
$FF26: `GRAPH_set_window` - set clipping region
$FF29: `GRAPH_set_colors` - set stroke, fill and background colors
$FF2C: `GRAPH_draw_line` - draw a line
$FF2F: `GRAPH_draw_rect` - draw a rectangle (optionally filled)
$FF32: `GRAPH_move_rect` - move pixels
$FF35: `GRAPH_draw_oval` - draw an oval or circle
$FF38: `GRAPH_draw_image` - draw a rectangular image
$FF3B: `GRAPH_set_font` - set the current font
$FF3E: `GRAPH_get_char_size` - get size and baseline of a character
$FF41: `GRAPH_put_char` - print a character

Function Name: GRAPH_init

Signature: void GRAPH_init(word vectors: r0);
Purpose: Activate framebuffer driver, enter and initialize graphics mode

Description: This call activates the framebuffer driver whose vector table is passed in r0. If r0 is 0, the default driver is activated. It then switches the video hardware into graphics mode, sets the window to full screen, initializes the colors and activates the system font.

Function Name: GRAPH_clear

Signature: void GRAPH_clear();
Purpose: Clear the current window with the current background color.

Function Name: GRAPH_set_window

Signature: void GRAPH_set_window(word x: r0, word y: r1, word width: r2, word height: r3);
Purpose: Set the clipping region

Description: All graphics commands are clipped to the window. This function configures the origin and size of the window. All 0 arguments set the window to full screen.

[Note: Only text output and GRAPH_clear currently respect the clipping region.]

Function Name: GRAPH_set_colors

Signature: void GRAPH_set_colors(byte stroke: .A, byte fill: .X, byte background: .Y);
Purpose: Set the three colors

Description: This function sets the three colors: The stroke color, the fill color and the background color.

Function Name: GRAPH_draw_line

Signature: void GRAPH_draw_line(word x1: r0, word y1: r1, word x2: r2, word y2: r3);
Purpose: Draw a line using the stroke color

Function Name: GRAPH_draw_rect

Signature: void GRAPH_draw_rect(word x: r0, word y: r1, word width: r2, word height: r3, word corner_radius: r4, bool fill: c);
Purpose: Draw a rectangle.

Description: This function will draw the frame of a rectangle using the stroke color. If `fill` is `true`, it will also fill the area using the fill color. To only fill a rectangle, set the stroke color to the same value as the fill color.

[Note: The border radius is currently unimplemented.]

Function Name: GRAPH_move_rect

Signature: void GRAPH_move_rect(word sx: r0, word sy: r1, word tx: r2, word ty: r3, word width: r4, word height: r5);
Purpose: Copy a rectangular screen area to a different location

Description: `GRAPH_move_rect` coll copy a rectangular area of the screen to a different location. The two areas may overlap.

[Note: Support for overlapping is not currently implemented.]

Function Name: GRAPH_draw_oval

Signature: void GRAPH_draw_oval(word x: r0, word y: r1, word width: r2, word height: r3, bool fill: c);
Purpose: Draw an oval or a circle

Description: This function draws an oval filling the given bounding box. If width equals height, the resulting shape is a circle. The oval will be outlined by the stroke color. If `fill` is `true`, it will be filled using the fill color. To only fill an oval, set the stroke color to the same value as the fill color.

Function Name: GRAPH_draw_image

Signature: void GRAPH_draw_image(word x: r0, word y: r1, word ptr: r2, word width: r3, word height: r4);
Purpose: Draw a rectangular image from data in memory

Description: This function copies pixel data from memory onto the screen. The representation of the data in memory has to have one byte per pixel, with the pixels organized line by line top to bottom, and within the line left to right.

Function Name: GRAPH_set_font

Signature: void GRAPH_set_font(void ptr: r0);
Purpose: Set the current font

Description: This function sets the current font to be used for the remaining font-related functions. The argument is a pointer to the font data structure in memory, which must be in the format of a single point size GEOS font (i.e. one GEOS font file VLIR chunk). An argument of 0 will activate the built-in system font.

Function Name: GRAPH_get_char_size

Signature: (byte baseline: .A, byte width: .X, byte height_or_style: .Y, bool is_control: c) GRAPH_get_char_size(byte c: .A, byte format: .X);
Purpose: Get the size and baseline of a character, or interpret a control code

Description: This functionality of `GRAPH_get_char_size` depends on the type of code that is passed in: For a printable character, this function returns the metrics of the character in a given format. For a control code, it returns the resulting format. In either case, the current format is passed in .X, and the character in .A.

- The format is an opaque byte value whose value should not be relied upon, except for `0`, which is plain text.
- The resulting values are measured in pixels.
- The baseline is measured from the top.

Function Name: GRAPH_put_char

Signature: void GRAPH_put_char(inout word x: r0, inout word y: r1, byte c: .A);
Purpose: Print a character onto the graphics screen

Description: This function prints a single character at a given location on the graphics screen. The location is then updated. The following control codes are supported:

- $01: SWAP COLORS
- $04: ATTRIBUTES: UNDERLINE
- $06: ATTRIBUTES: BOLD
- $07: BELL
- $08: BACKSPACE
- $09: TAB
- $0A: LF
- $0B: ATTRIBUTES: ITALICS
- $0C: ATTRIBUTES: OUTLINE
- $0D/$8D: REGULAR/SHIFTED RETURN
- $11/$91: CURSOR: DOWN/UP
- $12: ATTRIBUTES: REVERSE
- $13/$93: HOME/CLEAR
- $14 DEL
- $92: ATTRIBUTES: CLEAR ALL
- all color codes

Notes:

- CR ($0D) SHIFT+CR ($8D) and LF ($0A) all set the cursor to the beginning of the next line. The only difference is that CR and SHIFT+CR reset the attributes, and LF does not.
- BACKSPACE ($08) and DEL ($14) move the cursor to the beginning of the previous character but does not actually clear it. Multiple consecutive BACKSPACE/DEL characters are not supported.
- There is no way to individually disable attributes (underlined, bold, reversed, italics, outline). The only way to disable them is to reset the attributes using code $92, which switches to plain text.
- All 16 PETSCII color codes are supported. Code $01 to swap the colors will swap the stroke and fill colors.
- The stroke color is used to draw the characters, and the underline is drawn using the fill color. In reverse text mode, the text background is filled with the fill color.
- *[BELL ($07), TAB ($09) and SHIFT+TAB ($18) are not yet implemented.]*

Console

$FEDB: `console_init` - initialize console mode
$FEDE: `console_put_char` - print character to console
$FED8: `console_put_image` - draw image as if it was a character
$FEE1: `console_get_char` - get character from console
$FED5: `console_set_paging_message` - set paging message or disable paging

The console is a screen mode that allows text output and input in proportional fonts that support the usual styles. It is useful for rich text-based interfaces.

Function Name: console_init

Signature: void console_init(word x: r0, word y: r1, word width: r2, word height: r3);
Purpose: Initialize console mode.
Call address: $FEDB

Description: This function initializes console mode. It sets up the window (text clipping area) passed into it, clears the window and positions the cursor at the top left. All 0 arguments create a full screen console. You have to switch to graphics mode using `screen_mode` beforehand.

Function Name: console_put_char

Signature: void console_put_char(byte char: .A, bool wrapping: c);
Purpose: Print a character to the console.
Call address: $FEDE

Description: This function prints a character to the console. The c flag specifies whether text should be wrapped at character (c=0) or word (c=1) boundaries. In the latter case, characters will be buffered until a SPACE, CR or LF character is sent, so make sure the text that is printed

always ends in one of these characters.

Note: If the bottom of the screen is reached, this function will scroll its contents up to make extra room.

Function Name: console_put_image

Signature: void console_put_image(word ptr: r0, word width: r1, word height: r2);
Purpose: Draw image as if it was a character.
Call address: $FED8

Description: This function draws an image (in GRAPH_draw_image format) at the current cursor position and advances the cursor accordingly. This way, an image can be presented inline. A common example would be an emoji bitmap, but it is also possible to show full-width pictures if you print a newline before and after the image.

Notes:

- If the bottom of the screen is reached, this function will scroll its contents up to make extra room.
- Subsequent line breaks will take the image height into account, so that the new cursor position is below the image.

Function Name: console_get_char

Signature: (byte char: .A) console_get_char();
Purpose: Get a character from the console.
Call address: $FEE1

Description: This function gets a character to the console. It does this by collecting a whole line of character, i.e. until the user presses RETURN. Then, the line will be sent character by character.

This function allows editing the line using BACKSPACE/DEL, but does not allow moving the cursor within the line, write more than one line, or using control codes.

Function Name: console_set_paging_message

Signature: void console_set_paging_message(word message: r0);
Purpose: Set the paging message or disable paging.
Call address: $FED5

Description: The console can halt printing after a full screen height worth of text has been printed. It will then show a message, wait for any key, and continue printing. This function sets this message. A zero-terminated text is passed in r0. To turn off paging, call this function with r0 = 0 - this is the default.

Note: It is possible to use control codes to change the text style and color. Do not use codes that change the cursor position, like CR or LF. Also, the text must not overflow one line on the screen.

Other

$FF47: `enter_basic` - enter BASIC
$FECF: `entropy_get` - get 24 random bits
$FEAB: `extapi` - extended API
$FECC: `monitor` - enter machine language monitor
$FF5F: `screen_mode` - get/set screen mode
$FF62: `screen_set_charset` - activate 8x8 text mode charset
$FFED: `SCREEN` - get the text resolution

Function Name: enter_basic

Purpose: Enter BASIC
Call address: $FF47
Communication registers: .P
Preparatory routines: None
Error returns: Does not return

Description: Call this to enter BASIC mode, either through a cold start (c=1) or a warm start (c=0).

EXAMPLE:

```
CLC
JMP enter_basic ; returns to the "READY." prompt
```

Function Name: entropy_get

Purpose: Get 24 random bits
Call address: $FECF
Communication registers: .A .X .Y
Preparatory routines: None
Error returns: None
Registers affected: .A .X .Y

Description: This routine returns 24 somewhat random bits in registers .A, .X, and .Y. In order to get higher-quality random numbers, this data should be used to seed a pseudo-random number generator, as this is not a proper high quality pseudo-random number generator in and of itself.

How to Use:

1. Call this routine.

EXAMPLE:

```
; throw a die
again:
  JSR entropy_get
  STX tmp   ; combine 24 bits
  EOR tmp   ; using exclusive-or
  STY tmp   ; to get a higher-quality
  EOR tmp   ; 8 bit random value
  STA tmp
  LSR
  LSR
  LSR
  LSR       ; combine resulting 8 bits
  EOR tmp   ; to get 4 bits
  AND #7    ; we're down to values 0-7
  CMP #0
  BEQ again ; 0 is illegal
  CMP #7
  BEQ again ; 7 is illegal
  ORA #$30  ; convert to ASCII
  JMP $FFD2 ; print character
```

Function Name: extapi

Purpose: Additional API functions
Minimum ROM version: R47
Call address: $FEAB
Communication registers: .A .X .Y .P
Preparatory routines: None
Error returns: Varies, but usually c=1
Registers affected: Varies

Description: This API slot provides access to various extended calls. The call is selected by the .A register, and each call has its own register use and return behavior.

Call #	Name	Description	Inputs	Outputs	Preserves
$01	clear_status	resets the KERNAL IEC status to zero	none	none	-
$02	getlfs	getter counterpart to setlfs	none	.A .X .Y	-
$03	mouse_sprite_offset	get or set mouse sprite pixel offset	r0 r1 .P	r0 r1	-

$04	joystick_ps2_keycodes	get or set joy0 keycode mappings	r0L-r6H .P	r0L-r6H	-
$05	iso_cursor_char	get or set the ISO mode cursor char	.X .P	.X	-
$06	ps2kbd_typematic	set the keyboard repeat delay and rate	.X	-	-
$07	pfkey	program macros for F1-F8 and the RUN key	.X	-	-
$08	ps2data_fetch	Polls the SMC for PS/2 keyboard and mouse data	-	-	-
$09	ps2data_raw	If the most recent `ps2data_fetch` received a mouse packet or keycode, returns its raw value	-	.A .Y .X .P r0L-r1H	-
$0A	cursor_blink	Blinks or un-blinks the KERNAL editor cursor if appropriate	-	-	-
$0B	led_update	Illuminates or clears the SMC activity LED based on disk activity or error status	-	-	-
$0C	mouse_set_position	Moves the mouse cursor to a specific X/Y location	.X (.X)-(.X+3)	-	-
$0D	scnsiz	Directly sets the kernal editor text dimensions	.X .Y	-	-
$0E	kbd_leds	Set or get the state of the PS/2 keyboard LEDs	.X .P	.X	-

---

extapi Function Name: clear_status

Purpose: Reset the IEC status byte to 0
Minimum ROM version: R47
Call address: $FEAB, .A=1
Communication registers: none
Preparatory routines: none
Error returns: none
Registers affected: .A

Description: This function explicitly clears the IEC status byte. This is the value which is returned by calling `readst`.

---

extapi Function Name: getlfs

Purpose: Return the values from the last call to `setlfs`
Minimum ROM version: R47
Call address: $FEAB, .A=2
Communication registers: .A .X .Y
Preparatory routines: none
Error returns: none
Registers affected: .A .X .Y

Description: This function returns the values from the most recent call to `setlfs`. This is most useful for fetching the most recently-used disk device.

EXAMPLE:

```
LOADFILE:
    ; getlfs returns the most recently used disk device (`fa`) in .X
    ; Also returns `la` in .A and `sa` in .Y, but we ignore those
    LDA #2    ; extapi:getlfs
    JSR $FEAB ; extapi
    LDA #1
    LDY #2
    JSR $FFBA ; SETLFS
    LDA #FNEND-FN
    LDX #<FN
    LDY #>FN
    JSR $FFBD ; SETNAM
    LDA #1
    STA $00   ; ram_bank
```

```
    LDA #0
    LDX #<$A000
    LDY #>$A000
    JSR $FFD5 ; LOAD
    RTS
FN:
    .byte "MYFILENAME.EXT"
FNEND = *
```

---

extapi Function Name: mouse_sprite_offset

Purpose: Set the mouse sprite x/y offset
Minimum ROM version: R47
Call address: $FEAB, .A=3
Communication registers: r0 r1
Preparatory routines: `mouse_config`
Error returns: none
Registers affected: .A .X .Y .P r0 r1

Description: This function allows you to set or retrieve the display offset of the mouse sprite, relative to the calculated mouse position. Setting it negative can be useful for mouse sprites in which the locus is not the upper left corner. Combined with configuring a smaller X/Y with mouse_config, it can be set positive to confine the mouse pointer to a limited region of the screen.

- Set: If carry is clear when called, the X and Y sprite offsets are configured from the values in r0 and r1 respectively.
- Get: If carry is set when called, the X and Y sprite offsets are retrieved and placed in r0 and r1 respectively.

How to Use:

1. Set up your mouse sprite and call `mouse_config`. Any call to `mouse_config` resets this offset.
2. Load r0 with the 16-bit X offset and r1 with the 16-bit Y offset. Most of the time these values will be negative. For instance, a 16x16 sprite pointer in which the locus is near the center would have an offset of -8 ($FFF8) on both axes.
3. Clear carry and call `mouse_sprite_offset`

EXAMPLE:

```
; configure your mouse sprite here

; configure mouse before setting offset
LDA #$FF
LDY #0
LDX #0
JSR $FF68 ; mouse_config (resets sprite offsets to zero)

LDA #<(-8)
STA r0L
STA r1L
LDA #>(-8)
STA r0H
STA r1H
LDA #3    ; mouse_sprite_offset
CLC
JSR $FEAB ; extapi
```

---

extapi Function Name: joystick_ps2_keycodes

Purpose: Set or get the keyboard mapping for joystick 0
Minimum ROM version: R47
Call address: $FEAB, .A=4
Communication registers: .P r0L-r6H
Preparatory routines: none
Error returns: none
Registers affected: .A .X .Y .P r0L-r6H

Description: This function allows you to set or retrieve the list of keycodes that are mapped to joystick 0

- Set: If carry is clear when called, the current values are set based on the contents of the 14 registers r0L-r6H.
- Get: If carry is set when called, the current values are retrieved and placed in the 14 registers r0L-r6H.

Register	Controller Input	Default
r0L	D-pad Right	KEYCODE_RIGHTARROW ($59)
r0H	D-pad Left	KEYCODE_LEFTARROW ($4F)
r1L	D-pad Down	KEYCODE_DOWNARROW ($54)
r1H	D-pad Up	KEYCODE_UPARROW ($53)
r2L	Start	KEYCODE_ENTER ($2B)
r2H	Select	KEYCODE_LSHIFT ($2C)
r3L	Y	KEYCODE_A ($1F)
r3H	B	KEYCODE_Z ($2E)
r4L	B	KEYCODE_LALT ($3C)
r4H	R	KEYCODE_C ($30)
r5L	L	KEYCODE_D ($21)
r5H	X	KEYCODE_S ($20)
r6L	A	KEYCODE_X ($2F)
r6H	A	KEYCODE_LALT ($3C)

- Note that there are two mappings for the controller button B, and two mappings for the controller button A. Both mapped keys will activate the controller button.

How to Use:

1. Unless you're replacing the entire set of mappings, call `joystick_ps2_keycodes` first with carry set to fetch the existing values into r0L-r6H.
2. Load your desired changes into r0L-r6H. The keycodes are enumerated here , and their names, similar to that of PS/2 codes, are based on their function in the ***US layout***. You can also disable a mapping entirely with the value 0.
3. Clear carry and call `joystick_ps2_keycodes`

EXAMPLE:

```
; first fetch the original values
LDA #4    ; joystick_ps2_keycodes
SEC       ; get values
JSR $FEAB ; extapi
LDA #$10  ; KEYCODE_TAB
STA r2H   ; Tab is to be mapped to the select button
STZ r4L   ; Disable the secondary B button mapping
STZ r6H   ; Disable the secondary A button mapping
LDA #4    ; joystick_ps2_keycodes
CLC       ; set values
JSR $FEAB ; extapi (brings the new mapping into effect)
```

---

extapi Function Name: iso_cursor_char

Purpose: get or set the ISO mode cursor character
Minimum ROM version: R47
Call address: $FEAB, .A=5
Communication registers: .X .P
Preparatory routines: none

Error returns: none
Registers affected: .A .X .Y .P

Description: This function allows you to set or retrieve the cursor screen code which is used in ISO mode.

- Set: If carry is clear when called, the current value of .X is used as the blinking cursor character if the screen console is in ISO mode.
- Get: If carry is set when called, the current value of the blinking cursor character is returned in .X.

When entering ISO mode, such as by sending a `$0F` to the screen via `BSOUT` or pressing Ctrl+O, the cursor character is reset to the default of `$9F` .

---

extapi Function Name: ps2kbd_typematic

Purpose: set the PS/2 typematic delay and repeat rate
Minimum ROM version: R47
Call address: $FEAB, .A=6
Communication registers: .X
Preparatory routines: none
Error returns: none
Registers affected: .A .X .Y .P

Description: This function allows you to set the delay and repeat rate of the PS/2 keyboard. Since the keyboard doesn't allow you to query the current value, there is no getter counterpart to this routine.

NOTE: Since the SMC communicates with the keyboard using PS/2 scancode set 2, there is no way to instruct the keyboard to turn off typematic repeat entirely. However, with a very simple custom KERNAL key handler, you can suppress processing repeated key down events without an intervening key up.

NOTE: **This routine does not work with the emulator**, as the key repeat rate is controlled by the operating system.

This function takes 7 bits of input in .X, a bitfield composed of two parameter options.

- .X = 0ddrrrrr

Where dd is the delay before repeating,

- dd = 00: 250 ms
- dd = 01: 500 ms
- dd = 10: 750 ms
- dd = 11: 1000 ms

and rrrrr is the repeat rate, given this conversion to Hz.

```
$00 = 30.0 Hz, $01 = 26.7 Hz, $02 = 24.0 Hz, $03 = 21.8 Hz
$04 = 20.7 Hz, $05 = 18.5 Hz, $06 = 17.1 Hz, $07 = 16.0 Hz
$08 = 15.0 Hz, $09 = 13.3 Hz, $0a = 12.0 Hz, $0b = 10.9 Hz
$0c = 10.0 Hz, $0d =  9.2 Hz, $0e =  8.6 Hz, $0f =  8.0 Hz
$10 =  7.5 Hz, $11 =  6.7 Hz, $12 =  6.0 Hz, $13 =  5.5 Hz
$14 =  5.0 Hz, $15 =  4.6 Hz, $16 =  4.3 Hz, $17 =  4.0 Hz
$18 =  3.7 Hz, $19 =  3.3 Hz, $1a =  3.0 Hz, $1b =  2.7 Hz
$1c =  2.5 Hz, $1d =  2.3 Hz, $1e =  2.1 Hz, $1f =  2.0 Hz
```

---

extapi Function Name: pfkey

Purpose: Reprogram a function key macro
Minimum ROM version: R47
Call address: $FEAB, .A=7
Communication registers: .X .Y r0
Preparatory routines: None
Error returns: c=1
Registers affected: .A .X .Y .P r0

Description: This routine can be called to replace an F-key macro in the KERNAL editor with a user-defined string. The maximum length of each macro is 10 bytes, matching the size of the X16 KERNAL's keyboard buffer. It can also replace the action of SHIFT+RUN with a user-defined action.

These macros are only available in the KERNAL editor, which is usually while editing BASIC program, or during a BASIN from the screen. The BASIC statements INPUT and LINPUT also operate in this mode.

Inputs:

- r0 = pointer to string
- .X = key number (1-9)
- .Y = string length

How to Use:

1. Load r0L and r0H a pointer to the replacement macro string (ZP locations $02 and $03).
2. Load .X with the key number to replace. Values 1-8 correspond to F1-F8. A value of 9 corresponds to SHIFT+RUN.
3. Load .Y with the string length. This may be a range from 0-10 inclusive. A value of 0 disables the macro entirely.
4. Call `pfkey`. If carry is set when returning, an error occurred. The most likely reason is that one of the input parameters was out of range.

EXAMPLE:

Disable the SHIFT+RUN action, and replace the macro in F1 with "HELP" followed by a carriage return.

```
EXTAPI = $FEAB

change_fkeys:
  lda #<string1
  sta $02
  lda #>string1
  sta $03
  lda #$02
  ldx #1
  ldy #<(string1_end-string1)
  jsr EXTAPI
  lda #<string9
  sta $02
  lda #>string9
  sta $03
  lda #7
  ldx #9
  ldy #<(string9_end-string9)
  jsr EXTAPI
  rts

string1: .byte "HELP",13
string1_end:
string9:
string9_end:
```

BASIC equivalent:

```
10 A$="HELP"+CHR$(13)
20 K=1
30 GOSUB 100
40 A$=""
50 K=9
60 GOSUB 100
70 END
100 AL=LEN(A$)
110 AP=STRPTR(A$)
120 POKE $02,(AP-(INT(AP/256)*256))
130 POKE $03,INT(AP/256)
140 POKE $30C,7
150 POKE $30D,K
160 POKE $30E,AL
170 SYS $FEAB
180 RETURN
```

---

extapi Function Name: ps2data_fetch

Purpose: Poll the SMC for PS/2 events
Minimum ROM version: R47
Call address: $FEAB, .A=8
Communication registers: None
Preparatory routines: None
Error returns: None
Registers affected: .A .X .Y .P

Description: This routine is called from the default KERNAL interrupt service handler to fetch a queued keycode, and if the mouse is enabled, a mouse packet. The values are stored inside internal KERNAL state used by subsequent calls to `mouse_scan`, `kbd_scan`, or `ps2data_raw`.

If the mouse has not been enabled via `mouse_config`, no mouse data is polled.

This call is mainly useful when overriding the default KERNAL IRQ handler, and since this function is not re-entrant safe, it is unsafe to call outside of an interrupt handler if interrupts are enabled and the default KERNAL IRQ handler is in place.

---

extapi Function Name: ps2data_raw

Purpose: Return the most recently-fetched PS/2 mouse packet and keycode
Minimum ROM version: R47
Call address: $FEAB, .A=9
Communication registers: .A .Y .X .P r0L-r1H
Preparatory routines: `mouse_config`, `ps2data_fetch`
Error returns: None
Registers affected: .A .X .Y .P r0L-r1H

Description: This routine returns the most-recently fetched mouse data packet and keycode. If a mouse packet exists, it sets .X to the length of the packet, either 3 or 4 depending on mouse type, and stores the values into r0L-r1H. If there's no mouse packet to return, .X is set to zero. If there's a keycode to return, .A is set to the keycode, otherwise .A is set to zero. If there's an extended keycode, .A will equal $7F for key down or $FF for key up, and .Y will contain the extended code.

If .X = 0, no mouse packet was received, and r0L-r1H memory is unchanged.

If the zero flag is set, neither the keyboard nor mouse had pending events.

This call is mainly useful when overriding the default KERNAL ISR and implementing a fully custom mouse and keyboard routine. It is also available when using the default ISR as these values are kept even after processing, until the next `ps2data_fetch` call.

Return values:

Keyboard

- .A = keycode

If .A == $7F or .A == $FF

- .Y = extended keycode

Mouse

- .X = number of mouse bytes

If .X == 0, memory is left unchanged.

If .X >= 3

- r0L = mouse byte 1
- r0H = mouse byte 2
- r1L = mouse byte 3

If .X == 4

- r1H = mouse byte 4

How to Use:

1. Call `mouse_config` with a non-zero value to enable the mouse.
2. If you're overriding the default KERNAL IRQ handler entirely, call `ps2data_fetch`. If not, this will be called for you.
3. Call `ps2data_raw`. If .X is nonzero upon return, memory starting at r0L will contain the raw mouse packet.

EXAMPLE:

```
CHROUT = $FFD2
STOP = $FFE1
EXTAPI = $FEAB
MOUSE_CONFIG = $FF68
SCREEN_MODE = $FF5F

TMP1 = $22
r0 = $02

start:
        sec
        jsr SCREEN_MODE ; get the screen size to pass to MOUSE_CONFIG
        lda #1
        jsr MOUSE_CONFIG
loop:
        wai ; wait for interrupt
        lda #9 ; ps2data_raw
        jsr EXTAPI
        beq aftermouse
        stx TMP1
        ora #0
        beq afterkbd
        jsr print_hex_byte
        lda #13
        jsr CHROUT
afterkbd:
        ldx TMP1
        beq aftermouse
        ldx #0
printloop:
        lda r0,x
        phx
        jsr print_hex_byte
        plx
        inx
        cpx TMP1
        bne printloop
        lda #13
        jsr CHROUT
aftermouse:
        jsr STOP
        bne loop
done:
        rts

print_hex_byte:
        jsr byte_to_hex
        jsr CHROUT
        txa
        jsr CHROUT
        rts

byte_to_hex:
        pha
        and #$0f
        tax
        pla
        lsr
        lsr
        lsr
        lsr
        pha
        txa
```

```
        jsr @hexify
        tax
        pla
@hexify:
        cmp #10
        bcc @nothex
        adc #$66
@nothex:
        eor #%00110000
        rts
```

---

extapi Function Name: cursor_blink

Purpose: Blink or un-blink the cursor in the KERNAL editor
Minimum ROM version: R47
Call address: $FEAB, .A=10
Communication registers: None
Preparatory routines: None
Error returns: None
Registers affected: .A .X .Y .P

Description: This routine is called from the default KERNAL interrupt service handler to cause the text mode cursor to blink on or off as appropriate, depending on the number of times this function has been called since the last blink event. If the editor is not waiting for input, this function has no effect.

This call is mainly useful when overriding the default KERNAL IRQ handler.

---

extapi Function Name: led_update

Purpose: Set the illumination status of the SMC's activity LED based on disk status
Minimum ROM version: R47
Call address: $FEAB, .A=11
Communication registers: None
Preparatory routines: None
Error returns: None
Registers affected: .A .X .Y .P

Description: This routine is called from the default KERNAL IRQ handler to update the status of the SMC's activity LED based on CMDR-DOS's status flags. It is illuminated solid during DOS disk activity, and flashes when there was a disk error.

This call is mainly useful when overriding the default KERNAL IRQ handler.

---

extapi Function Name: mouse_set_position

Purpose: Move the mouse pointer to an absolute X/Y position
Minimum ROM version: R47
Call address: $FEAB, .A=12
Communication registers: .X (.X)-(.X+3)
Preparatory routines: `mouse_config`
Error returns: None
Registers affected: .A .X .Y .P

Description: This routine set the absolute position of the mouse pointer and updates the pointer sprite.

Inputs:

- .X = the zeropage location from which to read the new values
- $00+X = X position low byte
- $01+X = X position high byte
- $02+X = Y position low byte
- $03+X = Y position high byte

For instance, if you want the function to read the values from memory locations $22 through $25, set .X to #$22.

How to Use:

1. Call `mouse_config` with a non-zero value to enable the mouse.

2. Store the new X/Y position in four contiguous zeropage locations as described above. Load .X with the starting zeropage location.
3. Call `mouse_set_position`

EXAMPLE:

This demo program causes the mouse pointer to slowly drift down and to the right.

```
r0L = $02
r0H = $03
r1L = $04
r1H = $05

EXTAPI = $FEAB
MOUSE_CONFIG = $FF68
MOUSE_GET = $FF6B
SCREEN_MODE = $FF5F
STOP = $FFE1

start:
        sec
        jsr SCREEN_MODE
        lda #1
        jsr MOUSE_CONFIG
loop:
        ldx #r0L ; starting ZP location for mouse_get
        jsr MOUSE_GET
        inc r0L
        bne :+
        inc r0H
:       inc r1L
        bne :+
        inc r1H
:
        ldx #r0L ; starting ZP location for mouse_set_position
        lda #12 ; mouse_set_position
        jsr EXTAPI
        wai ; delay until next interrupt
        jsr STOP
        bne loop
done:
        rts
```

---

extapi Function Name: scnsiz

Purpose: Set the number of text rows and columns for the kernal screen editor
Minimum ROM version: R48
Call address: $FEAB, .A=13
Communication registers: .X .Y
Preparatory routines: None
Error returns: c=1
Registers affected: .A .X .Y .P

Description: This routine is implicitly called by `screen_mode` to set the bounds of the kernal editor's screen, and can be used directly to change the row and column bounds of the screen editor. `scnsiz` does not change the screen scaling.

This call is mainly useful to set custom row and column counts not available from any built-in screen mode.

Due to limits within the KERNAL's editor and what screen sizes it expects to work with, this routine will error and return with carry set if:

- .X < 20
- .X > 80
- .Y < 4
- .Y > 60

If the requested size exceeds the allowed bounds (.X = 20-80, .Y = 4-60), the existing text resolution won't be changed.

How to Use:

1. Set .X to the number of desired columns and .Y to the desired number of rows.
2. Call `scnsiz`
3. The in-bounds area of the screen as defined by these new dimensions will be cleared and the cursor will be placed at the upper-left home position.

EXAMPLE:

This example assembly routine sets up an 80x25 region, also adding top and bottom border regions so that the viewable area only shows the 80x25 text region.

```
SCREEN_MODE = $FF5F
EXTAPI = $FEAB
E_SCNSIZ = $0D
VERA_CTRL = $9F25
VERA_DC_VSTART = $9F2B
VERA_DC_VSTOP = $9F2C

TOP = 20 ; 20 rows from the top
BOTTOM = 480-20 ; 20 rows from the bottom

do_80x25:
        lda #1
        clc
        jsr SCREEN_MODE ; set screen mode to 80x30, which also clears the screen
        ldx #80
        ldy #25
        lda #E_SCNSIZ
        jsr EXTAPI ; reset to 80x25
        lda #(1 << 1) ; DCSEL = 1
        sta VERA_CTRL
        lda #(TOP >> 1) ; each step in DC_VSTART is 2 pixel rows
        sta VERA_DC_VSTART
        lda #(BOTTOM >> 1) ; each step in DC_VSTOP is 2 pixel rows
        sta VERA_DC_VSTOP
        stz VERA_CTRL
        rts
```

---

extapi Function Name: kbd_leds

Purpose: Set or retrieve the PS/2 keyboard LED state
Minimum ROM version: R48
Call address: $FEAB, .A=14
Communication registers: .X .P
Preparatory routines: None
Error returns: (none)
Registers affected: .A .X .Y .P

Description: This routine is used to send a command to the keyboard to set the state of the Num Lock, Caps Lock, and Scroll Lock LEDs. You can also query the KERNAL for its idea of what the state of the LEDs is.

Note: This call does **not** change the state of the kernal's caps lock toggle.

How to Use:

1. To query the state of the LEDs, set carry, otherwise to set the LED state, clear carry and set .X to the desired value of the LED register. Bit 0 is Scroll Lock, bit 1 is Num Lock, and bit 2 is Caps Lock.
2. Call `kbd_leds`
3. If carry was set on the call to `kbd_leds`, the routine will return with .X set to the current state, otherwise the routine will send the updated LED state to the keyboard. In this case, there will be no confirmation on whether it was successful.

EXAMPLE:

This example toggles the state of the LEDs to the opposite state that they were initially.

```
EXTAPI = $FEAB
E_KBD_LEDS = $0E

flip_leds:
        sec
        lda #E_KBD_LEDS
        jsr EXTAPI ; fetch state
        txa
        eor #7 ; invert the LED state
        tax
        clc
        lda #E_KBD_LEDS
        jsr EXTAPI ; set state and send to keyboard
        rts
```

Function Name: monitor

Purpose: Enter the machine language monitor
Call address: $FECC
Communication registers: None
Preparatory routines: None
Error returns: Does not return
Registers affected: Does not return

Description: This routine switches from BASIC to machine language monitor mode. It does not return to the caller. When the user quits the monitor, it will restart BASIC.

How to Use:

1. Call this routine.

EXAMPLE:

```
      JMP monitor
```

Function Name: SCREEN

Purpose: Get the text resolution of the screen
Call address: $FFED
Communication registers: .X, .Y
Preparatory routines: None
Error returns: None
Registers affected: .A, .X, .Y, .P

Description: This routine returns the KERNAL screen editor's view of the text resolution. The column count is returned in .X and the row count is returned in .Y.

In contrast to calling `screen_mode` with carry set, this function returns the configured resolution if ever it is updated by `scnsiz`. `screen_mode` only returns the text dimensions the currently configured mode would have configured, ignoring any changes made by calls to `scnsiz`.

EXAMPLE:

```
SCREEN = $FFED

get_res:
        jsr SCREEN
        sty my_rows
        stx my_columns
        rts
```

Function Name: screen_mode

Purpose: Get/Set the screen mode
Call address: $FF5F
Communication registers: .A, .X, .Y, .P
Preparatory routines: None
Error returns: c = 1 in case of error
Registers affected: .A, .X, .Y

Description: If c is set, a call to this routine gets the current screen mode in .A, the width (in tiles) of the screen in .X, and the height (in tiles) of the screen in .Y. If c is clear, it sets the current screen mode to the value in .A. For a list of possible values, see the basic statement `SCREEN`. If the mode is unsupported, c will be set, otherwise cleared.

If you use this function to get the text resolution instead of calling `SCREEN`, this function only returns the text dimensions the currently configured mode would have set, ignoring any changes made by calls to `scnsiz`. If you want to fetch the KERNAL editor's text resolution, call `SCREEN` instead.

EXAMPLE:

```
LDA #$80
CLC
JSR screen_mode ; SET 320x200@256C MODE
BCS FAILURE
```

Function Name: screen_set_charset

Purpose: Activate a 8x8 text mode charset
Call address: $FF62

Communication registers: .A, .X, .Y
Preparatory routines: None
Registers affected: .A, .X, .Y

Description: A call to this routine uploads a character set to the video hardware and activates it. The value of .A decides what charset to upload:

Value	Description
0	use pointer in .X/.Y
1	ISO
2	PET upper/graph
3	PET upper/lower
4	PET upper/graph (thin)
5	PET upper/lower (thin)
6	ISO (thin)
7	CP437 (since r47)
8	Cyrillic ISO (since r47)
9	Cyrillic ISO (thin) (since r47)
10	Eastern Latin ISO (since r47)
11	Eastern ISO (thin) (since r47)
12	Katakana (thin) (since r48)

If .A is zero, .X (lo) and .Y (hi) contain a pointer to a 2 KB RAM area that gets uploaded as the new 8x8 character set. The data has to consist of 256 characters of 8 bytes each, top to bottom, with the MSB on the left, set bits (1) represent the foreground colored pixels.

EXAMPLE:

```
LDA #0
LDX #<MY_CHARSET
LDY #>MY_CHARSET
JSR screen_set_charset ; UPLOAD CUSTOM CHARSET "MY_CHARSET"
```

Function Name: JSRFAR

Purpose: Execute a routine on another RAM or ROM bank
Call address: $FF6E
Communication registers: None
Preparatory routines: None
Error returns: None
Registers affected: None

Description: The routine `JSRFAR` enables code to execute some other code located on a specific RAM or ROM bank. This works independently of which RAM or ROM bank the currently executing code is residing in. The 16 bit address and the 8 bit bank number have to follow the instruction stream. The `JSRFAR` routine will switch both the ROM and the RAM bank to the specified bank and restore it after the routine's `RTS` . Execution resumes after the 3 byte arguments. **Note**: The C128 also has a `JSRFAR` function at $FF6E, but it is incompatible with the X16 version.

How to Use:

1. Call this routine.

EXAMPLE:

```
      JSR JSRFAR
      .WORD $C000 ; ADDRESS
      .BYTE 1     ; BANK
```

65C816 support

When writing native 65C816 code for the Commander X16, extra care must be given when using the KERNAL API. With the exception of `extapi16` , documented below, the entire kernal API must be called:

- With m=1, x=1 (accumulator and index are 8 bits)
- SP set to the KERNAL stack ($01xx). see
- DP=$0000 (must be set so that zeropage is the direct page)

$FEA8: `extapi16` - 16-bit extended API for 65C816 native mode

Function Name: extapi16

Purpose: API functions for 65C816
Minimum ROM version: R47
Call address: $FEA8
Communication registers: .C, .X, .Y, .P
Preparatory routines: None
Error returns: Varies, but usually c=1
Registers affected: Varies

Description: This API slot provides access to various native mode 65C816 calls. The call is selected by the .C register (accumulator), and each call has its own register use and return behavior.

IMPORTANT

- All of the calls behind this API **must** be called in native 65C816 mode, with m=0, .DP=$0000.
- In addition, some of these **must** be called with `rom_bank` (zp address $01) set to bank 0 (the KERNAL bank) and not via KERNAL support in other ROM banks. If your program is launched from BASIC, the default bank is usually 4 until explicitly changed by your program.

Call #	Name	Description	Inputs	Outputs	Additional Prerequisites
`$00`	`test`	Used by unit tests	.X .Y	.C	-

$01	stack_push	Switches to a new stack context	.X	none	x=0, $01=0
$02	stack_pop	Returns to the previous stack context	none	none	x=0, $01=0
$03	stack_enter_kernal_stack	Switches to the $01xx stack	none	none	x=0, $01=0
$04	stack_leave_kernal_stack	Returns to the previous stack context after stack_enter_kernal_stack	none	none	x=0, $01=0

65C816 extapi16 Function Name: test

Purpose: Used by unit tests for jsrfar
Minimum ROM version: R47
Call address: $FEA8, .C=0
Communication registers: .C .X .Y
Preparatory routines: none
Error returns: none
Registers affected: .C

Description: This API is used by unit tests and is not useful for applications.

65C816 extapi16 Function Name: stack_push

Purpose: Point the SP to a new stack
Minimum ROM version: R47
Call address: $FEA8, .C=1
Communication registers: .X
Preparatory routines: none
Error returns: none
Registers affected: .A .X .Y .P .SP

Description: This function informs the KERNAL that you're moving the stack pointer to a new location so that it can preserve the previous SP, and then brings the new SP into effect. The main purpose of this call is to preserve the position of the $01xx stack pointer (AKA KERNAL stack), and to track the length of the chain of stacks in the case of multiple pushes. In order for the 65C02 code in the emulated mode IRQ handler to run properly, it must be able to temporarily switch to using the KERNAL stack, regardless of the SP in main code.

How to Use:

1. Ensure `rom_bank` (ZP $01) is set to `0`. This function will not work if it traverses through `jsrfar`.
2. Load .X with the new SP to switch to, then call the routine. Upon return, .SP will be set to the new stack value. If the stack chain depth is greater than 1, the new stack will also have the old stack's address pushed onto it.
3. To return to the previous stack context, call `stack_pop`.

Notes:

- If you wish to preserve your current SP while temporarily switching back to the $01xx stack, for instance, to use the KERNAL API, begin that section of code with a call to `stack_enter_kernal_stack` and end with a call to `stack_leave_kernal_stack`.

65C816 extapi16 Function Name: stack_pop

Purpose: Point the SP to the previously-saved stack
Minimum ROM version: R47
Call address: $FEA8, .C=2
Communication registers: none
Preparatory routines: `stack_push`
Error returns: none
Registers affected: .A .X .Y .P .SP

Description: This function informs the KERNAL that you're finished using the stack set previously by `stack_push`. It brings the previous SP into effect.

How to Use:

1. Ensure `rom_bank` (ZP $01) is set to `0`. This function will not work if it traverses through `jsrfar`.
2. Ensure the current SP is set to the same value that was set immediately after the return from `stack_push`. In other words, you cannot use this function to bail out early from a deep subroutine chain without taking care to reset the stack first. In addition, you cannot

simply reset the stack to the value that *you* called `stack_push` with since the new stack may have had state pushed by the call to `stack_push`.
3. Call `stack_pop`. The call will return to the address immediately after, but with the previously-pushed SP.

65C816 extapi16 Function Name: stack_enter_kernal_stack

Purpose: Point the SP to the previously-saved $01xx stack, preserving the current one
Minimum ROM version: R47
Call address: $FEA8, .C=3
Communication registers: none
Preparatory routines: `stack_push`
Error returns: none
Registers affected: .A .X .Y .P .SP

Description: This function requests that the KERNAL temporarily bring the $01xx stack into effect during use a different stack. This is useful for applications which have moved the SP away from $01xx but need to call the KERNAL API or legacy code.

How to Use:

1. Ensure `rom_bank` (ZP $01) is set to `0`. This function will not work if it traverses through `jsrfar`.
2. A prior call to `stack_push` must be in effect that hasn't been undone by `stack_pop`, and the current SP must not be the default $01xx stack.
3. Call `stack_enter_kernal_stack`, call the legacy functions, then call `stack_leave_kernal_stack`.

65C816 extapi16 Function Name: stack_leave_kernal_stack

Purpose: Point the SP to the previously-preserved stack
Minimum ROM version: R47
Call address: $FEA8, .C=4
Communication registers: none
Preparatory routines: `stack_enter_kernal_stack`
Error returns: none
Registers affected: .A .X .Y .P .SP

Description: This function is the counterpart to `stack_enter_kernal_stack`, and restores the previously preserved stack.

How to Use:

1. Ensure `rom_bank` (ZP $01) is set to `0`. This function will not work if it traverses through `jsrfar`.
2. A prior call to `stack_enter_kernal_stack` must be in effect that hasn't been undone by this function.
3. Call `stack_leave_kernal_stack`.

Chapter 6: Math Library

The Commander X16 contains a floating point Math library with a precision of 40 bits, which corresponds to 9 decimal digits. It is a stand-alone derivative of the library contained in Microsoft BASIC. Except for the different base address, it is compatible with the C128 and C65 libraries.

The full documentation of these functions can be found in the book C128 Developers Package for Commodore 6502 Development . The Math Library documentation starts in Chapter 13. (PDF page 257)

The following functions are available from machine language code after setting the ROM bank to 4, which is the default.

Format Conversions

Address	Symbol	Description
$FE00	AYINT	convert floating point to integer (signed word)
$FE03	GIVAYF	convert integer (signed word) to floating point
$FE06	FOUT	convert floating point to ASCII string
$FE09	VAL_1	convert ASCII string in .X:.Y length in .A, to floating point in FACC. *Caveat! Read below!*
$FE0C	GETADR	convert floating point to an address (unsigned word)
$FE0F	FLOATC	convert address (unsigned word) to floating point

Important caveat ragarding the `VAL_1` routine in its current implementation:

Unlike the other routines in the math library, this routine calls into the VAL implementation that is inside BASIC, and so it requires much of the BASIC zeropage to be intact to function correctly. The reason is that that routine ultimately relies on some internal BASIC routines that use a lot of BASIC zero page space. Ideally in the future, the `VAL_1` routine gets a new implementation that doesn't rely on the code in BASIC, thereby removing this restriction.

X16 Additions

The following calls are new to the X16 and were not part of the C128 math library API:

Address	Symbol	Description
$FE87	FLOAT	FACC = (s8).A convert signed byte to float
$FE8A	FLOATS	FACC = (s16)facho+1:facho
$FE8D	QINT	facho:facho+1:facho+2:facho+3 = u32(FACC)
$FE93	FOUTC	Convert FACC to ASCIIZ string at fbuffr - 1 + .Y

Movement

`PACK` indicates a conversion from a normalized floating-point number in FACC to its packed format in memory; `UNPACK` indicates a conversion from the packed format in memory to the normalized format in the destination.

Address	Symbol	Description
$FE5A	CONUPK	ARG = UNPACK(RAM MEM)
$FE5D	ROMUPK	ARG = UNPACK(ROM MEM) (use CONUPK)
$FE60	MOVFRM	FACC = UNPACK(RAM MEM) (use MOVFM)
$FE63	MOVFM	FACC = UNPACK(ROM MEM)
$FE66	MOVMF	MEM = PACK(ROUND(FACC))
$FE69	MOVFA	FACC = ARG
$FE6C	MOVAF	FACC = ROUND(FACC); ARG = FACC

X16 Additions

The following calls are new to the X16 and were not part of the C128 math library API:

Address	Symbol	Description
$FE81	MOVEF	ARG = FACC

Math Functions

Address	Symbol	Description
$FE12	FSUB	FACC = MEM - FACC
$FE15	FSUBT	FACC = ARG - FACC
$FE18	FADD	FACC = MEM + FACC
$FE1B	FADDT	FACC = ARG + FACC
$FE1E	FMULT	FACC = MEM * FACC
$FE21	FMULTT	FACC = ARG * FACC
$FE24	FDIV	FACC = MEM / FACC
$FE27	FDIVT	FACC = ARG / FACC
$FE2A	LOG	FACC = natural log of FACC
$FE2D	INT	FACC = INT() truncate of FACC
$FE30	SQR	FACC = square root of FACC
$FE33	NEGOP	negate FACC (switch sign)
$FE36	FPWR	FACC = raise ARG to the MEM power
$FE39	FPWRT	FACC = raise ARG to the FACC power
$FE3C	EXP	FACC = EXP of FACC
$FE3F	COS	FACC = COS of FACC
$FE42	SIN	FACC = SIN of FACC
$FE45	TAN	FACC = TAN of FACC
$FE48	ATN	FACC = ATN of FACC
$FE4B	ROUND	FACC = round FACC
$FE4E	ABS	FACC = absolute value of FACC
$FE51	SIGN	.A = test sign of FACC
$FE54	FCOMP	.A = compare FACC with MEM
$FE57	RND_0	FACC = random floating point number

X16 Additions to math functions

The following calls are new to the X16 and were not part of the C128 math library API:

Address	Symbol	Description
$FE6F	FADDH	FACC += .5
$FE72	ZEROFC	FACC = 0
$FE75	NORMAL	Normalize FACC

$FE78	NEGFAC	FACC = -FACC (just use NEGOP)
$FE7B	MUL10	FACC *= 10
$FE7E	DIV10	FACC /= 10
$FE84	SGN	FACC = sgn(FACC)
$FE90	FINLOG	FACC += (s8).A add signed byte to float
$FE96	POLYX	Polynomial Evaluation 1 (SIN/COS/ATN/LOG)
$FE99	POLY	Polynomial Evaluation 2 (EXP)

How to use the routines

Concepts:

- **FACC** (sometimes abbreviated to FAC): the floating point accumulator. You can compare this to the 6502 CPU's .A register, which is the accumulator for most integer operations performed by the CPU. FACC is the primary floating point register. Calculations are done on the value in this register, usually combined with ARG. After the operation, usually the original value in FACC has been replaced by the result of the calculation.
- **ARG**: the second floating point register, used in most calculation functions. Often the value in this register will be lost after a calculation.
- **MEM**: means a floating point value stored in system memory somewhere. The format is 40 bits (5 bytes) Microsoft binary format . To be able to work with given values in calculations, they need to be stored in memory somewhere in this format. To do this you'll likely need to use a separate program to pre-convert floating point numbers to this format, unless you are using a compiler that directly supports it.

Note that FACC and ARG are just a bunch of zero page locations. This means you can poke around in them. But that's not good practice because their locations aren't guaranteed/public, and the format is slightly different than how the 5-byte floats are normally stored into memory. Just use one of the Movement routines to copy values into or out of FACC and ARG.

To perform a floating point calculation, follow the following pattern:

1. load a value into FACC. You can convert an integer, or move a MEM float number into FACC.
2. do the same but for ARG, the second floating point register.
3. call the required floating point calculation routine that will perform a calculation on FACC with ARG.
4. repeat the previous 2 steps if required.
5. the result is in FACC, move it into MEM somewhere or convert it to another type or string.

An example program that calculates and prints the distance an object has fallen over a certain period using the formula $d = \dfrac{1}{2} g {t}^{2}$

```
; calculate how far an object has fallen:  d = 1/2 * g * t^2.
; we set g = 9.81 m/sec^2, time = 5 sec -> d = 122.625 m.

CHROUT = $ffd2
FOUT   = $fe06
FMULTT = $fe21
FDIV   = $fe24
CONUPK = $fe5a
MOVFM  = $fe63

    lda  #4
    sta  $01         ; rom bank 4 (BASIC) contains the fp routines.
    lda  #<flt_two
    ldy  #>flt_two
    jsr  MOVFM
    lda  #<flt_g
    ldy  #>flt_g
    jsr  FDIV        ; FACC= g/2
    lda  #<flt_time
    ldy  #>flt_time
    jsr  CONUPK      ; ARG = time
    jsr  FMULTT      ; FACC = g/2 * time
```

```
    lda  #<flt_time
    ldy  #>flt_time
    jsr  CONUPK      ; again ARG = time
    jsr  FMULTT      ; FACC = g/2 * time * time
    jsr  FOUT        ; to string
    ; print string in AY
    sta  $02
    sty  $03
    ldy  #0
loop:
    lda  ($02),y
    beq  done
    jsr  CHROUT
    iny
    bne  loop
done:
    rts

flt_g:      .byte  $84, $1c, $f5, $c2, $8f  ; float 9.81
flt_time:   .byte  $83, $20, $00, $00, $00  ; float 5.0
flt_two:    .byte  $82, $00, $00, $00, $00  ; float 2.0
```

Notes

- `RND_0` : For .Z=1, the X16 behaves differently than the C128 and C65 versions. The X16 version takes entropy from .A/.X/.Y instead of from a CIA timer. So in order to get a "real" random number, you would use code like this:

```
LDA #$00
PHP
JSR entropy_get ; KERNAL call to get entropy into .A/.X/.Y
PLP             ; restore .Z=1
JSR RND_0
```

- The calls `FADDT`, `FMULTT`, `FDIVT` and `FPWRT` were broken on the C128/C65. They are fixed on the X16.
- For more information on the additional calls, refer to Mapping the Commodore 64 by Sheldon Leemon, ISBN 0-942386-23-X, but note these errata:
  - `FMULT` adds mem to FACC, not ARG to FACC

Chapter 7: Machine Language Monitor

The built-in machine language monitor can be started with the `MON` BASIC command. It is based on the monitor of the Final Cartridge III and supports most of its features.

If you invoke the monitor by mistake, you can exit with by typing `X`, followed by the `RETURN` key.

Some features specific to this monitor are:

- The `I` command prints a PETSCII/ISO-encoded memory dump.
- The `EC` command prints a binary memory dump. This is also useful for character sets.
- Scrolling the screen with the cursor keys or F3/F5 will continue memory dumps and disassemblies, and even disassemble backwards.

The following commands are used to dump memory contents in various formats:

Dump	Prefix	description
`M`	`:`	8 hex bytes
`I`	`'`	32 PETSCII/ISO characters
`EC`	`[`	1 binary byte (character data)
`ES`	`]`	3 binary bytes (sprite data)
`D`	`,`	disassemble
`R`	`;`	registers

Except for `R`, these commands take a start address and an optional end address (inclusive). The dumps are prefixed with one of the "Prefix" characters in the table above, so they can be edited by navigating the cursor over a printed line, changing the data and pressing RETURN.

Note that editing a disassembled line (prefix `,`) only allows changing the 1-3 opcode bytes. To edit the assembly, change the prefix to `A` (see below).

These are the remaining commands:

Command	Syntax	Description
`F`	*start end byte*	fill
`H`	*start end byte* [*byte*...]	hunt
`C`	*start end start*	compare
`T`	*start end start*	transfer
`A`	*address instruction*	assemble
`G`	[*address*]	run code
`J`	[*address*]	run subroutine
`$`	*value*	convert hex to decimal
`#`	*value*	convert decimal to hex
`X`		exit monitor
`O`	*bank*	set ROM bank
`K`	*bank*	set RAM/VRAM bank/I2C
`L`	["*filename*"[,*dev*[,*start*]]]	load file
`S`	"*filename*",*dev*,*start*,*end*	save file
`@`	*command*	send drive command

- All addresses have to be 4 digits.

- All bytes have to be 2 digits (including device numbers).
- The end address of `S` is exclusive.
- The bank argument for `K` is
  - `00` - `FF` : switch to main RAM, set RAM bank
  - `V0` - `V1` : switch to Video RAM, set VRAM bank
  - `I` : switch to the I2C address space
- The bank argument for `O` is
  - `00` - `FF` : set ROM bank
- `@` takes:
  - `8` , `9` to change the default drive (also for `L`)
  - `$` to display the disk directory
  - anything else as a disk command

Chapter 8: Memory Map

The Commander X16 has 512 KB of ROM and 2,088 KB (2 MB ^1 + 40 KB) of RAM with up to 3.5MB of RAM or ROM available to cartridges.

Some of the ROM/RAM is always visible at certain address ranges, while the remaining ROM/RAM is banked into one of two address windows.

This is an overview of the X16 memory map:

Addresses	Description
$0000-$9EFF	Fixed RAM (40 KB minus 256 bytes)
$9F00-$9FFF	I/O Area (256 bytes)
$A000-$BFFF	Banked RAM (8 KB window into one of 256 banks for a total of 2 MB)
$C000-$FFFF	Banked System ROM and Cartridge ROM/RAM (16 KB window into one of 256 banks, see below)

Banked Memory

Writing to the following zero-page addresses sets the desired RAM or ROM bank:

Address	Description
$0000	Current RAM bank (0-255)
$0001	Current ROM/Cartridge bank (ROM is 0-31, Cartridge is 32-255)

The currently set banks can also be read back from the respective memory locations. Both settings default to 0 on RESET.

ROM Allocations

Here is the ROM/Cartridge bank allocation:

Bank	Name	Description
0	KERNAL	KERNAL operating system and drivers
1	KEYBD	Keyboard layout tables
2	CBDOS	The computer-based CMDR-DOS for FAT32 SD cards
3	FAT32	The FAT32 driver itself
4	BASIC	BASIC interpreter
5	MONITOR	Machine Language Monitor
6	CHARSET	PETSCII and ISO character sets (uploaded into VRAM)
7	DIAG	Memory diagnostic
8	GRAPH	Kernal graph and font routines
9	DEMO	Demo routines
10	AUDIO	Audio API routines
11	UTIL	System Configuration (Date/Time, Display Preferences)
12	BANNEX	BASIC Annex (code for some added BASIC functions)
13-14	X16EDIT	The built-in text editor
15	BASLOAD	A transpiler that converts BASLOAD dialect to BASIC V2
16-31	–	*[Currently unused]*

32-255	–	Cartridge RAM/ROM

Important: The layout of the banks may still change.

Cartridge Allocation

Cartridges can use the remaining 32-255 banks in any combination of ROM, RAM, Memory-Mapped IO, etc. See Kevin's reference cartridge design for ideas on how this may be used. This provides up to 3.5MB of additional RAM or ROM.

Important: The layout of the banks is not yet final.

RAM Contents

This is the allocation of fixed RAM in the KERNAL/BASIC environment.

Addresses	Description
$0000-$00FF	Zero page
$0100-$01FF	CPU stack
$0200-$03FF	KERNAL and BASIC variables, vectors
$0400-$07FF	Available for machine code programs or custom data storage
$0800-$9EFF	BASIC program/variables; available to the user

The `$0400-$07FF` can be seen as the equivalent of `$C000-$CFFF` on a C64. A typical use would be for helper machine code called by BASIC.

Zero Page

Addresses	Description
$0000-$0001	Banking registers
$0002-$0021	16 bit registers r0-r15 for KERNAL API
$0022-$007F	Available to the user
$0080-$009C	Used by KERNAL and DOS
$009D-$00A8	Reserved for DOS/BASIC
$00A9-$00D3	Used by the Math library (and BASIC)
$00D4-$00FF	Used by BASIC

Machine code applications are free to reuse the BASIC area, and if they don't use the Math library, also that area.

Banking

This is the allocation of banked RAM in the KERNAL/BASIC environment.

Bank	Description
0	Used for KERNAL/CMDR-DOS variables and buffers
1-255	Available to the user

(On systems with only 512 KB RAM, banks 64-255 are unavailable.)

During startup, the KERNAL activates RAM bank 1 as the default for the user.

Bank 0

Addresses	Description
$A000-$BEFF	System Reserved

$BF00-$BFFF	Parameter passing space

You can use the space at $0:BF00-0:$BFFF to pass parameters between programs. This space is initalized to zeroes, so you may use it however you wish.

The suggested use is to store a PETSCII string in this space and use semicolons to separate parameters. The string should be null terminated:

Example:

```
FRANK;3;BLUE\x00
```

A program that reads the parameters is responsible for resetting the data to zeroes, so that another program does not see unexpected data and malfunction.

I/O Area

This is the memory map of the I/O Area:

Addresses	Description	Speed
$9F00-$9F0F	VIA I/O controller #1	8 MHz
$9F10-$9F1F	VIA I/O controller #2	8 MHz
$9F20-$9F3F	VERA video controller	8 MHz
$9F40-$9F41	YM2151 audio controller	2 MHz
$9F42-$9F5F	Unavailable	---
$9F60-$9F7F	Expansion Card Memory Mapped IO3	8 MHz
$9F80-$9F9F	Expansion Card Memory Mapped IO4	8 MHz
$9FA0-$9FBF	Expansion Card Memory Mapped IO5	2 MHz
$9FC0-$9FDF	Expansion Card Memory Mapped IO6	2 MHz
$9FE0-$9FFF	Cartidge/Expansion Memory Mapped IO7	2 MHz

Expansion Cards & Cartridges

Expansion cards can be accessed via memory-mapped I/O (MMIO), as well as I2C. Cartridges are essentially expansion cards which are housed in an external enclosure and may contain RAM, ROM and an I2C EEPOM (for save data). Internal expansion cards may also use the RAM/ROM space, though this could cause conflicts.

While they may be uncomon, since cartridges are essentially external expansion cards in a shell, that means they can also use MMIO. This is only necessary when a cartridge includes some sort of hardware expansion and MMIO was desired (as opposed to using the I2C bus). In that case, it is recommended cartridges use the IO7 range and that range should be the last option used by expansion cards in the system. **MMIO is unneeded for cartridges which simply have RAM/ROM.**

For more information, consult the Hardware section of the manual.

---

^1: Current development systems have 2 MB of bankable RAM. Actual hardware is currently planned to have an option of either 512 KB or 2 MB of RAM.

Chapter 9: VERA Programmer's Reference

This document describes the **V**ersatile **E**mbedded **R**etro **A**dapter or VERA. Which was originally written and conceived by Frank van den Hoef.

The VERA video chip supports resolutions up to 640x480 with up to 256 colors from a palette of 4096, two layers of either a bitmap or tiles, 128 sprites of up to 64x64 pixels in size. It can output VGA as well as a 525 line interlaced signal, either as NTSC or as RGB (Amiga-style).

The FPGA core used in the Commander X16 has been forked from Version 0.9 of the VERA. The original documentation can be found here .

The Commander X16 uses a modified version of VERA which includes extra functionality, notably the FX Aid additions. See Chapter 10 for more information on the FX additions.

The VERA consists of:

- Video generator featuring:
  - Multiple output formats (VGA, NTSC Composite, NTSC S-Video, RGB video) at a fixed resolution of 640x480@60Hz
  - Support for 2 layers, both supporting either tile or bitmap mode.
  - Support for up to 128 sprites.
  - Embedded video RAM of 128kB.
  - Palette with 256 colors selected from a total range of 4096 colors.
- 16-channel Programmable Sound Generator with multiple waveforms (Pulse, Sawtooth, Triangle, Noise)
- High quality PCM audio playback from an 4kB FIFO buffer featuring up to 48kHz 16-bit stereo sound.
- SPI controller for SecureDigital storage.

Registers

Addr	Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
$9F20	ADDRx_L (x=ADDRSEL)	VRAM Address (7:0)							
$9F21	ADDRx_M (x=ADDRSEL)	VRAM Address (15:8)							
$9F22	ADDRx_H (x=ADDRSEL)	Address Increment				DECR	Nibble Increment	Nibble Address	VRAM Address (16)
$9F23	DATA0	VRAM Data port 0							
$9F24	DATA1	VRAM Data port 1							
$9F25	CTRL	Reset	DCSEL						ADDRSEL
$9F26	IEN	IRQ line (8)	Scan line (8)	-		AFLOW	SPRCOL	LINE	VSYNC
$9F27	ISR	Sprite collisions				AFLOW	SPRCOL	LINE	VSYNC
$9F28	IRQLINE_L (Write only)	IRQ line (7:0)							
$9F28	SCANLINE_L (Read only)	Scan line (7:0)							
$9F29	DC_VIDEO (DCSEL=0)	Current Field	Sprites Enable	Layer1 Enable	Layer0 Enable	NTSC/RGB: 240P	NTSC: Chroma Disable / RGB: HV Sync	Output Mode	
$9F2A	DC_HSCALE (DCSEL=0)	Active Display H-Scale							
$9F2B	DC_VSCALE (DCSEL=0)	Active Display V-Scale							

$9F2C	DC_BORDER (DCSEL=0)	Border Color							
$9F29	DC_HSTART (DCSEL=1)	Active Display H-Start (9:2)							
$9F2A	DC_HSTOP (DCSEL=1)	Active Display H-Stop (9:2)							
$9F2B	DC_VSTART (DCSEL=1)	Active Display V-Start (8:1)							
$9F2C	DC_VSTOP (DCSEL=1)	Active Display V-Stop (8:1)							
$9F29	FX_CTRL (DCSEL=2)	Transp. Writes	Cache Write Enable	Cache Fill Enable	One-byte Cache Cycling	16-bit Hop	4-bit Mode	Addr1 Mode	
$9F2A	FX_TILEBASE (DCSEL=2) (Write only)	FX Tile Base Address (16:11)						Affine Clip Enable	2-bit Polygon
$9F2B	FX_MAPBASE (DCSEL=2) (Write only)	FX Map Base Address (16:11)						Map Size	
$9F2C	FX_MULT (DCSEL=2) (Write only)	Reset Accum.	Accumulate	Subtract Enable	Multiplier Enable	Cache Byte Index		Cache Nibble Index	Two-byte Cache Incr. Mode
$9F29	FX_X_INCR_L (DCSEL=3) (Write only)	X Increment (-2:-9) (signed)							
$9F2A	FX_X_INCR_H (DCSEL=3) (Write only)	X Incr. 32x	X Increment (5:-1) (signed)						
$9F2B	FX_Y_INCR_L (DCSEL=3) (Write only)	Y/X2 Increment (-2:-9) (signed)							
$9F2C	FX_Y_INCR_H (DCSEL=3) (Write only)	Y/X2 Incr. 32x	Y/X2 Increment (5:-1) (signed)						
$9F29	FX_X_POS_L (DCSEL=4) (Write only)	X Position (7:0)							
$9F2A	FX_X_POS_H (DCSEL=4) (Write only)	X Pos. (-9)	-				X Position (10:8)		
$9F2B	FX_Y_POS_L (DCSEL=4) (Write only)	Y/X2 Position (7:0)							
$9F2C	FX_Y_POS_H (DCSEL=4) (Write only)	Y/X2 Pos. (-9)	-				Y/X2 Position (10:8)		
$9F29	FX_X_POS_S (DCSEL=5) (Write only)	X Postion (-1:-8)							

$9F2A	FX_Y_POS_S (DCSEL=5) (Write only)	Y/X2 Postion (-1:-8)				
$9F2B	FX_POLY_FILL_L (DCSEL=5, 4-bit Mode=0) (Read only)	Fill Len >= 16	X Position (1:0)	Fill Len (3:0)		0
$9F2B	FX_POLY_FILL_L (DCSEL=5, 4-bit Mode=1, 2-bit Polygon=0) (Read only)	Fill Len >= 8	X Position (1:0)	X Pos. (2)	Fill Len (2:0)	0
$9F2B	FX_POLY_FILL_L (DCSEL=5, 4-bit Mode=1, 2-bit Polygon=1) (Read only)	X2 Pos. (-1)	X Position (1:0)	X Pos. (2)	Fill Len (2:0)	X Pos. (-1)
$9F2C	FX_POLY_FILL_H (DCSEL=5) (Read only)	Fill Len (9:3)				0
$9F29	FX_CACHE_L (DCSEL=6) (Write only)	Cache (7:0) | Multiplicand (7:0) (signed)				
$9F29	FX_ACCUM_RESET (DCSEL=6) (Read only)	Reset Accumulator				
$9F2A	FX_CACHE_M (DCSEL=6) (Write only)	Cache (15:8) | Multiplicand (15:8) (signed)				
$9F2A	FX_ACCUM (DCSEL=6) (Read only)	Accumulate				
$9F2B	FX_CACHE_H (DCSEL=6) (Write only)	Cache (23:16) | Multiplier (7:0) (signed)				
$9F2C	FX_CACHE_U (DCSEL=6) (Write only)	Cache (31:24) | Multiplier (15:8) (signed)				
$9F29	DC_VER0 (DCSEL=63) (Read only)	The ASCII character "V"				
$9F2A	DC_VER1 (DCSEL=63) (Read only)	Major release				
$9F2B	DC_VER2 (DCSEL=63) (Read only)	Minor release				
$9F2C	DC_VER3 (DCSEL=63) (Read only)	Minor build number				

$9F2D	L0_CONFIG	Map Height	Map Width	T256C	Bitmap Mode	Color Depth	
$9F2E	L0_MAPBASE	Map Base Address (16:9)					
$9F2F	L0_TILEBASE	Tile Base Address (16:11)				Tile Height	Tile Width
$9F30	L0_HSCROLL_L	H-Scroll (7:0)					
$9F31	L0_HSCROLL_H	-		H-Scroll (11:8)			
$9F32	L0_VSCROLL_L	V-Scroll (7:0)					
$9F33	L0_VSCROLL_H	-		V-Scroll (11:8)			
$9F34	L1_CONFIG	Map Height	Map Width	T256C	Bitmap Mode	Color Depth	
$9F35	L1_MAPBASE	Map Base Address (16:9)					
$9F36	L1_TILEBASE	Tile Base Address (16:11)				Tile Height	Tile Width
$9F37	L1_HSCROLL_L	H-Scroll (7:0)					
$9F38	L1_HSCROLL_H	-		H-Scroll (11:8)			
$9F39	L1_VSCROLL_L	V-Scroll (7:0)					
$9F3A	L1_VSCROLL_H	-		V-Scroll (11:8)			
$9F3B	AUDIO_CTRL	FIFO Full / FIFO Reset	FIFO Empty (read-only)	16-Bit	Stereo	PCM Volume	
		FIFO Loop (write-only)					
$9F3C	AUDIO_RATE	PCM Sample Rate					
$9F3D	AUDIO_DATA	Audio FIFO data (write-only)					
$9F3E	SPI_DATA	Data					
$9F3F	SPI_CTRL	Busy	-			Slow clock	Select

VRAM address space layout

Address range	Description
$0:0000 - $1:F9BF	Video RAM
$1:F9C0 - $1:F9FF	PSG registers
$1:FA00 - $1:FBFF	Palette
$1:FC00 - $1:FFFF	Sprite attributes

The X16 KERNAL uses the following video memory layout:

Addresses	Description
$0:0000-$1:2BFF	320x240@256c Bitmap
$1:2C00-$1:2FFF	*unused* (1024 bytes)
$1:3000-$1:AFFF	Sprite Image Data (up to $1000 per sprite at 64x64 8-bit)

$1:B000-$1:EBFF	Text Mode
$1:EC00-$1:EFFF	*unused* (1024 bytes)
$1:F000-$1:F7FF	Charset
$1:F800-$1:F9BF	*unused* (448 bytes)
$1:F9C0-$1:F9FF	VERA PSG Registers (16 x 4 bytes)
$1:FA00-$1:FBFF	VERA Color Palette (256 x 2 bytes)
$1:FC00-$1:FFFF	VERA Sprite Attributes (128 x 8 bytes)

This memory map is not fixed: All of the address space between $0:0000 and $1:F9BF is available for any use in your programs, if you do not need text displayed by KERNAL or BASIC. This includes allocating multiple text or graphic buffers, or simply re-arranging the buffers to allow for certain tile set layouts. Just be aware that once you move things around, you'll have to fully manage your bitmaps, tiles, and text/tile buffers.

To restore the standard text mode, call `CINT` ($FF81). This will reset the screen to the default screen mode. If you have configured custom settings in your NVRAM, these will be used.

Also, the registers in $1:F9C0-$1:FFFF are actually write-only. However, they share the same address as part of the video RAM. Be aware that when you read back the register data, you are actually reading the last value sent by the host system, which is not necessarily the value in the register. To make sure this data is filled with known values, we recommend fully initializng the registers before use. Normally, the X16 KERNAL handles this for you, but if you are writing a cartridge program, using the system with a custom ROM, or even running VERA on another computer, then you'll need to make sure this block gets initialized to known values.

Video RAM access

The video RAM (VRAM) isn't directly accessible on the CPU bus. VERA only exposes an address space of 32 bytes to the CPU as described in the section Registers . To access the VRAM (which is 128kB in size) an indirection mechanism is used. First the address to be accessed needs to be set (ADDRx_L/ADDRx_M/ADDRx_H) and then the data on that VRAM address can be read from or written to via the DATA0/1 register. To make accessing the VRAM more efficient an auto-increment mechanism is present.

There are 2 data ports to the VRAM. Which can be accessed using DATA0 and DATA1. The address and increment associated with the data port is specified in ADDRx_L/ADDRx_M/ADDRx_H. These 3 registers are multiplexed using the ADDR_SEL in the CTRL register. When ADDR_SEL = 0, ADDRx_L/ADDRx_M/ADDRx_H become ADDR0_L/ADDR0_M/ADDR0_H.
When ADDR_SEL = 1, ADDRx_L/ADDRx_M/ADDRx_H become ADDR1_L/ADDR1_M/ADDR1_H.

By setting the 'Address Increment' field in ADDRx_H, the address will be increment after each access to the data register. The increment register values and corresponding increment amounts are shown in the following table:

Register value	Increment amount
0	0
1	1
2	2
3	4
4	8
5	16
6	32
7	64
8	128
9	256
10	512
11	40

12	80
13	160
14	320
15	640

Setting the **DECR** bit, will decrement instead of increment by the value set by the 'Address Increment' field.

Reset

When **RESET** in **CTRL** is set to 1, the FPGA will reconfigure itself. All registers will be reset. The palette RAM will be set to its default values.

Interrupts

Interrupts will be generated for the interrupt sources set in the lower 4 bits of **IEN**. **ISR** will indicate the interrupts that have occurred. Writing a 1 to one of the lower 3 bits in **ISR** will clear that interrupt status. **AFLOW** can only be cleared by filling the audio FIFO for at least 1/4.

IRQ_LINE (write-only) specifies at which line the **LINE** interrupt will be generated. Note that bit 8 of this value is present in the **IEN** register. For interlaced modes the interrupt will be generated each field and the bit 0 of **IRQ_LINE** is ignored.

SCANLINE (read-only) indicates the current scanline being sent to the screen. Bit 8 of this value is present in the **IEN** register. The value is 0 during the first visible line and 479 during the last. This value continues to count beyond the last visible line, but returns $1FF for lines 512-524 that are beyond its 9-bit resolution. **SCANLINE** is not affected by interlaced modes and will return either all even or all odd values during an even or odd field, respectively. Note that VERA renders lines ahead of scanout such that line 1 is being rendered while line 0 is being scanned out. Visible changes may be delayed one scanline because of this.

The upper 4 (read-only) bits of the **ISR** register contain the sprite collisions as determined by the sprite renderer.

Display composer

The display composer is responsible of combining the output of the 2 layer renderers and the sprite renderer into the image that is sent to the video output.

The video output mode can be selected using OUT_MODE in DC_VIDEO.

OUT_MODE	Description
0	Video disabled
1	VGA output
2	NTSC (composite/S-Video)
3	RGB 15KHz, composite or separate H/V sync, via VGA connector

Setting **'Chroma Disable'** disables output of chroma in NTSC composite mode and will give a better picture on a monochrome display. *(Setting this bit will also disable the chroma output on the S-video output.)*

Setting **'HV Sync'** enables separate HSync/VSync signals in RGB output mode. Clearing the bit will enable the default of composite sync over RGB.

Setting **'240P'** enables 240P progressive mode over NTSC or RGB. It has no effect if the VGA output mode is active. Instead of 262.5 scanlines per field, this mode outputs 263 scanlines per field. On CRT displays, the scanlines from both the even and odd fields will be displayed on even scanlines.

'Current Field' is a read-only bit which reflects the active interlaced field in composite and RGB modes. In non-interlaced modes, this reflects if the current line is even or odd. (0: even, 1: odd)

Setting **'Layer0 Enable'** / **'Layer1 Enable'** / **'Sprites Enable'** will respectively enable output from layer0 / layer1 and the sprites renderer.

DC_HSCALE and **DC_VSCALE** will set the fractional scaling factor of the active part of the display. Setting this value to 128 will output 1 output pixel for every input pixel. Setting this to 64 will output 2 output pixels for every input pixel.

DC_BORDER determines the palette index which is used for the non-active area of the screen.

DC_HSTART/**DC_HSTOP** and **DC_VSTART**/**DC_VSTOP** determines the active part of the screen. The values here are specified in the native 640x480 display space. HSTART=0, HSTOP=640, VSTART=0, VSTOP=480 will set the active area to the full resolution. Note that the lower 2 bits of **DC_HSTART**/**DC_HSTOP** and the lower 1 bit of **DC_VSTART**/**DC_VSTOP** isn't available. This means that horizontally the start and stop values can be set at a multiple of 4 pixels, vertically at a multiple of 2 pixels.

DC_VER0, **DC_VER1**, **DC_VER2**, and **DC_VER3** can be queried for the version number of the VERA bitstream. If reading **DC_VER0** returns `$56`, the remaining registers returns values forming the major, minor, and build numbers respectively. If **DC_VER0** returns a value other than `$56`, the VERA bitstream version number is undefined.

Layer 0/1 registers

'Map Base Address' specifies the base address of the tile map. *Note that the register only specifies bits 16:9 of the address, so the address is always aligned to a multiple of 512 bytes.*

'Tile Base Address' specifies the base address of the tile data. *Note that the register only specifies bits 16:11 of the address, so the address is always aligned to a multiple of 2048 bytes.*

'H-Scroll' specifies the horizontal scroll offset. A value between 0 and 4095 can be used. Increasing the value will cause the picture to move left, decreasing will cause the picture to move right. Hardware scrolling is only possible in tile mode; in bitmap mode, this register is not functional for scrolling. Also half of it is repurposed: the **'H-Scroll (11:8)'** register is instead used to specify the palette offset for the bitmap.

'V-Scroll' specifies the vertical scroll offset. A value between 0 and 4095 can be used. Increasing the value will cause the picture to move up, decreasing will cause the picture to move down. Hardware scrolling is only possible in tile mode; in bitmap mode, this register is not functional.

'Map Width', **'Map Height'** specify the dimensions of the tile map:

Value	Map width / height
0	32 tiles
1	64 tiles
2	128 tiles
3	256 tiles

'Tile Width', **'Tile Height'** specify the dimensions of a single tile:

Value	Tile width / height
0	8 pixels
1	16 pixels

Layer display modes

The features of the 2 layers are the same. Each layer supports a few different modes which are specified using **T256C** / **'Bitmap Mode'** / **'Color Depth'** in Lx_CONFIG.

'Color Depth' specifies the number of bits used per pixel to encode color information:

Color Depth	Description
0	1 bpp
1	2 bpp
2	4 bpp
3	8 bpp

The layer can either operate in tile mode or bitmap mode. This is selected using the **'Bitmap Mode'** bit; 0 selects tile mode, 1 selects bitmap mode.

The handling of 1 bpp tile mode is different from the other tile modes. Depending on the **T256C** bit the tiles use either a 16-color foreground and background color or a 256-color foreground color. Other modes ignore the **T256C** bit.

Tile mode 1 bpp (16 color text mode)

T256C should be set to 0.

MAP_BASE points to a tile map containing tile map entries, which are 2 bytes each:

Offset	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
0	Character index							
1	Background color				Foreground color			

TILE_BASE points to the tile data.

Each bit in the tile data specifies one pixel. If the bit is set the foreground color as specified in the map data is used, otherwise the background color as specified in the map data is used.

Tile mode 1 bpp (256 color text mode)

T256C should be set to 1.

MAP_BASE points to a tile map containing tile map entries, which are 2 bytes each:

Offset	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
0	Character index							
1	Foreground color							

TILE_BASE points to the tile data.

Each bit in the tile data specifies one pixel. If the bit is set the foreground color as specified in the map data is used, otherwise color 0 is used (transparent).

Tile mode 2/4/8 bpp

MAP_BASE points to a tile map containing tile map entries, which are 2 bytes each:

Offset	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
0	Tile index (7:0)							
1	Palette offset				V-flip	H-flip	Tile index (9:8)	

TILE_BASE points to the tile data.

Each pixel in the tile data gives a color index of either 0-3 (2bpp), 0-15 (4bpp), 0-255 (8bpp). This color index is modified by the palette offset in the tile map data using the following logic:

- Color index 0 (transparent) and 16-255 are unmodified.
- Color index 1-15 is modified by adding 16 x palette offset.
- T256C causes bit 7 of the color index to become 1.

Note that 2bpp mode packs 4 pixels per byte and 4bpp mode packs 2 pixels per byte. For packed pixels, bit 7 refers to the leftmost pixel and bit 0 refers to the rightmost pixel.

Bitmap mode 1/2/4/8 bpp

MAP_BASE isn't used in these modes. **TILE_BASE** points to the bitmap data.

TILEW specifies the bitmap width. TILEW=0 results in 320 pixels width and TILEW=1 results in 640 pixels width.

When a layer is in bitmap mode, it can no longer be hardware scrolled using the HSCROLL and VSCROLL registers. **'H-Scroll (7:0)'** and both **'V-Scroll (7:0)'** and **'V-Scroll (11:8)'** are not functional in this mode.

The palette offset (in **'H-Scroll (11:8)'**), as well as T256C in non-1bpp mode modifies the color indexes of the bitmap in the same way as in the tile modes.

SPI controller

The SPI controller is connected to the SD card connector. The speed of the clock output of the SPI controller can be controlled by the **'Slow Clock'** bit. When this bit is 0 the clock is 12.5MHz, when 1 the clock is about 390kHz. The slow clock speed is to be used during the

initialization phase of the SD card. Some SD cards require a clock less than 400kHz during part of the initialization.

A transfer can be started by writing to **SPI_DATA**. While the transfer is in progress the BUSY bit will be set. After the transfer is done, the result can be read from the **SPI_DATA** register.

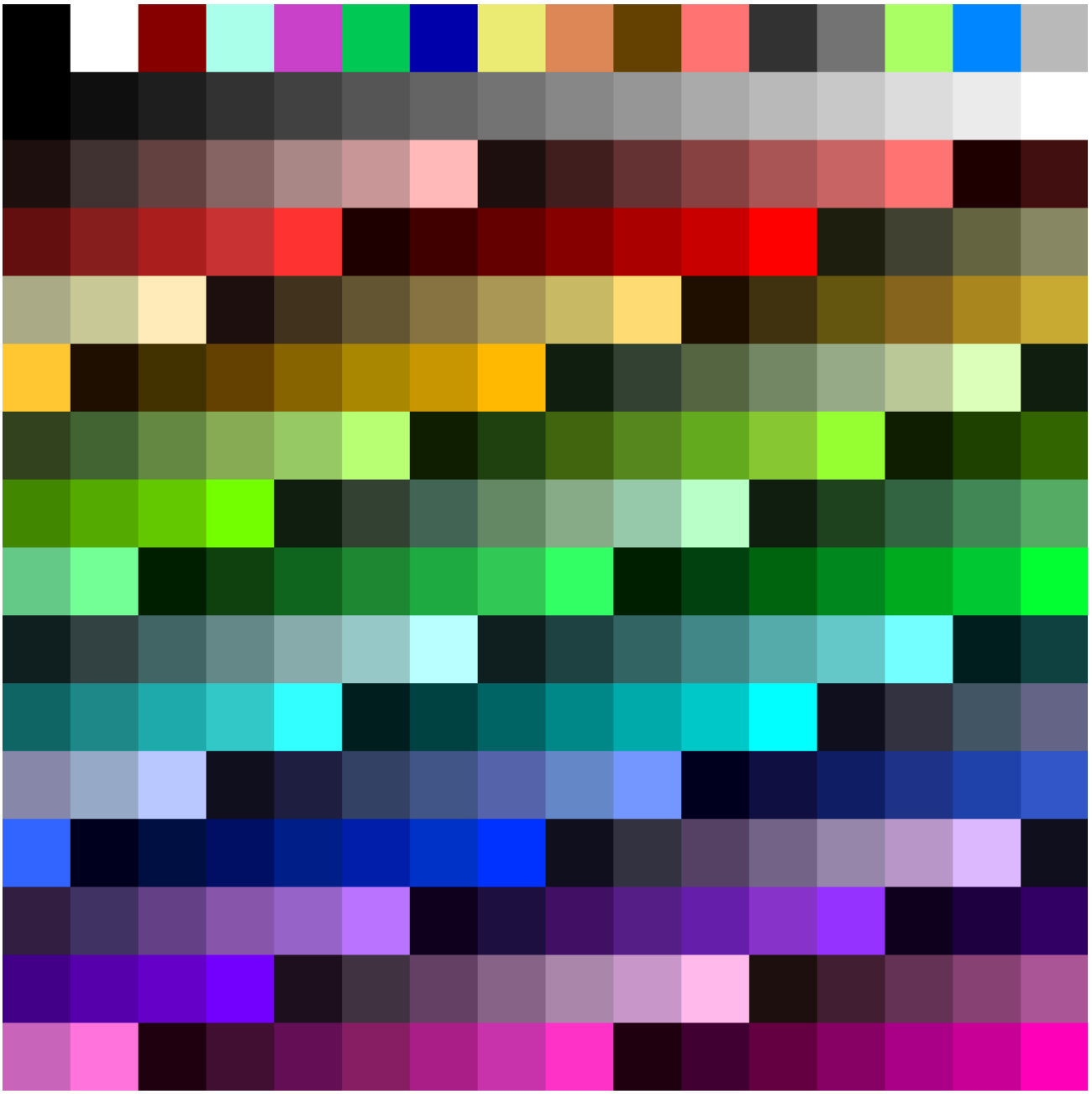
The chip select can be controlled by writing the **SELECT** bit. Writing 1 will assert the chip-select (logic-0) and writing 0 will release the chip-select (logic-1).

Palette

The palette translates 8-bit color indexes into 12-bit output colors. The palette has 256 entries, each with the following format:

Offset	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
0	Green				Blue			
1	-				Red			

At reset, the palette will contain a predefined palette:



- Color indexes 0-15 contain a palette somewhat similar to the C64 color palette.
- Color indexes 16-31 contain a grayscale ramp.
- Color indexes 32-255 contain various hues, saturation levels, brightness levels.

Sprite attributes

128 entries of the following format:

Offset	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
0	Address (12:5)							
1	Mode	-			Address (16:13)			
2	X (7:0)							

3	-			X (9:8)	
4	Y (7:0)				
5	-			Y (9:8)	
6	Collision mask		Z-depth	V-flip	H-flip
7	Sprite height	Sprite width	Palette offset		

Mode	Description
0	4 bpp
1	8 bpp

Z-depth	Description
0	Sprite disabled
1	Sprite between background and layer 0
2	Sprite between layer 0 and layer 1
3	Sprite in front of layer 1

Sprite width / height	Description
0	8 pixels
1	16 pixels
2	32 pixels
3	64 pixels

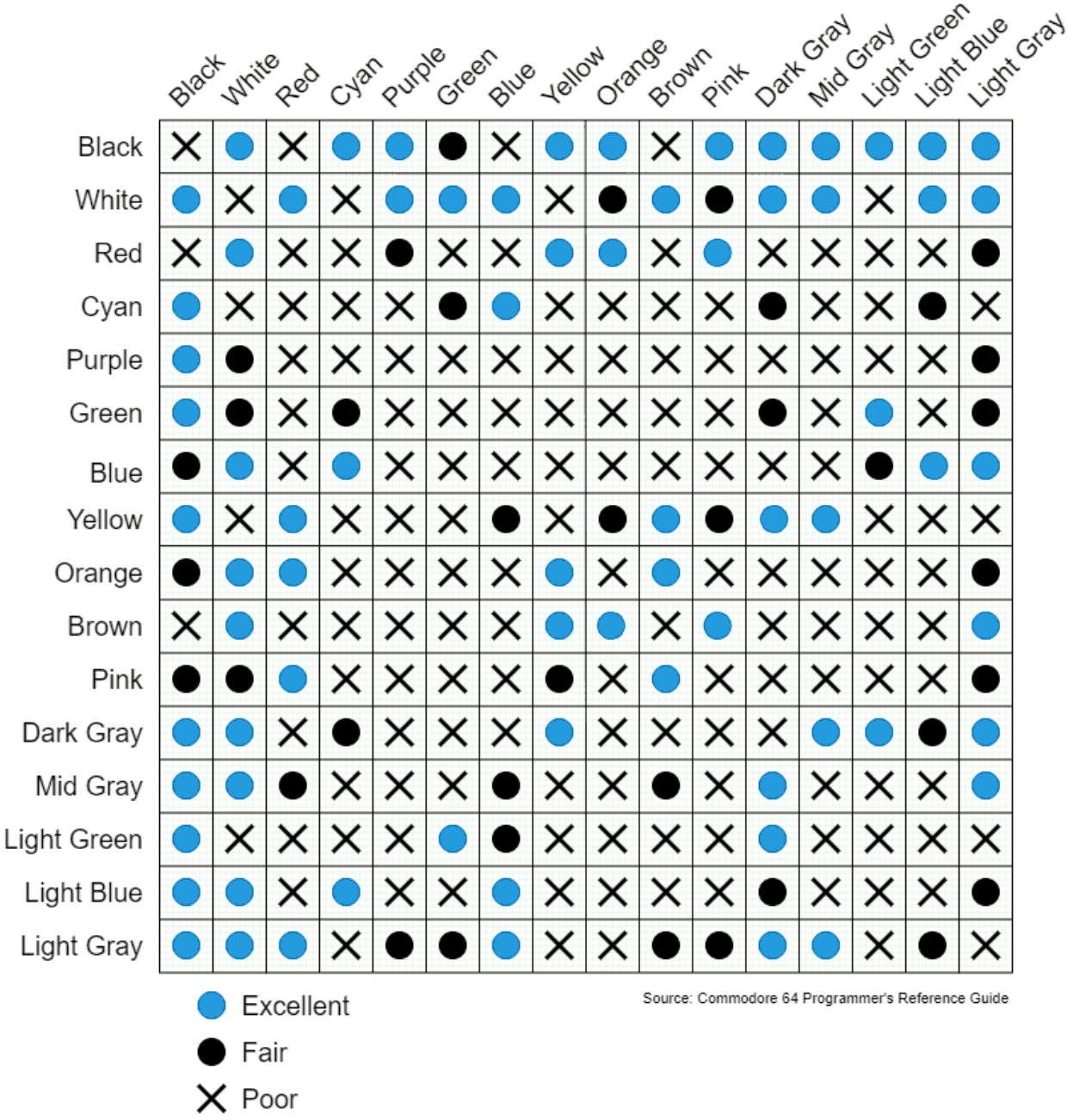
Rendering Priority The sprite memory location dictates the order in which it is rendered. The sprite whose attributes are at the lowest location will be rendered in front of all other sprites; the sprite at the highest location will be rendered behind all other sprites, and so forth.

Palette offset works in the same way as with the layers.

Composite video

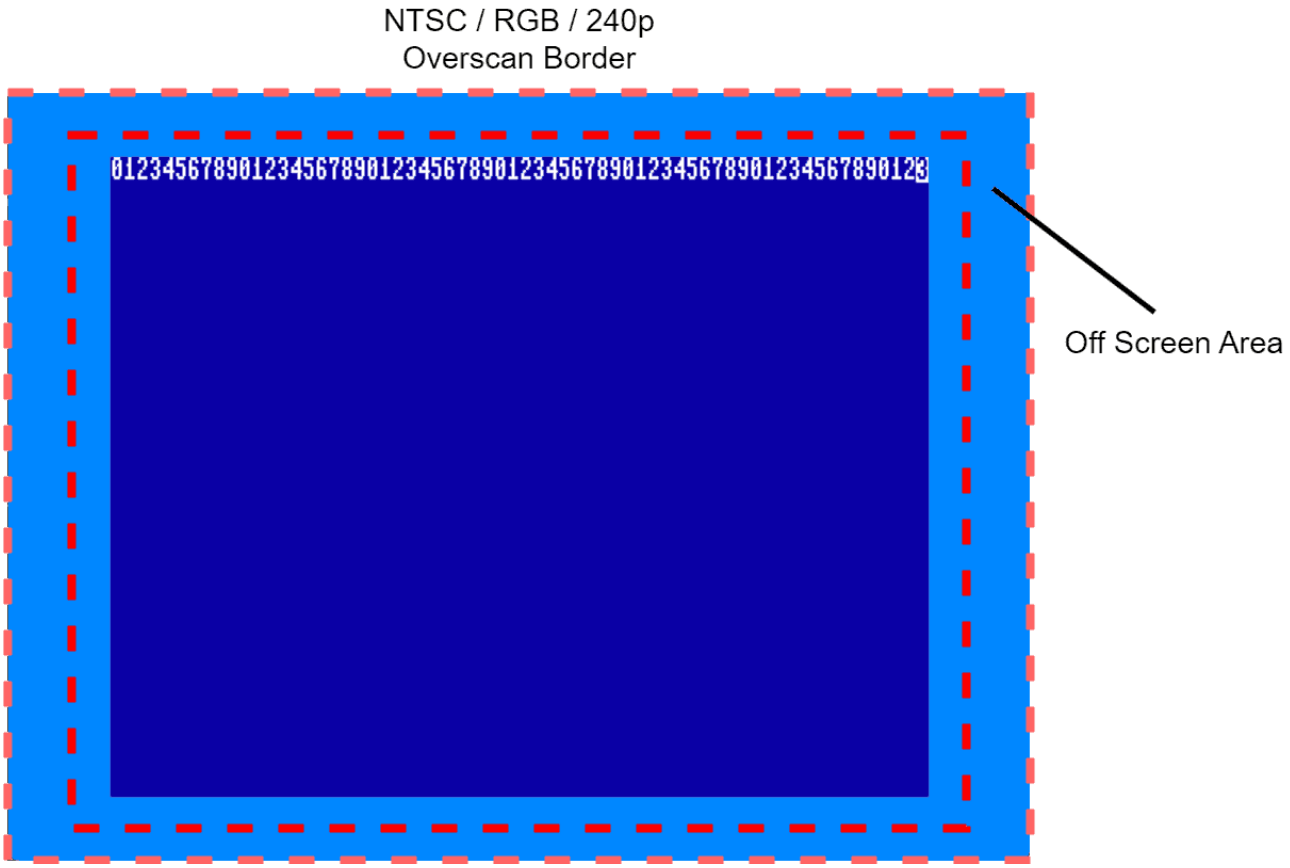
Color bleed

CRT Televisions and composite monitors experience color bleeding when certain colors are placed next to each other. Color bleed is especially apparent when choosing text color against certain background colors. Sprite pixel colors, character colors, and tiles will require careful color choice for better contrast. This chart shows which color combinations to avoid, and which work especially well together.



Overscan

Overscan is the border region in composite televisions and monitors that extend off screen. This overscan region varies by device, so there are no exact pixel measurements to describe the overscan region. Enabling the border can be a guideline for the visible draw region.



A game or application developer can use techniques adjust on-screen artifacts when composite video is in use.

- V-scale and H-scale registers to shrink the screen
- move some of the screen assets in closer
- develop in a screen mode with an enabled border

Setting to screen mode 3 or 11 while RGB or NTSC out is selected will also set 240p mode for games that are 320x240. However, a high resolution program may have poor presentation in 240p.

Sprite collisions

At the start of the vertical blank **Collisions** in **ISR** is updated. This field indicates which groups of sprites have collided. If the field is non-zero the **SPRCOL** interrupt will be set. The interrupt is generated once per field / frame and can be cleared by making sure the sprites no longer collide.

Note that collisions are only detected on lines that are actually rendered. This can result in subtle differences between non-interlaced and interlaced video modes.

VERA FX

The FX feature set is available in VERA firmware version v0.3.1 or later. The Commander X16 emulators also have this feature officially as of R44.

FX is a set of mainly addressing mode changes. VERA FX does not accelerate rendering, but it merely assists the CPU with some of the slower tasks, and when used cleverly, can allow for the programmer to perform some limited perspective transforms or basic 3D effects.

FX features are controlled mainly by registers $9F29-$9F2C with DCSEL set to 2 through 6. FX_CTRL ($9F29 w/ DCSEL=2) is the master switch for enabling or disabling FX behaviors. When writing an application that uses FX, it is important that the FX mode be preserved and disabled in interrupt handlers in cases where the handler accesses VERA registers or VRAM, including the PSG sound registers. Reading from FX_CTRL returns the current state, and writing 0 to FX_CTRL suspends the FX behaviors so that the VERA can be accessed normally without mutating other FX state.

Preliminary documentation for the feature can be found in Chapter 10 , but as this is a brand new feature, examples and documentation still need to be written.

Audio

The audio functionality contains of 2 independent systems. The first is the PSG or Programmable Sound Generator. The second is the PCM (or Pulse-Code Modulation) playback system.

Programmable Sound Generator (PSG)

The PSG consists of 16 voices, each with their own set of registers:

Offset	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
0	Frequency word (7:0)							
1	Frequency word (15:8)							
2	Right	Left	Volume					
3	Waveform		Pulse Width / XOR					

Frequency word sets the frequency of the sound. The formula for calculating the output frequency is:

```
sample_rate = 25MHz / 512 = 48828.125 Hz

output_frequency = sample_rate / (2^17) * frequency_word
```

Thus the output frequency can be set in steps of about 0.373 Hz.

*Example: to output a frequency of 440Hz (note A4) the **Frequency word** should be set to 440 / (48828.125 / (2^17)) = 1181*

Volume controls the volume of the sound with a logarithmic curve; 0 is silent, 63 ($3F) is the loudest. The **Left** and **Right** bits control to which channels the sound should be output.

Waveform controls the waveform of the sound:

Waveform	Description
0	Pulse
1	Sawtooth
2	Triangle
3	Noise

Pulse Width / XOR controls the duty cycle of the pulse waveform or the XOR permutation when used with the triangle or saw. For pulse, a value of 63 ($3F) will give a 50% duty cycle or square wave, 0 will give a very narrow pulse.

When the triangle or saw waveform is selected, the value influences an XOR calculation that changes the resulting waveform. This is most noticeable with the triangle waveform. It can be used to provide an NES-like fuzzy triangle as well as an overdriven saw sound (similar to the VRC6 NES chip) among several other varieties of sounds.

When used with the saw, the result is more subtle. It adds some overtones to the saw.

Setting the PW/XOR to 0 for Tri/Saw inverts the waveform from what it was prior to the addition of the XOR feature, and PW of 63 results in the original waveform. Be aware of phasing effects that this difference could cause.

Noise Just like the other waveform types, the frequency of the noise waveform can be controlled using frequency. In this case a higher frequency will give brighter noise and a lower value will give darker noise. The PWM/XOR values do not influence the noise shape.

PCM audio

For PCM playback, VERA contains a 4kB FIFO buffer. This buffer needs to be filled in a timely fashion by the CPU. To facilitate this an **AFLOW** (Audio FIFO low) interrupt can be generated when the FIFO is less than 1/4 filled.

Audio registers

`AUDIO_CTRL ($9F3B)`

FIFO Full (bit 7) is a read-only flag that indicates whether the FIFO is full. Any writes to the FIFO while this flag is 1 will be ignored. Writing a 1 to this register (**FIFO Reset**) will perform a FIFO reset, which will clear the contents of the FIFO buffer, except when written in combination with a 1 in bit 6.

FIFO Loop (bit 6+7): If a 1 is written to both bit 6 and 7 (at the same time), the FIFO will loop when played. Any other write to AUDIO_CTRL clears this loop flag. Note: this feature is currently only available in x16-emulator and is not in any released VERA firmware.

FIFO Empty (bit 6) is a read-only flag that indicates whether the FIFO is empty.

16-bit (bit 5) sets the data format to 16-bit. If this bit is 0, 8-bit data is expected.

Stereo (bit 4) sets the data format to stereo. If this bit is 0 (mono), the same audio data is send to both channels.

PCM Volume (bits 0..3)controls the volume of the PCM playback, this has a logarithmic curve. A value of 0 is silence, 15 is the loudest.

`AUDIO_RATE ($9F3C)`

PCM sample rate controls the speed at which samples are read from the FIFO. A few example values:

PCM sample rate	Description
128	normal speed (25MHz / 512 = 48828.125 Hz)
64	half speed (24414 Hz)
32	quarter speed (12207 Hz)
0	stop playback
>128	*invalid*

Using a value of 128 will give the best quality (lowest distortion); at this value for every output sample, an input sample from the FIFO is read. Lower values will output the same sample multiple times to the audio DAC. Input samples are always read as a complete set (being 1/2/4 bytes).

`AUDIO_DATA ($9F3D)`

Audio FIFO data Writes to this register add one byte to the PCM FIFO. If the FIFO is full, the write will be ignored.

NOTE: When setting up for PCM playback it is advised to first set the sample rate at 0 to stop playback. First fill the FIFO buffer with some initial data and then set the desired sample rate. This can prevent undesired FIFO underruns.

Audio data formats

Audio data is two's complement signed. Depending on the selected mode the data needs to be written to the FIFO in the following order:

Mode	Order in which to write data to FIFO
8-bit mono	<mono sample>
8-bit stereo	<left sample> <right sample>
16-bit mono	<mono sample (7:0)> <mono sample (15:8)>
16-bit stereo	<left sample (7:0)> <left sample (15:8)> <right sample (7:0)> <right sample (15:8)>

Chapter 10: VERA FX Reference

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This is preliminary documentation and the specification can still change at any point.

Introduction

This is a reference for the VERA FX features. It is meant to be a complement to the tutorial, currently found here .

The FX Update mainly adds "helpers" inside of VERA that can be used by the CPU. There is no "magic button" that allows you to do 3D graphics for example. It mainly helps at certain CPU time-consuming tasks, most notably the ones that are present in the (deep) inner-loop of a game/graphics engine. The FX Update does therefore not fundamentally change the architecture or nature of VERA, it extends and improves it.

In other words: the CPU is still the orchestrator of all that is done, but it is alleviated from certain operations where it is not (very) good at or does not have direct access to.

FX Update extends addressing modes, it does not add or extend renderers.

Usage

DCSEL

VERA is mapped as 32 8-bit registers in the memory space of the Commander X16, starting at address $9F20 and ending at $9F3F. Many of these are (fully) used, but some bits remain unused. The DCSEL bits in register $9F25 (also called CTRL) has been extended to 6-bits to allow for the 4 registers $9F29-$9F2C to have additional meanings.

Addr	Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
$9F25	CTRL	Reset	**DCSEL**						ADDRSEL

The FX features use DCSEL values 2, 3, 4, 5, and 6. This effectively gives FX 20 8-bit registers. Note that 15 of these registers are *write-only*, 2 of them are *read-only* and 3 are both *readable* and *writable*,

Important: *unless DCSEL values of 2-6 are used, the behavior of VERA is exactly the same as it was before the FX update. This ensures that the FX update is backwards compatible with traditional non-FX uses of VERA.*

Addr1 Mode

When DCSEL=2, the main FX configuration register becomes available (FX_CTRL/$9F29), which is both readable and writable. The 2 lower bits are the addr1 mode bits, which will change the behavior of how and when ADDR1 is updated. This puts the FX helpers in a certain "role".

Addr	Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
$9F29	FX_CTRL (DCSEL=2)	Transp. Writes	Cache Write Enable	Cache Fill Enable	One-byte Cache Cycling	16-bit Hop	4-bit Mode	**Addr1 Mode**	

Addr1 Mode	Description
0	Traditional VERA behavior
1	Line draw helper
2	Polygon filler helper
3	Affine helper

By default, Addr1 Mode is set to 0 (=00b), which is the **normal** and already-known behavior of `ADDR1` .

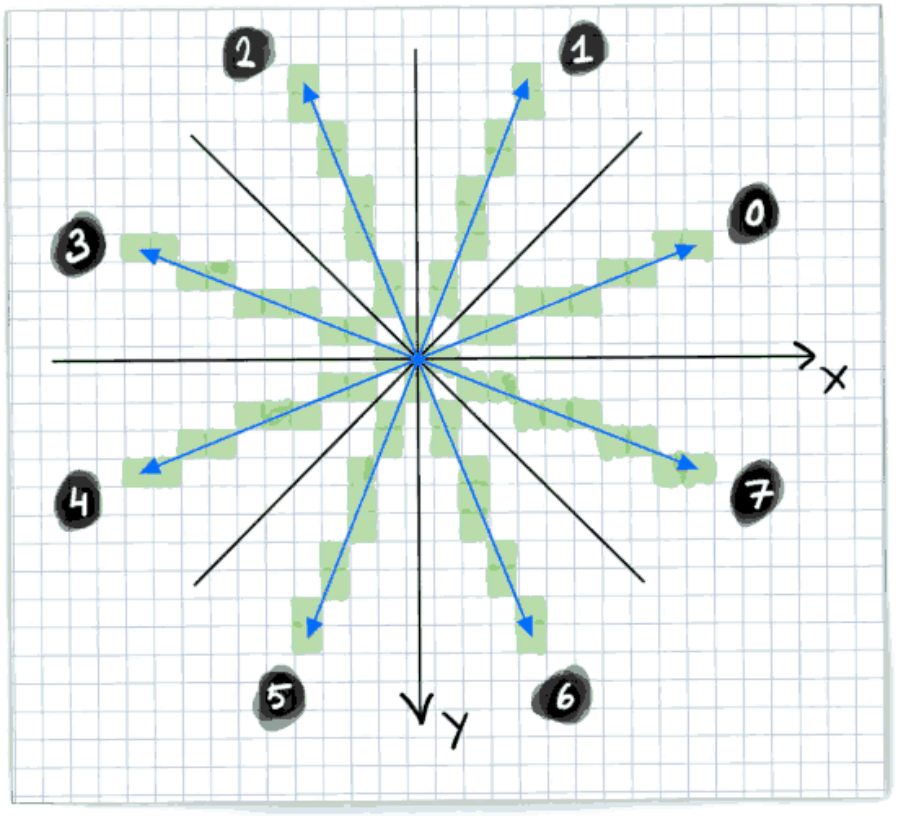
Line draw helper

When Addr1 Mode is set to 1 (=01b) the **line draw helper** is enabled.

Setting up the line draw helper

- Set `ADDR1` to the address of the starting pixel
- Determine the octant (see below) you are going to draw in, which will inform your `ADDR0` and `ADDR1` increments.
  - Set `ADDR1` increment in the direction you will ***always*** increment each step
    - For 8-bit mode: (+1, -1, -320, or +320)
    - For 4-bit mode: (-0.5, +0.5, -160, or +160)
  - Set `ADDR0` increment in the direction you will ***sometimes*** increment. Even though this is the increment for `ADDR0`, we are using it in line draw mode as an incrementer for `ADDR1`.
    - For 8-bit mode: (+1, -1, -320, or +320).
    - For 4-bit mode: (-0.5, +0.5, -160, or +160)
  - For 4-bit mode, the half increments are set via the Nibble Increment bit and optionally the DECR bit in `ADDRx_H`. For the Nibble Increment bit to have effect, the main Address Increment must be set to 0, and the 4-bit Mode bit must be set in FX_CTRL ($9F29, DCSEL=2).

Addr	Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
$9F22	ADDRx_H (x=ADDRSEL)	Address Increment				**DECR**	**Nibble Increment**	Nibble Address	VRAM Address (16)



Octant	8-bit `ADDR1` increment	8-bit `ADDR0` increment	4-bit `ADDR1` increment	4-bit `ADDR0` increment

0	+1	-320	+0.5	-160
1	-320	+1	-160	+0.5
2	-320	-1	-160	-0.5
3	-1	-320	-0.5	-160
4	-1	+320	-0.5	+160
5	+320	-1	+160	-0.5
6	+320	+1	+160	+0.5
7	+1	+320	+0.5	+160

- Set your slope into the two "X Increment" registers (DCSEL=3, see below). Note that increment registers are 15-bit signed fixed-point numbers, and for this mode, the range should be 0.0 to 1.0 inclusive, so you'll either want to store the value of 1, or you'll want to set only the fractional part.

Addr	Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
$9F29	FX_X_INCR_L (DCSEL=3) (Write only)	**X Increment (-2:-9) (signed)**							
$9F2A	FX_X_INCR_H (DCSEL=3) (Write only)	X Incr. 32x	X Increment (5:1) (signed)					**X Incr. (0)**	**X Incr. (-1)**

Note: Of the two incrementers, the line draw helper uses only the X incrementer. However depending on the octant you are drawing in, this incrementer will be used to depict either x or y pixel increments. So the "X" should not be taken literally here, it just means the first of the two incrementers.

- As a side effect of in line draw mode, by setting `FX_X_INCR_H` ($9F2A, DCSEL=3), the fractional part (the lower 9 bits) of *X Position* are automatically set to half a pixel. Furthermore, the lowest bit of the pixel position (which acts as an overflow bit) is set to 0 as well. This effectively sets the starting X-position to 0.5 (the center) of a pixel.

Note: There is no need to set the higher bits of the X position, since the FX X position (accumulator) is only used to track the fractional (subpixel) part of the line draw.

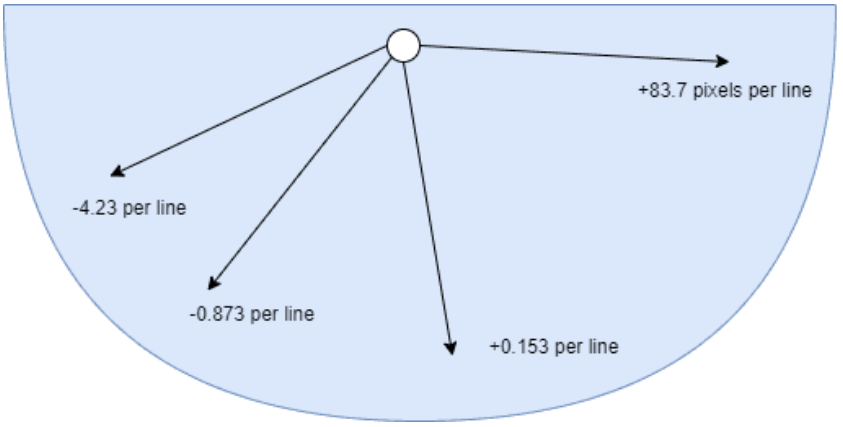
Polygon filler helper

When Addr1 Mode is set to 2 (=10b) the polygon filler helper is enabled.

Setting up the polygon filler helper

Assuming a 320 pixel-wide screen

- Set `ADDR0` to the address of the y-position of the top point of the triangle and x=0 (so on the left of the screen). Set its increment to +320 (for 8-bit mode) or +160 (for 4-bit mode).
  - Note: `ADDR0` is used as "base address" for calculating `ADDR1` for each horizontal line of the triangle. `ADDR0` should therefore start at the top of the triangle and increment exactly one line each time.
  - There is no need to set `ADDR1`. This is done by VERA.
- Calculate your slopes (dx/dy) for both the left and right point. Unlike the line draw helper, these slopes can be negative and can exceed 1.0. They are not dependent on octant, but cover the whole 180 degrees downwards. Below is an illustration of some (not-to-scale) examples of increments:



- Set `ADDR1` increment to +1 (for 8-bit mode) or +0.5 (for 4-bit mode)
  - `ADDR1` increment can also be +4 if you use 32-bit cache writes, explained later)
- Set your left slope into the two "X increment" registers and your right slope into the two "Y increment" registers (DCSEL=3, see below).
  - Important: They should be set to half the increment (or decrement) per horizontal line! This is because the polygon filler increments in two steps per line.
- Note that increment registers are 15-bit signed fixed-point numbers:
- 6 bits for the integer pixel increment
- 9 bits for the fractional (subpixel) increment
- 1 additional bit that indicates the actual value should be multiplied by 32

Addr	Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
$9F29	FX_X_INCR_L (DCSEL=3) (Write only)	X Increment (-2:-9) (signed)							
$9F2A	FX_X_INCR_H (DCSEL=3) (Write only)	X Incr. 32x	X Increment (5:0) (signed)						X Incr. (-1)
$9F2B	FX_Y_INCR_L (DCSEL=3) (Write only)	Y/X2 Increment (-2:-9) (signed)							
$9F2C	FX_Y_INCR_H (DCSEL=3) (Write only)	Y/X2 Incr. 32x	Y/X2 Increment (5:0) (signed)						Y/X2 Incr. (-1)

- Due to the fact that we are in "polygon fill"-mode, by setting the high bits of the "X increment" ($9F2A, DCSEL=3), the "X position" (the lower 9 bits of the position in DCSEL=4 and DCSEL=5) are automatically set to half a pixel. The same goes for the high bits of the Y/X2 increment ($9F2C, DCSEL=3) and Y/X2 position.
- Set the "X position" and "Y/X2 position" to the x-pixel-position of the top triangle point.

Addr	Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
$9F29	FX_X_POS_L (DCSEL=4) (Write only)	**X Position (7:0)**							
$9F2A	FX_X_POS_H (DCSEL=4) (Write only)	X Pos. (-9)	-				**X Position (10:8)**		
$9F2B	FX_Y_POS_L (DCSEL=4) (Write only)	**Y/X2 Position (7:0)**							
$9F2C	FX_Y_POS_H (DCSEL=4) (Write only)	Y/X2 Pos. (-9)	-				**Y/X2 Position (10:8)**		

Steps that are needed for filling a triangle part with lines:

- Read from `DATA1`
  - This will not return any useful data but will do two things in the background:
    - Increment/decrement the X1 and X2 positions by their corresponding increment values.
    - Set `ADDR1` to `ADDR0` + X1
- Then read the “Fill length (low)”-register. Its output depends on whether you're in 4 or 8-bit mode.

Addr	Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
$9F2B	FX_POLY_FILL_L (DCSEL=5, 4-bit Mode=0) (Read only)	Fill Len >= 16	X Position (1:0)		Fill Len (3:0)				0
$9F2B	FX_POLY_FILL_L (DCSEL=5, 4-bit Mode=1, 2-bit Polygon=0) (Read only)	Fill Len >= 8	X Position (1:0)		X Pos. (2)	Fill Len (2:0)			0

- If fill_len >= 16 (or >= 8 in 4-bit mode) then also read the “Fill length (high)”-register:

Addr	Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
$9F2C	FX_POLY_FILL_H (DCSEL=5) (Read only)	Fill Len (9:3)							0

  Important: when the two highest bits of Fill Len (bits 8 and 9) are both 1, it means there is a negative fill length. The line should not be drawn!
- Together they give you 10-bits of fill length (ignore the other bits for now). Since `ADDR1` is already set properly you can immediately start drawing this number of pixels (given by Fill Len).
  - `sta DATA1` ; as many times as Fill Len states
- Then read from `DATA0` : this will (also) increment X1 and X2
- Check if all lines of this triangle part have been drawn, if not go to the first step.

There is also a 2-bit polygon mode, which is better explained in the tutorial

Affine helper

When Addr1 Mode is set to 3 (=11b) the affine (transformation) helper is enabled.

When reading from ADDR1 in this mode, the affine helper reads tile data from a special tile area defined by two new FX registers:

- FX_TILEBASE is pointed to a set of 8x8 tiles in either 4-bit or 8-bit depth. FX can support up to 256 tile definitions, and can overlap the traditional layer tile bases.
- FX_MAPBASE points to a square-shaped tile map, one byte per tile. This tile map has no attribute bytes. unlike the traditional layer 0/1 tile maps.

Addr	Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
$9F2A	FX_TILEBASE (DCSEL=2) (Write only)	**FX Tile Base Address (16:11)**						**Affine Clip Enable**	2-bit Polygon
$9F2B	FX_MAPBASE (DCSEL=2) (Write only)	**FX Map Base Address (16:11)**						**Map Size**	

- **Affine Clip Enable** changes the behavior when the X/Y positions are outside of the tile map such that it always reads data from tile 0. The default behavior is to wrap the X/Y position to the opposite side of the map.
- **Map Size** is a 2 bit value that affects both the width and height of the tile map.

Map Size	Dimensions
0	2×2
1	8×8
2	32×32
3	128×128

- The **Transparent Writes** toggle in FX_CTRL is especially useful in Affine helper mode. Setting this toggle causes a write of zero to leave the byte (or the nibble) at the target address intact. This toggle is not limited to affine helper mode, and it affects writes to both DATA0 and DATA1.

Addr	Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
$9F29	FX_CTRL (DCSEL=2)	**Transp. Writes**	Cache Write Enable	Cache Fill Enable	One-byte Cache Cycling	16-bit Hop	4-bit Mode	Addr1 Mode	

When using the affine helper, the X and Y position registers (DCSEL=4) are used to set ADDR1 to the source pixel indirectly in the aforementioned tile map, while the X and Y increments determine the step after each read of ADDR1.

Addr	Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
$9F29	FX_X_POS_L (DCSEL=4) (Write only)	**X Position (7:0)**							
$9F2A	FX_X_POS_H (DCSEL=4) (Write only)	X Pos. (-9)	-				**X Position (10:8)**		
$9F2B	FX_Y_POS_L (DCSEL=4) (Write only)	**Y/X2 Position (7:0)**							
$9F2C	FX_Y_POS_H (DCSEL=4) (Write only)	Y/X2 Pos. (-9)	-				**Y/X2 Position (10:8)**		

The affine helper supports the full range of X and Y increment values, including negative values.

Addr	Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
$9F29	FX_X_INCR_L (DCSEL=3)	X Increment (-2:-9) (signed)							

	(Write only)			
$9F2A	FX_X_INCR_H (DCSEL=3) (Write only)	X Incr. 32x	X Increment (5:0) (signed)	X Incr. (-1)
$9F2B	FX_Y_INCR_L (DCSEL=3) (Write only)	Y/X2 Increment (-2:-9) (signed)		
$9F2C	FX_Y_INCR_H (DCSEL=3) (Write only)	Y/X2 Incr. 32x	Y/X2 Increment (5:0) (signed)	Y/X2 Incr. (-1)

32-bit cache

When the CPU reads a byte via DATA0 or DATA1, and "cache fill enable" is set, the value read will be copied into an indexed location inside the 32-bit cache.

Addr	Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
$9F29	FX_CTRL (DCSEL=2)	Transp. Writes	Cache Write Enable	**Cache Fill Enable**	One-byte Cache Cycling	16-bit Hop	4-bit Mode	Addr1 Mode	

In 8-bit mode, a byte is cached, but in 4-bit mode, a nibble is cached instead. Afterwards, by default, the index into the cache is incremented, and loops back around to 0 after the last index. The index can be set explicitly via the FX_MULT register. 8-bit mode uses bits 3:2 and ranges from 0-3. 4-bit mode uses bits 3:1 and ranges from 0-7.

Addr	Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
$9F2C	FX_MULT (DCSEL=2) (Write only)	Reset Accum.	Accumulate	Subtract Enable	Multiplier Enable	**Cache Byte Index**		**Cache Nibble Index**	Two-byte Cache Incr. Mode

Alternatively, the cache index can cycle between two adjacent bytes: 0, 1, and back to 0; or 2, 3, and back to 2. This option only has effect in 8-bit mode.

Addr	Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
$9F2C	FX_MULT (DCSEL=2) (Write only)	Reset Accum.	Accumulate	Subtract Enable	Multiplier Enable	Cache Byte Index		Cache Nibble Index	**Two-byte Cache Incr. Mode**

Setting the cache data directly

Instead of filling the cache by reading from DATA0 or DATA1, the cache data can also be set directly by writing to the FX_CACHE* registers. Setting the cache directly does not affect the cache index.

Addr	Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
$9F29	FX_CACHE_L (DCSEL=6) (Write only)	Cache (7:0) | Multiplicand (7:0) (signed)							
$9F2A	FX_CACHE_M (DCSEL=6) (Write only)	Cache (15:8) | Multiplicand (15:8) (signed)							
$9F2B	FX_CACHE_H (DCSEL=6)	Cache (23:16) | Multiplier (7:0) (signed)							

	(Write only)	
$9F2C	FX_CACHE_U (DCSEL=6) (Write only)	Cache (31:24) | Multiplier (15:8) (signed)

Writing the cache to VRAM

If "Cache write enabled" is set, the cache contents are written to VRAM when writing to DATA0 or DATA1. The primary use is to write all or part of the 32-bit cache to the 4-byte-aligned region of memory at the current address.

Control over which parts are written are chosen by the value written to DATA0 or DATA1. The value written is treated as a **nibble mask** where a 0-bit writes the data and a 1-bit masks the data from being written.In other words, writing a 0 will flush the entire 32-bit cache. Writing `#%00001111` will write the second and third byte in the cache to VRAM in the second and third memory locations in the 4-byte-aligned region.

Addr	Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
$9F29	FX_CTRL (DCSEL=2)	Transp. Writes	**Cache Write Enable**	Cache Fill Enable	One-byte Cache Cycling	16-bit Hop	4-bit Mode	Addr1 Mode	

Transparency writes

Transparent writes, when enabled, also applies to cache writes. If enabled, zero bytes (or zero nibbles in 4-bit mode) in the cache, which are treated as transparency pixels, are not written.

Addr	Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
$9F29	FX_CTRL (DCSEL=2)	**Transp. Writes**	Cache Write Enable	Cache Fill Enable	One-byte Cache Cycling	16-bit Hop	4-bit Mode	Addr1 Mode	

When "one-byte cache cycling" is turned on and DATA0 or DATA1 is written to, the byte at the current cache index is written to VRAM. When "Cache write enable" is set as well, the byte is duplicated 4 times when writing to VRAM.

Usually the incrementing of the cache index is only triggered by reading from DATA0 or DATA1 when cache filling is enabled. However it can also be triggered by reading from DATA0 in polygon mode when cache filling is not enabled and "one-byte cache cycling" is enabled.

Addr	Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
$9F29	FX_CTRL (DCSEL=2)	Transp. Writes	Cache Write Enable	Cache Fill Enable	**One-byte Cache Cycling**	16-bit Hop	4-bit Mode	Addr1 Mode	

Multiplier and accumulator

The 32-bit cache also doubles as an input to the hardware multiplier when Multiplier Enable is set.

Addr	Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
$9F2C	FX_MULT (DCSEL=2) (Write only)	Reset Accum.	Accumulate	Subtract Enable	**Multiplier Enable**	Cache Byte Index		Cache Nibble Index	Two-byte Cache Incr. Mode

To do a single multiplication, put the two 16-bit inputs into the two halves of the 32-bit cache.

```
    lda #(2 << 1)
    sta VERA_CTRL        ; $9F25
    stz VERA_FX_CTRL     ; $9F29 (mainly to reset Addr1 Mode to 0)
    lda #%00010000
    sta VERA_FX_MULT     ; $9F2C
```

```
    lda #(6 << 1)
    sta VERA_CTRL        ; $9F25
    lda #<69
    sta VERA_FX_CACHE_L  ; $9F29
    lda #>69
    sta VERA_FX_CACHE_M  ; $9F2A
    lda #<420
    sta VERA_FX_CACHE_H  ; $9F2B
    lda #>420
    sta VERA_FX_CACHE_U  ; $9F2C
```

The accumulator can be used to accumulate the sum of several multiplications. Before doing this single multiplication, ensure this is reset this to zero, otherwise the output will be added to the value of the accumulator before being written. There are two methods to do this. The first is to write a 1 into bit 7 of FX_MULT ($9F2C, DCSEL=2). The other, more conveniently, is to read FX_ACCUM_RESET (the same register location as VERA_FX_CACHE_L).

```
    lda FX_ACCUM_RESET   ; $9F29 (DCSEL=6)
```

To perform the multiplication, it must be written to VRAM first. This is done via the cache write mechanism. Usually the cache itself is written to VRAM if "Cache Write Enable" is set. However, if the "Multiplier Enable" bit is also enabled, the multiplier result is written to VRAM instead.

```
    ; Set the ADDR0 pointer to $00000 and write our multiplication result there
    lda #(2 << 1)
    sta VERA_CTRL        ; $9F25
    lda #%01000000       ; Cache Write Enable
    sta VERA_FX_CTRL     ; $9F29
    stz VERA_ADDRx_L     ; $9F20 (ADDR0)
    stz VERA_ADDRx_M     ; $9F21
    stz VERA_ADDRx_H     ; $9F22 ; no increment
    stz VERA_DATA0       ; $9F23 ; multiply and write out result
    lda #%00010000       ; Increment 1
    sta VERA_ADDRx_H     ; $9F22 ; so we can read out the result
    lda VERA_DATA0
    sta $0400
    lda VERA_DATA0
    sta $0401
    lda VERA_DATA0
    sta $0402
    lda VERA_DATA0
    sta $0403
```

Note: the VERA works by pre-fetching the contents from VRAM whenever the address pointer is changed or incremented. This happens even when the address increment is 0. Due to this behavior, it is possible to have stale data latched in one of the two data ports if the underlying VRAM is changed via the other data port. This example avoids this scenario by only using ADDR0/DATA0. This potential gotcha was not introduced by the FX update, but rather has always been how VERA behaves.

Accumulation

One can also trigger the multiplication and add it to (or subtract it from) the multiplication accumulator by calling "accumulate" in one of two different ways. We could write a 1 into bit 6 of FX_MULT ($9F2C, DCSEL=2), but more conveniently, we can read FX_ACCUM (the same register location as VERA_FX_CACHE_M)

```
    lda FX_ACCUM         ; $9F2A (DCSEL=6)
```

Once the accumulation is triggered, the result of the operation is stored back into the accumulator.

The default accumulation operation is (multiply then) add. This can be switched to subtraction by setting the Subtract Enable bit in FX_MULT

Addr	Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
$9F2C	FX_MULT (DCSEL=2)	Reset Accum.	Accumulate	**Subtract Enable**	Multiplier Enable	Cache Byte Index		Cache Nibble Index	Two-byte Cache Incr. Mode

	(Write only)							

If the multiplication accumulator has a nonzero value, any multiplications carried out via a VRAM Cache write will be offset by the value of the accumulator (either added to or subtracted from the accumulator), but they will not change the value of the accumulator.

16-bit hop

There is a special address increment mode that can be used to read pairs of bytes via ADDR1.

Addr	Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
$9F29	FX_CTRL (DCSEL=2)	Transp. Writes	Cache Write Enable	Cache Fill Enable	One-byte Cache Cycling	**16-bit Hop**	4-bit Mode	Addr1 Mode	

In this mode, setting ADDR1's increment to +4 will result in alternating increments of +1 and +3. Setting it to +320 will result in alternating increments of +1 and +319. All other increment values, including negative increments, lack this special hop property.

After this bit is set, writing to ADDRx_L resets the hop alignment such that the first increment is +1.

This mode is useful for reading out a series of 16-bit values after a series of multiplications.

For a more detailed explanation of chained math operations, see the tutorial .

Chapter 11: Sound Programming

Audio bank API

The Commander X16 provides many convenience routines for controlling the YM2151 and VERA PSG. These are called similarly to how KERNAL API calls are done in machine language.

In order to gain access to these routines, you must either use `jsrfar` from the KERNAL API:

```
AUDIO_BANK = $0A

jsr jsrfar  ; $FF6E
.word ym_init ; $C063
.byte AUDIO_BANK
```

or switch to ROM bank `$0A` directly:

```
lda #$0A ; Audio bank number
sta $01  ; ROM bank register
```

Conveniently, the KERNAL API still exists in this bank, and calling a KERNAL API routine will automatically switch your ROM bank back to the KERNAL bank to perform the routine and then switch back right before returning, so there's usually no need for your audio-centric program to switch away from the audio bank to perform the occasional KERNAL API call.

Audio API routines

For the audio chips, some of the documentation uses the words *channel* and *voice* interchangeably. This table of API routines uses *channel* for the 8 on the YM2151, and *voice* for the 16 on the PSG.

Label	Address	Class	Description	Inputs	Returns	Preserves
`audio_init`	`$C09F`	-	Wrapper routine that calls both `psg_init` and `ym_init` followed by `ym_loaddefpatches`. This is the routine called by the KERNAL at reset.	none	none	none
`bas_fmchordstring`	`$C08D`	BASIC	Starts playing all of notes specified in a string. This uses the same parser as `bas_fmplaystring` but instead of playing the notes in sequence, it starts playback of each note in the string, on many channels as is necessary, then returns to the caller without delay. The first FM channel that is used is the one specified by calling `bas_playstringvoice` prior to calling this routine. The string pointer must point to low RAM (`$0000-$9EFF`).	.A = string length .X .Y = pointer to string	none	none
`bas_fmfreq`	`$C000`	BASIC	Plays a note specified in Hz on an FM channel	.A = channel .X .Y = 16-bit frequency in Hz c clear = normal c set = no retrigger	c clear = success c set = error	none

bas_fmnote	$C003	BASIC	Plays a note specified in BASIC format on an FM channel	.A = channel .X = note (BASIC format) .Y = fractional semitone c clear = normal c set = no retrigger	c clear = success c set = error	none
bas_fmplaystring	$C006	BASIC	Plays a note script using the FM channel which was specified on a previous call to bas_playstringvoice. This string pointer must point to low RAM ($0000-$9EFF). This routine depends on interrupts being enabled. In particular, it uses WAI as a delay for timing, so it expects IRQ to be asserted and acknowledged once per video frame, which is the case by default on the system. Stops playback and returns control if the STOP key is pressed.	.A = string length .X .Y = pointer to string	none	none
bas_fmvib	$C009	BASIC	Sets the LFO speed and both amplitude and frequency depth based on inputs. Also sets the LFO waveform to triangle.	.A = speed .X = PMD/AMD depth	c clear = success c set = error	none
bas_playstringvoice	$C00C	BASIC	Preparatory routine for bas_fmplaystring and bas_psgplaystring to set the voice/channel number for playback	.A = PSG/YM voice/channel	none	.A .X
bas_psgchordstring	$C090	BASIC	Starts playing all of notes specified in a string. This uses the same parser as bas_psgplaystring but instead of playing the notes in sequence, it starts playback of each note in the string, on many voices as is necessary, then returns to the caller without delay. The first PSG voice that is used is the one specified by calling bas_playstringvoice prior to calling this routine. The string pointer must point to low RAM ($0000-$9EFF).	.A = string length .X .Y = pointer to string	none	none
bas_psgfreq	$C00F	BASIC	Plays a note specified in Hz on a PSG voice	.A = voice .X .Y = 16-bit frequency	c clear = success c set = error	none
bas_psgnote	$C012	BASIC	Plays a note specified in BASIC format on a PSG voice	.A = voice .X = note (BASIC format) .Y = fractional semitone	c clear = success c set = error	none
bas_psgwav	$C015	BASIC	Sets a waveform and duty cycle for a PSG voice	.A = voice .X 0-63 = Pulse, 1/128 - 64/128 duty	c clear = success c set = error	none

				cycle .X 64-127 = Sawtooth .X 128-191 = Triangle .X 192-255 = Noise		
bas_psgplaystring	$C018	BASIC	Plays a note script using the PSG voice which was specified on a previous call to bas_playstringvoice. This string pointer must point to low RAM ($0000-$9EFF). This routine depends on interrupts being enabled. In particular, it uses WAI as a delay for timing, so it expects IRQ to be asserted and acknowledged once per video frame, which is the case by default on the system. Stops playback and returns control if the STOP key is pressed.	.A = string length .X .Y = pointer to string	none	none
notecon_bas2fm	$C01B	Conversion	Convert a note in BASIC format to a YM2151 KC code	.X = note (BASIC format)	.X = note (YM2151 KC) c clear = success c set = error	.Y
notecon_bas2midi	$C01E	Conversion	Convert a note in BASIC format to a MIDI note number	.X = note (BASIC format)	.X = MIDI note c clear = success c set = error	.Y
notecon_bas2psg	$C021	Conversion	Convert a note in BASIC format to a PSG frequency	.X = note (BASIC format) .Y = fractional semitone	.X .Y = PSG frequency c clear = success c set = error	none
notecon_fm2bas	$C024	Conversion	Convert a note in YM2151 KC format to a note in BASIC format	.X = YM2151 KC	.X = note (BASIC format) c clear = success c set = error	.Y
notecon_fm2midi	$C027	Conversion	Convert a note in YM2151 KC format to a MIDI note number	.X = YM2151 KC	.X = MIDI note c clear = success c set = error	.Y
notecon_fm2psg	$C02A	Conversion	Convert a note in YM2151 KC format to a PSG frequency	.X = YM2151 KC .Y = fractional semitone	.X .Y = PSG frequency c clear = success c set = error	none
notecon_freq2bas	$C02D	Conversion	Convert a frequency in Hz to a note in BASIC format and a fractional semitone	.X .Y = 16-bit frequency in Hz	.X = note (BASIC format) .Y = fractional	none

					semitone c clear = success c set = error	
notecon_freq2fm	$C030	Conversion	Convert a frequency in Hz to YM2151 KC and a fractional semitone (YM2151 KF)	.X .Y = 16-bit frequency in Hz	.X = YM2151 KC .Y = fractional semitone (YM2151 KF) c clear = success c set = error	none
notecon_freq2midi	$C033	Conversion	Convert a frequency in Hz to a MIDI note and a fractional semitone	.X .Y = 16-bit frequency in Hz	.X = MIDI note .Y = fractional semitone c clear = success c set = error	none
notecon_freq2psg	$C036	Conversion	Convert a frequency in Hz to a VERA PSG frequency	.X .Y = 16-bit frequency in Hz	.X .Y = 16-bit frequency in VERA PSG format c clear = success c set = error	none
notecon_midi2bas	$C039	Conversion	Convert a MIDI note to a note in BASIC format	.X = MIDI note	.X = note (BASIC format) c clear = success c set = error	.Y
notecon_midi2fm	$C03C	Conversion	Convert a MIDI note to a YM2151 KC. Fractional semitone is unneeded as it is identical to KF already.	.X = MIDI note.	.X = YM2151 KC c clear = success c set = error	.Y
notecon_midi2psg	$C03F	Conversion	Convert a MIDI note and fractional semitone to a PSG frequency	.X = MIDI note .Y = fractional semitone	.X .Y = 16-bit frequency in VERA PSG format c clear = success c set = error	none
notecon_psg2bas	$C042	Conversion	Convert a frequency in VERA PSG format to a note in BASIC format and a fractional semitone	.X .Y = 16-bit frequency in VERA PSG format	.X = note (BASIC format) .Y = fractional semitone c clear = success c set = error	none
notecon_psg2fm	$C045	Conversion	Convert a frequency in VERA PSG format to YM2151 KC and a	.X .Y = 16-bit frequency in	.X = YM2151 KC	none

			fractional semitone (YM2151 KF)	VERA PSG format	.Y = fractional semitone (YM2151 KF) c clear = success c set = error	
notecon_psg2midi	$C048	Conversion	Convert a frequency in VERA PSG format to a MIDI note and a fractional semitone	.X .Y = 16-bit frequency in VERA PSG format	.X = MIDI note .Y = fractional semitone c clear = success c set = error	none
psg_getatten	$C093	VERA PSG	Retrieve the attenuation value for a voice previously set by psg_setatten	.A = voice	.X = attenuation value	.A
psg_getpan	$C096	VERA PSG	Retrieve the simple panning value that is currently set for a voice.	.A = voice	.X = pan value	.A
psg_init	$C04B	VERA PSG	Initialize the state of the PSG. Silence all voices. Reset the attenuation levels to 0. Set "playstring" defaults including O4, T120, S1, and L4. Set all PSG voices to the pulse waveform at 50% duty with panning set to both L+R	none	none	none
psg_playfreq	$C04E	VERA PSG	Turn on a PSG voice at full volume (factoring in attenuation) and set its frequency	.A = voice .X .Y = 16 bit frequency in VERA PSG format	none	none
psg_read	$C051	VERA PSG	Read a value from one of the VERA PSG registers. If the selected register is a volume register, return either the cooked value (attenuation applied) or the raw value (as received by psg_write or psg_setvol, or as set by psg_playfreq) depending on the state of the carry flag	.X = PSG register address (offset from $1F9C0) c clear = if volume, return raw c set = if volume, return cooked	.A = register value	.X
psg_setatten	$C054	VERA PSG	Set the attenuation value for a PSG voice. The valid range is from $00 (full volume) to $3F (fully muted). API routines which affect volume will deduct the attenuation value from the intended volume before setting it. Calls to this routine while a note is playing will change the output volume of the voice immediately. This control can be considered a "master volume" for the voice.	.A = voice .X = attenuation	none	none

`psg_setfreq`	`$C057`	VERA PSG	Set the frequency of a PSG voice without changing any other attributes of the voice	.A = voice .X .Y = 16 bit frequency in VERA PSG format	none	none
`psg_setpan`	`$C05A`	VERA PSG	Set the simple panning for the voice. A value of `0` will silence the voice entirely until another pan value is set.	.A = voice .X 0 = none .X 1 = left .X 2 = right .X 3 = both	none	none
`psg_setvol`	`$C05D`	VERA PSG	Set the volume for the voice. The volume that's written to the VERA has attenuation applied. Valid volumes range from `$00` to `$3F` inclusive	.A = voice .X = volume	none	none
`psg_write`	`$C060`	VERA PSG	Write a value to one of the VERA PSG registers. If the selected register is a volume register, attenuation will be applied before the value is written to the VERA	.A = value .X = PSG register address (offset from `$1F9C0`)	none	.A .X
`psg_write_fast`	`$C0A2`	VERA PSG	Same effect as `psg_write` but does not preserve the state of the VERA CTRL and ADDR registers. It also assumes VERA_CTRL bit 0 is clear, VERA_ADDR0_H = $01 (auto increment 0 recommended), and VERA_ADDR0_M = $F9. This routine is meant for use by sound engines that typically write out multiple PSG registers in a loop.	.A = value .X = PSG register address (offset from `$1F9C0`)	none	.A .X
`ym_getatten`	`$C099`	YM2151	Retrieve the attenuation value for a channel previously set by `ym_setatten`	.A = channel	.X = attenuation value	.A
`ym_getpan`	`$C09C`	YM2151	Retrieve the simple panning value that is currently set for a channel.	.A = channel	.X = pan value	.A
`ym_init`	`$C063`	YM2151	Initialize the state of the YM chip. Silence all channels by setting the release part of the ADSR envelope to max and then setting all channels to released. Reset all attenuation levels to 0. Set "playstring" defaults including `O4`, `T120`, `S1`, and `L4`. Set panning for all channels set to both L+R. Reset LFO state. Set all of the other registers to `$00`	none	c clear = success c set = error	none

`ym_loaddefpatches`	`$C066`	YM2151	Load a default set of patches into the 8 channels.
			`C0: Piano (0)`
			`C1: E. Piano (5)`
			`C2: Vibraphone (11)`
			`C3: Fretless (35)`
			`C4: Violin (40)`
			`C5: Trumpet (56)`
			`C6: Blown Bottle (76)`
			`C7: Fantasia (88)`
				none	c clear = success
					c set = error
						none

ym_loadpatch	$C069	YM2151	Load into a channel a patch preset by number (0-161) from the audio bank, or from an arbitrary memory location. High RAM addresses ($A000-$BFFF) are accepted in this mode.	.A = channel c clear = .X .Y = patch address c set = .X = patch number	c clear = success c set = error	none
ym_loadpatchlfn	$C06C	YM2151	Load patch into a channel by way of an open logical file number. This routine will read 26 bytes from the open file, or possibly fewer bytes if there's an error condition. The routine will leave the file open on return. On return if c is set, check .A for the error code.	.A = channel .X = Logical File Number	c clear = success c set .A=0 = YM error c set .A&3=2 = read timeout c set .A&3=3 = file not open c set .A&64=64 = EOF c set .A&128=128 = device not present	none
ym_playdrum	$C06F	YM2151	Load a patch associated with a MIDI drum note number and trigger it on a channel. Valid drum note numbers mirror the General MIDI percussion standard and range from 25 (Snare Roll) through 87 (Open Surdo). Note 0 will release the note. After the drum is played, the channel will still contain the patch for the drum sound and thus may not sound musical if you attempt to play notes on it before loading another instrument patch.	.A = channel .X = drum note	c clear = success c set = error	none
ym_playnote	$C072	YM2151	Set a KC/KF on a channel and optionally trigger it.	.A = channel .X = KC .Y = KF (fractional semitone) c clear = trigger c set = no trigger	c clear = success c set = error	none
ym_setatten	$C075	YM2151	Set the attenuation value for a channel. The valid range is from $00 (full volume) to $7F (fully muted). API routines which affect TL or CON will add the attenuation value to the intended TL on operators that are carriers before setting it. Calls to this routine will change the TL of the channel's carriers immediately. This control can be considered a "master volume" for the channel.	.A = channel .X = attenuation	c clear = success c set = error	.A .X

`ym_setdrum`	`$C078`	YM2151	Load a patch associated with a MIDI drum note number and set the KC/KF for it on a channel. Called by `ym_playdrum`.	.A = channel .X = drum note	c clear = success c set = error	none
`ym_setnote`	`$C07B`	YM2151	Set a KC/KF on a channel. Called by `ym_playnote`.	.A = channel .X = KC .Y = KF (fractional semitone)	c clear = success c set = error	none
`ym_setpan`	`$C07E`	YM2151	Set the simple panning for the channel. A value of `0` will silence the channel entirely until another pan value is set.	.A = channel .X 0 = none .X 1 = left .X 2 = right .X 3 = both	c clear = success c set = error	none
`ym_read`	`$C081`	YM2151	Read a value from the in-RAM shadow of one of the YM2151 registers. The YM2151's internal registers cannot be read from, but this API keeps state of what was written, so this routine will be able to retrieve chip values for you. If the selected register is a TL register, return either the cooked value (attenuation applied) or the raw value (as received by `ym_write`) depending on the state of the carry flag	.X = YM2151 register address c clear = if TL, return raw c set = if TL, return cooked	.A = register value c clear = success c set = error	.X
`ym_release`	`$C084`	YM2151	Release a note on a channel. If a note is not playing, this routine has no tangible effect	.A = channel	c clear = success c set = error	none
`ym_trigger`	`$C087`	YM2151	Trigger the currently configured note on a channel, optionally releasing the channel first depending on the state of the carry flag.	.A = channel c clear = release first c set = no release	c clear = success c set = error	none
`ym_write`	`$C08A`	YM2151	Write a value to one of the YM2151 registers and to the in-RAM shadow copy. If the selected register is a TL register, attenuation will be applied before the value is written. Writes which affect which operators are carriers will have TL values for that channel appropriately recalculated and rewritten	.A = value .X = YM register address	c clear = success c set = error	.A .X

A note on semitones (get it?)

It may be advantageous to consider storing note data internally as the MIDI representation with a fractional component if you want things like pitch slides to behave the same way between the PSG and YM2151.

Essentially, it can be thought of as an 8.8 fixed point 16-bit number.

The YM2151 handles semitones differently than the PSG and requires converting the MIDI note to the appropriate KC value using `notecon_midi2fm`. KF is the fractional semitone (albeit with only the top 6-bits used) and requires no conversion.

The PSG, by contrast, operates with linear pitch which is why `notecon_midi2psg` also takes the fractional component (y) as input.

Thus, if you manage all your pitch slides using MIDI notes along with a fractional component, you can then convert this directly over to PSG or YM2151 as required and end up with the same pitch (or close enough to it).

Direct communication with the YM2151 and VERA PSG vs API

Use of the API routines above is not required to access the capabilities of the sound chips. However, mixing raw writes to a chip and API access for the same chip is not recommended, particularly where PSG volumes and YM2151 TL and RLFBCON registers are concerned. The API processes volumes, calculating attenuation and adjusting the output volume accordingly, and the API will be oblivious to direct manipulation of the sound chips.

The sections below describe how to do raw access to the sound chips outside of the API.

VERA PSG and PCM Programming

- For VERA PSG and PCM, refer to Chapter 9.

YM2151 (OPM) FM Synthesis

The Yamaha YM2151 (OPM) sound chip is an FM synthesizer ASIC in the Commander X16. It is connected to the system bus at I/O address `0x9F40` (address register) and at `0x9F41` (data register). It has 8 independent voices with 4 FM operators each. Each voice is capable of left/right/both audio channel output. The four operators of each channel may be connected in one of 8 pre-defined "connection algorithms" in order to produce a wide variety of timbres.

YM2151 Communication

There are 3 basic operations to communicate with the YM chip: Reading its status, address select, and data write. These are performed by reading from or writing to one of the two I/O addresses as follows:

Address	Name	Read Action	Write Action
0x9F40	`YM_address`	Undefined (returns ?)	Selects the internal register address where data is written.
0x9F41	`YM_data`	Returns the `YM_status` byte	Writes the value into the currently-selected internal address.

The values stored in the YM's internal registers are write-only. If you need to know the values in the registers, you must store a copy of the values somewhere in memory as you write updates to the YM.

YM Write Procedure

1. Ensure YM is not busy (see Write Timing below).
2. Select the desired internal register address by writing it into `YM_address`.
3. Write the new value for this register into `YM_data`.

Note: You may write into the same register multiple times without repeating a write to `YM_address`. The same register will be updated with each data write.

Write Timing

The YM2151 is sensitive to the speed at which you write data into it. If you make writes when it is not ready to receive them, they will be dropped and the sound output will be corrupted.

You must include a delay between writes to the address select register ($9F40) and the subsequent data write. 10 CPU cycles is the recommended minimum delay.

The YM becomes `BUSY` for approximately 150 CPU cycles' (at 8Mhz) whenever it receives a data write. *Any writes into YM_data during this `BUSY` period will be ignored!*

In order to avoid this, you can use the `BUSY` flag which is bit 7 of the `YM status` byte. Read the status byte from `YM_data` (0x9F41). If the top bit (7) is set, the YM may not be written into at this time. Note that it is not *required* that you read `YM_status`, only that writes occur no less than ~150 CPU cycles apart. For instance, BASIC executes slowly enough that you are in no danger of writing into the YM too quickly, so BASIC programs may skip checking `YM_status`.

Lastly, the `BUSY` flag sometimes takes a (very) short period before it goes high. This has only been observed when IMMEDIATELY polling the flag after a write into `YM_data.` As long as your code does not do so, this quirk should not be an issue.

Example Code

Assembly Language:

```
check_busy:
    BIT YM_data      ; check busy flag
    BMI check_busy   ; wait until busy flag is clear
    LDA #$08         ; Select YM register $08 (Key-Off/On)
    STA YM_addr      ;
    NOP              ;<-+
    NOP              ;  |
    NOP              ;  +--slight pause before writing data
    NOP              ;  |
    NOP              ;<-+
    LDA #$04         ; Write $04 (Release note on channel 4).
    STA YM_data
    RTS
```

BASIC:

```
10 YA=$9F40      : REM YM_ADDRESS
20 YD=$9F41      : REM YM_DATA
30 POKE YA,$29   : REM CHANNEL 1 NOTE SELECT
40 POKE YD,$4A   : REM SET NOTE = CONCERT A
50 POKE YA,$08   : REM SELECT THE KEY ON/OFF REGISTER
60 POKE YD,$00+1 : REM RELEASE ANY NOTE ALREADY PLAYING ON CHANNEL 1
70 POKE YD,$78+1 : REM KEY-ON VOICE 1 TO PLAY THE NOTE
80 FOR I=1 TO 100 : NEXT I : REM DELAY WHILE NOTE PLAYS
90 POKE YD,$00+1 : REM RELEASE THE NOTE
```

YM2151 Internal Addressing

The YM register address space can be thought of as being divided into 3 ranges:

Range	Type	Description
00 .. 1F	Global Values	Affect individual global parameters such as LFO frequency, noise enable, etc.
20 .. 3F	Channel CFG	Parameters in groups of 8, one per channel. These affect the whole channel.
40 .. FF	Operator CFG	Parameters in groups of 32 - these map to individual operators of each voice.

YM2151 Register Map

Global Settings

Addr	Register	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Description
$01	Test Register	!	!	!	!	!	!	LR	!	Bit 1 is the LFO reset bit. Setting it disables the LFO and holds the oscillator at 0. Clearing it enables the LFO. All other bits control various test functions and should not be written into.
$08	Key Control	.	C2	M2	C1	M1	CHA			Starts and Releases notes on the 8 channels. Setting/Clearing bits for M1,C1,M2,C2 controls the key state for those operators on channel CHA. NOTE: The operator order is different than the order they appear in the Operator configuration registers!

$0F	Noise Control	NE	.	.	NFRQ				NE = Noise Enable NFRQ = Noise Frequency When eabled, C2 of channel 7 will use a noise waveform instead of a sine waveform.
$10	Ta High	CLKA1							Top 8 bits of Timer A period setting
$11	Ta Low	.	.	.	.	.	.	CLKA2	Bottom 2 bits of Timer A period setting
$12	Timer B	CLKB							Timer B period setting
$14	IRQ Control	CSM	.	Clock ACK		IRQ EN		Clock Start	CSM: When a timer expires, trigger note key-on for all channels. For the other 3 fields, lower bit = Timer A, upper bit = Timer B. Clock ACK: clears the timer's bit in the YM_status byte and acknowledges the IRQ.
$18	LFO Freq.	LFRQ							Sets LFO frequency. $00 = ~0.008Hz $FF = ~32.6Hz
$19	LFO Amplitude	0	AMD						AMD = Amplitude Modulation Depth PMD = Phase Modulation (vibrato) Depth Bit 7 determines which parameter is being set when writing into this register.
		1	PMD						
$1B	CT / LFO Waveform	CT		.	.	.	.	W	CT: sets output pins CT1 and CT1 high or low. (not connected to anything in X16) W: LFO Waveform: 0-4 = Saw, Square, Triange, Noise For sawtooth: PM->//// AM->\\\\

Channel CFG Registers

Register Range	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Description
$20 + channel	RL		FB			CON			RL Right/Left Output Enable FB M1 Feedback Level CON Operator connection algorithm KC Key Code KF Key Fraction PMS Phase Modulation Sensitivity AMS Amplitude Modulation Sensitivity
$28 + channel	.	KC							
$30 + channel	KF						.	.	
$38 + channel	.	PMS			.	.	AMS		

Operator CFG Registers

Register Range	Operator	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Description
$40	M1: $40+channel	.	DT1			MUL				DT1 Detune Amount (fine) MUL Frequency Multiplier
	M2: $48+channel									

	C1: $50+channel				
	C2: $58+channel				
$60	M1: $60+channel	.	TL		TL Total Level (volume attenuation) (0=max, $7F=min)
	M2: $68+channel				
	C1: $70+channel				
	C2: $78+channel				
$80	M1: $80+channel	KS	.	AR	KS Key Scaling (ADSR rate scaling) AR Attack Rate
	M2: $88+channel				
	C1: $90+channel				
	C2: $98+channel				
$A0	M1: $A0+channel	AM Ena	.	D1R	AM-Ena Amplitude Modulation Enable D1R Decay Rate 1 (From peak down to sustain level)
	M2: $A8+channel				
	C1: $B0+channel				
	C2: $B8+channel				
$C0	M1: $C0+channel	DT2	.	D2R	DT2 Detune Amount (coarse) D2R Decay Rate 2 (During sustain phase)
	M2: $C8+channel				
	C1: $D0+channel				
	C2: $D8+channel				
$E0	M1: $E0+channel	D1L		RR	D1L Decay 1 Level (Sustain level) Level at which decay switches from D1R to D2R RR Release Rate
	M2: $E8+channel				
	C1: $F0+channel				
	C2: $F8+channel				

YM2151 Register Details

Global Parameters

LR (LFO Reset)

Register $01, bit 1

Setting this bit will disable the LFO and hold it at level 0. Clearing this bit allows the LFO to operate as normal. (See LFRQ for further info)

KON (KeyON)

Register $08

- Bits 0-2: Channel_Number
- Bits 3-6: Operator M1, C1, M2, C2 control bits:
    - 0: Releases note on operator
    - 0->1: Triggers note attack on operator
    - 1->1: No effect

Use this register to start/stop notes. Typically, all 4 operators are triggered/released together at once. Writing a value of $78+channel_number will start a note on all 4 OPs, and writing a value of $00+channel_number will stop a note on all 4 OPs.

NE (Noise Enable)

Register $0F, Bit 7

When set, the C2 operator of channel 7 will use a noise waveform instead of a sine.

NFRQ (Noise Frequency)

Register $0F, Bits 0-4

Sets the noise frequency, $00 is the lowest and $1F is the highest. NE bit must be set in order for this to have any effect. Only affects operator C2 on channel 7.

CLKA1 (Clock A, high order bits)

Register $10, Bits 0-7

This is the high-order value for Clock A (a 10-bit value).

CLKA2 (Clock A, low order bits)

Register $11, Bits 0-1

Sets the 2 low-order bits for Clock A (a 10-bit value).

Timer A's period is Computed as (64*(1024-ClkA)) / PhiM ms. (PhiM = 3579.545Khz)

CLKB (Clock B)

Register $12, Bits 0-7

Sets the Clock B period. The period for Timer B is computed as (1024*(256-CLKB)) / PhiM ms. (PhiM = 3579.545Khz)

CSM

Register $14, Bit 7

When set, the YM2151 will generate a KeyON attack on all 8 channels whenever TimerA overflows.

Clock ACK

Register $14, Bits 4-5

Clear (acknowledge) IRQ status generated by TimerA and TimerB (respectively).

IRQ EN

Register $14, Bits 2-3

When set, enables IRQ generation when TimerA or TimerB (respectively) overflow. The IRQ status of the two timers is checked by reading from the YM2151_STATUS byte. Bit 0 = Timer A IRQ status, and Bit 1 = Timer B IRQ status. Note that these status bits are only active if the timer

has overflowed AND has its IRQ_EN bit set.

Clock Start

Register $14, Bits 0-1

When set, these bits clear the TimerA and TimerB (respectively) counters and starts it running.

LFRQ (LFO Frequency)

Register $18, Bits 0-7

Sets the LFO frequency.

- $00 = ~0.008Hz
- $FF = ~32.6Hz

Note that even setting the value zero here results in a positive LFO frequency. Any channels sensitive to the LFO will still be affected by the LFO unless the `LR` bit is set in register $01 to completely disable it.

AMD (Amplitude Modulation Depth)

Register $19 Bits 0-6, Bit 7 clearParameters

Sets the peak strength of the LFO's Amplitude Modulation effect. Note that bit 7 of the value written into $19 must be clear in order to set the AMD. If bit 7 is set, the write will be interpreted as PMD.

PMD (Phase Modulation Depth)

Register $19 Bits 0-6, Bit 7 set

Sets the peak strength of the LFO's Phase Modulation effect. Note that bit 7 of the value written into $19 must be set in order to set the PMD. If bit 7 is clear, the value is interpreted as AMD.

CT (Control pins)

Register $1B, Bits 6-7

These bits set the electrical state of the two CT pins to on/off. These pins are not connected to anything in the X16 and have no effect.

W (LFO Waveform)

Register $1B, Bits 0-1

Sets the LFO waveform: 0: Sawtooth, 1: Square (50% duty cycle), 2: Triangle, 3: Noise

Channel Control Parameters

RL (Right/Left output enable)

Register $20 (+ channel), Bits 6-7

Setting/Clearing these bits enables/disables audio output for the selected channel. (bit6=left, bit7=right)

FB (M1 Self-Feedback)

Register $20 (+ channel), bits 3-5

Sets the amount of self feedback on operator M1 for the selected channel. 0=none, 7=max

CON (Connection Algorithm)

Register $20 (+ channel), bits 0-2

Sets the selected channel to connect the 4 operators in one of 8 arrangements.

[insert picture here]

KC (Key Code - Note selection)

Register $28 + channel, bits 0-6

Sets the octave and semitone for the selected channel. Bits 4-6 specify the octave (0-7) and bits 0-3 specify the semitone:

0	1	2	4	5	6	8	9	A	C	D	E
C♯	D	D♯	E	F	F♯	G	G♯	A	A♯	B	C

Note that natural C is at the TOP of the selected octave, and that each 4th value is skipped. Thus if concert A (A-4, 440hz) is KC=$4A, then middle C is KC=$3E

KF (Key Fraction)

Register $30 + channel, Bits 2-7

Raises the pitch by 1/64th of a semitone * the KF value.

PMS (Phase Modulation Sensitivity)

Register $38 + channel, Bits 4-6

Sets the Phase Modulation (vibrato) sensitivity of the selected channel. The resulting vibrato depth is determined by the combination of the global PMD setting (see above) modified by each channel's PMS.

Sensitivity values: (+/- cents)

0	1	2	3	4	5	6	7
0	5	10	20	50	100	400	700

AMS (Amplitude Modulation Sensitivity)

Register $38 + channel, Bits 0-1

Sets the Amplitude Modulation sensitivity of the selected channel. Note that each operator may individually enable or disable this effect on its output by setting/clearing the AMS-Ena bit (see below). Operators acting as outputs will exhibit a tremolo effect (varying volume) and operators acting as modulators will vary their effectiveness on the timbre when enabled for amplitude modulation.

Sensitivity values: (dB)

0	1	2	3
0	23.90625	47.8125	95.625

Operator Control Parameters

Operators are arranged as follows:

name	M1	M2	C1	C2
index	0	1	2	3

These are the names used throughout this document for consistency, but they may function as either modulators or carriers, depending on which `CON` ALG is used.

The Operator Control parameters are mapped to channels/operators as follows: Register + 8*op + channel. You may also choose to think of these register addresses as using bits 0-2 = channel, bits 3-4 = operator, and bits 5-7 = parameter. This reference will refer to them using the address range, e.g. $60-$7F = TL. To set TL for channel 2, operator 1, the register address would be $6A ($60 + 1*8 + 2).

DT1 (Detune 1 - fine detune)

Registers $40-$5F, Bits 4-6

Detunes the operator from the channel's main pitch. Values 0 and 4=no detuning. Values 1-3=detune up, 5-7 = detune down.
The amount of detuning varies with pitch. It decreases as the channel's pitch increases.

MUL (Frequency Multiplier)

Registers $40-$5F, Bits 0-3

If MUL=0, it multiplies the operator's frequency by 0.5
Otherwise, the frequency is multiplied by the value in MUL (1,2,3...etc)

TL (Total Level - attenuation)

Registers $60-$7F, Bits 0-6

This is essentially "volume control" - It is an attenuation value, so $00 = maximum level and $7F is minimum level. On output operators, this is the volume output by that operator. On modulating operators, this affects the amount of modulation done to other operators.

KS (Key Scaling)

Registers $80-$9F, Bits 6-7

Controls the speed of the ADSR progression. The KS value sets four different levels of scaling. Key scaling increases along with the pitch set in KC. 0=min, 3=max

AR (Attack Rate)

Registers $80-$9F, Bits 0-4

Sets the attack rate of the ADSR envelope. 0=slowest, $1F=fastest

AMS-Enable (Amplitude Modulation Sensitivity Enable)

Registers $A0-$BF, Bit 7

If set, the operator's output level will be affected by the LFO according to the channel's AMS setting. If clear, the operator will not be affected.

D1R (Decay Rate 1)

Registers $A0-$BF, Bits 0-4

Controls the rate at which the level falls from peak down to the sustain level (D1L). 0=none, $1F=fastest.

DT2 (Detune 2 - coarse)

Registers $C0-$DF, Bits 6-7

Sets a strong detune amount to the operator's frequency. Yamaha suggests that this is most useful for sound effects. 0=off,

D2R (Decay Rate 2)

Registers $C0-$DF, Bits 0-4

Sets the Decay2 rate, which takes effect once the level has fallen from peak down to the sustain level (D1L). This rate continues until the level reaches zero or until the note is released.

0=none, $1F=fastest

D1L

Registers $E0-$FF, Bits 4-7

Sets the level at which the ADSR envelope changes decay rates from D1R to D2R. 0=minimum (no D2R), $0F=maximum (immediately at peak, which effectively disables D1R)

RR

Registers $E0-$FF, Bitst 0-3

Sets the rate at which the level drops to zero when a note is released. 0=none, $0F=fastest

---

Getting sound out of the YM2151 (a brief tutorial)

While there is a large number of parameters that affect the sound of the YM2151, its operation can be thought of in simplified terms if you consider that there are basically three components to deal with: Instrument configuration (patch), voice pitch selection, and "pressing/releasing" the "key" to trigger (begin) and release (end) notes. It's essentially the same as using a music keyboard. Pressing an instrument button (e.g. Marimba) makes the keyboard sound like a Marimba. Once this is done, you press a key on the keyboard to play a note, and release it to stop the note. With the YM, loading a patch (pressing the Marimba button) entails setting all of the various operators' registers on the voice(s) you want the instrument to be used on. On the music keyboard, pitch and note stop/start are done with a single piano key. In the YM2151, these are two distinct actions.

For this tutorial, we will start with the simplest operation, (triggering notes) and proceed to note selection, and finally patch configuration.

Triggering and Releasing Notes

Key On/Off (KON) Register ($08):

This is probably the most important single register in the YM2151. It is used to trigger and release notes. It controls the key on/off state for all 8 channels. A note is triggered whenever its key state changes from off to on, and is released whenever the state changes from on to off. Repeated writes of the same state (off->off or on->on) have no effect.

Whenever an operator is triggered, it progresses through the states of attack, decay1, and sustain/decay2. Whenever an active note is released, it enters the release state where the volume decreases until reaching zero. It then remains silent until the next time the operator is triggered. If you are familiar with the C64 SID chip, this is the same behavior as the "gate" bit on that chip.

Key state and voice selection are both contained in the value written into the KON register as follows:

- Key ON = $78 + channel number
- Key OFF = $0 + channel number

Simple Examples:

To release the note in channel 4: write $08 to `YM_address` ($9F40) and then write $04 ($00+4) to `YM_data` ($9F41).

To begin a note on channel 7, write $08 into `YM_address` to select the KON register. Then write $7F ($78+7) into `YM_data`

If the current key state of a channel is not known, you can write key off and then key on immediately (after waiting for the YM busy period to end, of course):

```
POKE $9F40,$08 : REM SELECT KEY ON/OFF REGISTER
POKE $9F41,$07 : REM KEY OFF FOR VOICE 7
POKE $9F41,$7F : REM KEY ON  FOR VOICE 7
```

Remember: BASIC is slow enough that you do not need to poll the `YM_status` byte, but assembly and other languages will need to do so.

The ADSR parameters will be discussed in more detail later.

Advanced:

Each channel (voice) of the YM2151 uses 4 operators which can be gated together or independently. Independent triggering gives lots of advanced possibilities. To trigger and release operators independently, you use different values than $78 or $00. These values are composed by 4 bits which signal the on/off state for each operator.

Suppose a note is playing on channel 2 with all 4 operators active. You can release only the M1 operator by writing $72 into register $08.

The KON value format:

7	6	5	4	3	2	1	0
-	C2	M2	C1	M1	Channel		

Pitch Control

YM Registers

- `KC` = $28 + channel number
- `KF` = $30 + channel number

For note selection, each voice has two parameters: `KC` (Key Code) and `KF` (Key Fraction). These are set in register ranges $28 and $30, respectively. The KC codes correspond directly to the notes of the chromatic scale. Each value maps to a specific octave & semitone. The `KF` value can even be ignored for basic musical playback. It is mostly useful for vibrato or pitch bend effects. `KF` raises the pitch selected in `KC` in 1/64th increments of the way up to the next semitone.

Like all registers in the YM, whenever a channel's `KC` or `KF` value is written, it takes effect immediately. If a note is playing, its pitch immediately changes. When triggering new notes, it is not important whether you write the pitch or key the note first. This happens quickly in real-time and you will not hear any real difference. Changing the pitch without re-triggering the ADSR envelope is how to achieve pitch slides or a legato effect.

Key Code (KC)

`KC` codes are "conveniently" arranged so that the upper nybble is the octave (0-7) and the lower nybble is the pitch. The pitches are arranged as follows within an octave:

Note	C♯	D	D♯	E	F	F♯	G	G♯	A	A♯	B	C
Low Nybble (hex)	0	1	2	4	5	6	8	9	A	C	D	E

(Note that every 4th value is skipped.)

Combine the above with an octave to get a note's `KC` value. For instance: concert A (440hz) is (by sheer coincidence) `$4A`. Middle C is `$3E`, and so forth.

Key Fraction (KF)

`KF` values are written into the top 6 bits of the voice's `KF` register. Basically the value is `0, 1<<2, 2<<2, .. 63<<2`

Loading a patch

The patch configuration is by far the most complicated aspect of using the YM. If you take as given that a voice has a patch loaded, then playing notes on it is fairly straightforward. For the moment, we will assume a pre-patched voice.

To get started quickly, here is some BASIC code to patch voice 0 with a marimba tone:

```
5 YA=$9F40 : YD=$9F41 : V=0
10 REM: MARIMBA PATCH FOR YM VOICE 0 (SET V=0..7 FOR OTHER VOICES)
20 DATA $DC,$00,$1B,$67,$61,$31,$21,$17,$1F,$0A,$DF,$5F,$DE
30 DATA $DE,$0E,$10,$09,$07,$00,$05,$07,$04,$FF,$A0,$16,$17
40 READ D
50 POKE YA,$20+V : POKE YD,D
60 FOR A=$38 TO $F8 STEP 8
70 READ D : POKE YA,A+V : POKE YD,D
80 NEXT A
```

Once a voice has been patched as above, you can now POKE notes into it with very few commands for each note.

Patches consist mostly of ADSR envelope parameters. A complete patch contains values for the $20 range register (LR|FB|CON), for the $38 range register (AMS|PMS), and 4 values for each of the parameter ranges starting at $40. (4 operators per voice means 4 values per parameter). Since this is a huge amount of flexibility, it is recommended to experiment with instrument creation in an application such as a chip tracker or VST, as the creative process of instrument design is very hands-on and subjective.

Using the LFO

There is a single global LFO in the YM2151 which can affect the level (volume) and/or pitch of all 8 channels simultaneously. It has a single frequency and waveform setting which must be shared among all channels, and shared between both phase and amplitude modulation. The global parameters `AMD` and `PMD` act as modifiers to the sensitivity settings of the channels. While the frequency and waveform of the LFO pattern must be shared, the depths of the two types of modulation are independent of each other.

You can re-trigger the LFO by setting and then clearing the `LR` bit in the test register ($01).

Vibrato

Use Phase Modulation on the desired channels. The `PMS` parameter for each channel allows them to vary their vibrato depths individually. Channels with `PMS` set to zero will have no vibrato. The values given earlier in the `PMS` parameter description represent their maximum amount of affect. These values are modified by the global `PMD.` A `PMD` valie of $7F means 100% effectiveness, $40 means all channels' vibrato depths will be reduced by half, etc.

The vibrato speed is global, depending solely on the value set to `LFRQ.`

Amplitude Modulation

Amplitude modulation works similarly to phase modulation, except that the intensity is a combination of the per-channel `AMS` value modified by the global `AMD` value. Additionally, within channels having non-zero amplitude modulation sensitivity, individual operators must have their `AMS-en` bit enabled in order to be affected by the modulation.

If the active operators are acting as carriers (generating output directly), then amplitude modulation will vary the volume of the sound being produced by that operator. This can be described as a "tremolo" effect. If the operators are acting as modulators, then the timbre of the voice will vary as the output level of the affected operators increases and decreases. You may simultaneously enable amplitude modulation on both types of operators.

The amplitude modulation speed is global, depending solely on the value set to `LFRQ`.

Chapter 12: I/O Programming

There are two 65C22 "Versatile Interface Adapter" (VIA) I/O controllers in the system, VIA#1 at address $9F00 and VIA#2 at address $9F10. The IRQ out lines of VIA#1 is connected to the CPU's NMI line, while the IRQ out line of VIA#2 is connected to the CPU's IRQ line.

The-following tables describe the connections of the I/O pins:

VIA#1

Pin	Name	Description
PA0	I2CDATA	I2C Data
PA1	I2CCLK	I2C Clock
PA2	NESLATCH	NES LATCH (for all controllers)
PA3	NESCLK	NES CLK (for all controllers)
PA4	NESDAT3	NES DATA (controller 3)
PA5	NESDAT2	NES DATA (controller 2)
PA6	NESDAT1	NES DATA (controller 1)
PA7	NESDAT0	NES DATA (controller 0)
PB0	*Unused*	
PB1	*Unused*	
PB2	*Unused*	
PB3	SERATNO	Serial ATN out
PB4	SERCLKO	Serial CLK out
PB5	SERDATAO	Serial DATA out
PB6	SERCLKI	Serial CLK in
PB7	SERDATAI	Serial DATA in
CA1	*Unused*	
CA2	*Unused*	
CB1	IECSRQ	
CB2	*Unused*	

The KERNAL uses Timer 2 for timing transmissions on the Serial Bus.

VIA#2

The second VIA is completely unused by the system. All its 16 GPIOs and 4 handshake I/Os can be freely used.

I2C Bus

The Commander X16 contains an I2C bus, which is implemented through two pins of VIA#1. The system management controller (SMC) and the real-time clock (RTC) are connected through this bus. The KERNAL APIs `i2c_read_byte` and `i2c_write_byte` allow talking to these devices.

System Management Controller

The system management controller (SMC) is device $42 on the I2C bus. It controls the activity LED, and can be used to power down the system or inject RESET and NMI signals. It also handles communication with the PS/2 keyboard and mouse.

Register	Value	Description

$01	$00	Power off
$01	$01	Hard reboot
$02	$00	Inject RESET
$03	$00	Inject NMI
$05	$00/$FF	Activity LED off/on
$07	-	Read from keyboard buffer
$08	$00..$FF	Echo
$18	-	Read ps2 status
$19	$00..$FF	Send ps2 command
$1A	$0000..$FFFF	Send ps2 command (2 bytes)
$20	$00	Set mouse device ID, standard mouse
$20	$03	Set mouse device ID, Intellimouse with scroll wheel
$20	$04	Set mouse device ID, Intellimouse with scroll wheel+extra buttons
$21	-	Read from mouse buffer
$22	-	Get mouse device ID
$30	-	Get SMC firmware version, major
$31	-	Get SMC firmware version, minor
$32	-	Get SMC firmare version, patch
$8F	$31	Start bootloader, if present

Real-Time-Clock

The Commander X16 contains a battery-backed Microchip MCP7940N real-time-clock (RTC) chip as device $6F. It provide a real-time clock/calendar, two alarms and 64 bytes of battery-backed SRAM (non-volatile RAM).

Register	Description
$00	Clock seconds
$01	Clock minutes
$02	Clock hours
$03	Clock weekday
$04	Clock day
$05	Clock month
$06	Clock year
$07	Control
$08	Oscillator trim
$09	*reserved*
$0A	Alarm 0 seconds
$0B	Alarm 0 minutes
$0C	Alarm 0 hours
$0D	Alarm 0 weekday

$0E	Alarm 0 day
$0F	Alarm 0 month
$10	*reserved*
$11	Alarm 1 seconds
$12	Alarm 1 minutes
$13	Alarm 1 hours
$14	Alarm 1 weekday
$15	Alarm 1 day
$16	Alarm 1 month
$17	*reserved*
$18	Power-fail minutes
$19	Power-fail hours
$1A	Power-fail day
$1B	Power-fail month
$1C	Power-up minutes
$1D	Power-up hours
$1E	Power-up day
$1F	Power-up month
$20-$5F	64 Bytes SRAM

SRAM (NVRAM)

Register	Description
$20-$3F	User NVRAM
$40-$5F	KERNAL NVRAM
$40	Active profile
$41-$4D	Profile 0 (80x60)
$4E-$5A	Profile 1 (40x30)
$41/$4E	Screen mode
$42/$4F	VERA_DC_VIDEO
$43/$50	VERA_DC_HSCALE
$44/$51	VERA_DC_VSCALE
$45/$52	VERA_DC_BORDER
$46/$53	VERA_DC_HSTART
$47/$54	VERA_DC_HSTOP
$48/$55	VERA_DC_VSTART
$49/$56	VERA_DC_VSTOP
$4A/$57	Color (bg/fg)

$4B/$58	Keymap
$4C/$59	Typematic
$4D/$5A	Unused
$5B-$5E	Expansion (unused)
$5F	Checksum

The second half of the RTC's SRAM (NVRAM) is reserved for use by the KERNAL. $20-$3F is available for use by user programs.

For more information, please refer to this device's datasheet.

Chapter 13: Working With CMDR-DOS

This manual describes Commodore DOS on FAT32, aka CMDR-DOS.

CMDR-DOS

Commander X16 duplicates and extends the programming interface used by Commodore's line of disk drives, including the famous (or infamous) VIC-1541. CMDR-DOS uses the industry-standard FAT-32 format. Partitions can be 32MB up to (in theory) 2TB and supports CMD-style partitions, subdirectories, timestamps and filenames up to 255 characters. It is the DOS built into the Commander X16 .

There are three basic interfaces for CMDR-DOS: the binary interface (LOAD, SAVE, etc.), the data file interface (OPEN, PRINT#, INPUT#, GET#), and the command interface. We will give a brief summary of BASIC commands here, but please refer to Chapter 4: BASIC Programming for full syntax of each command.

If you are familiar with the SD2IEC or the CMD hard drive, navigating partitions and subdirectories is similar, with "CD", "MD", and "RD" commands to navigate directories.

Binary Load/Save

The primary use of the binary interface is loading and saving program files and loading binary files into RAM.

Your binary commands are LOAD, SAVE, BLOAD, VLOAD, BVLOAD, VERIFY, and BVERIFY.

This is a brief summary of the LOAD and SAVE commands. For full documentation, refer to Chapter 4: BASIC Programming .

LOAD

`LOAD <filename> [,device][,secondary_address]` `LOAD <filename> [,device][,ram_bank,start_address]`

This reads a program file from disk. The first two bytes of the file are the memory location to which the file will be loaded, with the low byte first. BASIC programs will start with $01 $08, which translates to $0801, the start of BASIC memory. The device number should be 8 for reading from the SD card.

If using the first form, secondary_address has multiple meanings:

- 0 or not present: load the data to address $0801, regardless of the address header.
- 1: load to the address specified in the file's header
- 2: load the file headerless to the location $0801.

If using the second form, ram_bank sets the bank for the load, and start_address is the location to read your data into.

The value of the ram_bank argument only affects the load when the start_address is set in the range of $A000-$BFFF.

Examples:

`LOAD "ROBOTS.PRG",8,1` loads the program "ROBOTS.PRG" into memory at the address encoded in the file.

`LOAD "HELLO",8` loads a program to the start of BASIC at $0801.

`LOAD "*",8,1` loads the first program in the current directory. See the section below on wildcards for more information about using * and ? to access files of a certain type or with unprintable characters.

`LOAD "DATA.BIN",8,1,$A000` loads a file into banked RAM, RAM bank 1, starting at $A000. The first two bytes of the file are skipped. To avoid skipping the first two bytes, use the `BLOAD` command instead.

SAVE

`SAVE <filename>[,device]`

Saves a file from the computer to the SD card. SAVE always reads from the beginning of BASIC memory at $0801, up to the end of the BASIC program. Device is optional and defaults to 8 (the SD card, or an IEC disk drive, if one is plugged in.)

One word of caution: CMDR-DOS will not let you overwrite a file by default. To overwrite a file, you need to prefix the filename with @:, like this:

`SAVE "@:DEMO.PRG"`

BSAVE

`BSAVE <filename>,<device>,<ram_bank>,<start_address>,<end_address>`

Saves an arbitrary region of memory to a file without a two-byte header. To allow concatenating multiple regions of RAM into a single file with multiple successive calls to BSAVE, BSAVE allows the use of append mode in the filename string. To make use of this option, the first call to BSAVE can be called normally, which creates the file anew, while subsequent calls should be in append mode to the same file.

Another way to save arbitrary binary data from arbitrary locations is to use the S command in the MONITOR: Chapter 7: Machine Language Monitor.

`S "filename",8,<start_address>,<end_address>`

Where and are a 16-bit hexadecimal address.

After a SAVE or BSAVE, the DOS command is implicitly run to show the drive status. The Commodore file I/O model does not report certain failures back to BASIC, so you should double-check the result after a write operation.

```
00, OK,00,00

READY.
```

An OK reply means the file saved correctly. Any other result is an error that should be addressed:

```
63,FILE EXISTS,00,00
```

CMDR-DOS does not allow files to be overwritten without special handling. If you get FILE EXISTS, either change your file's name or save it with the @: prefix, like this:

`SAVE "@:HELLO"`

BLOAD

BLOAD loads a file *without an address header* to an arbitrary location in memory. Usage is similar to LOAD. However, BLOAD does not require or use the 2-byte header. The first byte in the file is the first byte loaded into memory.

`BLOAD "filename",8,<ram_bank>,<start_address>`

VLOAD

Read binary data into VERA. VLOAD skips the 2-byte address header and starts reading at the third byte of the file.

`VLOAD "filename",8,<vram_bank>,<start_address>`

BVLOAD

Read binary data into VERA without a header. This works like BLOAD, but into VERA RAM.

`BVLOAD "filename",8,<vram_bank>,<start_address>`

DOS WEDGE

The DOS wedge allows you to issue quick commands from BASIC with the > or @ symbol.

Command	Action
`/<filename>`	Load a BASIC program into RAM
`%<filename>`	Load a machine language program into RAM (like `,8,1`)
`↑<filename>`	Load a BASIC program into RAM and then unconditionally run it
`←<filename>`	Save a BASIC program to disk
`@`	Display (and clear) the disk drive status
`@$`	Display the disk directory without overwriting the BASIC program in memory
`@#<device number>`	Change default DOS device

`@<command>`	Execute a disk drive command (e.g. `@S0:<filename>`)
`><command>`	Execute a disk drive command (e.g. `>CD:<dir>`)

Sequential Files

Sequential files have two basic modes: read and write. The OPEN command opens a file for reading or writing. The PRINT# command writes to a file, and the GET# and INPUT# commands read from the file.

todo: examples

Command Channel

The command channel allows you to send commands to the CMDR-DOS interface. You can open and write to the command channel using the OPEN command, or you can use the DOS command to issue commands and read the status. While DOS can be used in immediate mode or in a program, only the combination of OPEN/INPUT# can read the command response back into a variable for later processing.

In either case, the ST psuedo-variable will allow you to quickly check the status. A status of 64 is "okay", and any other value should be checked by reading the error channel (shown below.)

To open the command channel, you can use the OPEN command with secondary address 15.

```
10 OPEN 15,8,15
```

If you want to issue a command immediately, add your command string at the end of the OPEN statement:

```
10 OPEN 15,8,15, "CD:/"
```

This example changes to the root directory of your SD card.

To know whether the OPEN command succeeded, you must open the command channel and read the result. To read the command channel (and clear the error status if an error occurred), you need to read four values:

```
20 INPUT#15,A,B$,C,D
```

A is the error number. B$ is the error message. C and D are unused in CMDR-DOS for most responses, but will return the track and sector when used with a disk drive on the IEC connector.

```
30 PRINT A;B$;C;D
40 CLOSE 15
```

So the entire program looks like:

```
10 OPEN 15,8,15, "CD:/"
20 INPUT#15,A,B$,C,D
30 PRINT A;B$;C;D
40 CLOSE 15
```

If the error number (`A`) is less than 20, no error occurred. Usually this result is 0 (or 00) for OK.

You can also use the DOS command to send a command to CMDR-DOS. Entering DOS by itself will print the drive's status on the screen. Entering a command in quotes or a string variable will execute the command. We will talk more about the status variable and DOS status message in the next section.

```
DOS
00, 0K, 00, 00
READY.
DOS "CD:/"
```

The special case of `DOS "$"` will print a directory listing.

```
DOS "$"
```

You can also read the name of the current directory with DOS"$=C"

```
DOS "$=C"
```

DOS Features

This is the base features set compared to other Commodore DOS devices:

Feature	1541	1571/1581	CMD HD/FD	SD2IEC	*CMDR-DOS*
Sequential files	yes	yes	yes	yes	yes
Relative files	yes	yes	yes	yes	not yet
Block access	yes	yes	yes	yes	not yet
Code execution	yes	yes	yes	no	yes
Burst commands	no	yes	yes	no	no
Timestamps	no	no	yes	yes	yes
Time API	no	no	yes	yes	not yet
Partitions	no	no	yes	yes	yes
Subdirectories	no	no	yes	yes	yes

It consists of the following components:

- Commodore DOS interface
  - `dos/main.s` : TALK/LISTEN dispatching
  - `dos/parser.s` : filename/path parsing
  - `dos/cmdch.s` : command channel parsing, status messages
  - `dos/file.s` : file read/write
- FAT32 interface
  - `dos/match.s` : FAT32 character set conversion, wildcard matching
  - `dos/dir.s` : FAT32 directory listing
  - `dos/function.s` : command implementations for FAT32
- FAT32 implementation
  - `fat32/*` : FAT32 for 65c02 library

All currently unsupported commands are decoded in `cmdch.s` anyway, but hooked into `31,SYNTAX ERROR,00,00` , so adding features should be as easy as adding the implementation.

CMDR-DOS implements the TALK/LISTEN layer (Commodore Peripheral Bus layer 3), it can therefore be directly hooked up to the Commodore IEEE KERNAL API (`talk` , `tksa` , `untlk` , `listn` , `secnd` , `unlsn` , `acptr` , `ciout`) and be used as a computer-based DOS, like on the C65 and the X16.

CMDR-DOS does not contain a layer 2 implementation, i.e. IEEE-488 (PET) or Commodore Serial (C64, C128, ...). By adding a Commodore Serial (aka "IEC") implementation, CMDR-DOS could be adapted for use as the system software of a standalone 65c02-based Serial device for Commodore computers, similar to an sd2iec device.

The Commodore DOS side and the FAT32 side are well separated, so a lot of code could be reused for a DOS that uses a different filesystem.

Or the core feature set, these are the supported functions:

Feature	Syntax	Supported	Comment
Reading	`,?,R`	yes	
Writing	`,?,W`	yes	
Appending	`,?,A`	yes	
Modifying	`,?,M`	yes	
Types	`,S/,P/,U/,L`	yes	ignored on FAT32
Overwriting	`@:`	yes	
Magic channels 0/1		yes	

Channel 15 command	`command:args...`	yes	
Channel 15 status	`code,string,a,b`	yes	
CMD partition syntax	`0:/1:/...`	yes	
CMD subdirectory syntax	`//DIR/:/DIR/:`	yes	
Directory listing	`$`	yes	
Dir with name filtering	`$:FIL*`	yes	
Dir with name and type filtering	`$:*=P/$:*=D/$:*=A`	yes	
Dir with timestamps	`$=T`	yes	with ISO-8601 times
Dir with time filtering	`$=T</$=T>`	not yet	
Dir long listing	`$=L`	yes	shows human readable file size instead of blocks, time in ISO-8601 syntax, attribute byte, and exact file size in hexadecimal
Partition listing	`$=P`	yes	
Partition filtering	`$:NAME*=P`	no	
Current Working Directory	`$=C`	yes	

And this table shows which of the standard commands are supported:

Name	Syntax	Description	Supported
BLOCK-ALLOCATE	`B-A` *medium medium track sector*	Allocate a block in the BAM	no[1]
BLOCK-EXECUTE	`B-E` *channel medium track sector*	Load and execute a block	not yet
BLOCK-FREE	`B-F` *medium medium track sector*	Free a block in the BAM	no[1]
BLOCK-READ	`B-R` *channel medium track sector*	Read block	no[1]
BLOCK-STATUS	`B-S` *channel medium track sector*	Check if block is allocated	no[1]
BLOCK-WRITE	`B-W` *channel medium track sector*	Write block	no[1]
BUFFER-POINTER	`B-P` *channel index*	Set r/w pointer within buffer	not yet
CHANGE DIRECTORY	`CD`[*path*]`:`*name*	Change the current sub-directory	yes
CHANGE DIRECTORY	`CD`[*medium*]`:←`	Change sub-directory up	yes
CHANGE PARTITION	`CP` *num*	Make a partition the default	yes
COPY	`C`[*path_a*]`:`*target_name*`=`[*path_b*]`:`*source_name*[`,`...]	Copy/concatenate files	yes
COPY	`C`*dst_medium*`=`*src_medium*	Copy all files between disk	no[1]
DUPLICATE	`D:`*dst_medium*`=`*src_medium*	Duplicate disk	no[1]
FILE LOCK	`F-L`[*path*]`:`*name*[`,`...]	Enable file write-protect	yes
FILE RESTORE	`F-R`[*path*]`:`*name*[`,`...]	Restore a deleted file	not yet
FILE UNLOCK	`F-U`[*path*]`:`*name*[`,`...]	Disable file write-protect	yes
GET DISKCHANGE	`G-D`	Query disk change	yes
GET PARTITION	`G-P`[*num*]	Get information about partition	yes

INITIALIZE	I[*medium*]	Re-mount filesystem	yes
LOCK	L[*path*]:*name*	Toggle file write protect	yes
MAKE DIRECTORY	MD[*path*]:*name*	Create a sub-directory	yes
MEMORY-EXECUTE	M-E *addr_lo addr_hi*	Execute code	yes
MEMORY-READ	M-R *addr_lo addr_hi* [*count*]	Read RAM	yes
MEMORY-WRITE	M-W *addr_lo addr_hi count data*	Write RAM	yes
NEW	N[*medium*]:*name*,*id*,FAT32	File system creation	yes[3]
PARTITION	/[*medium*][:*name*]	Select 1581 partition	no
PARTITION	/[*medium*]:*name*,*track sector count_lo count_hi* ,C	Create 1581 partition	no
POSITION	P *channel record_lo record_hi offset*	Set record index in REL file	not yet
REMOVE DIRECTORY	RD[*path*]:*name*	Delete a sub-directory	yes
RENAME	R[*path*]:*new_name*=*old_name*	Rename file	yes
RENAME-HEADER	R-H[*medium*]:*new_name*	Rename a filesystem	yes
RENAME-PARTITION	R-P:*new_name*=*old_name*	Rename a partition	no[1]
SCRATCH	S[*path*]:*pattern*[,...]	Delete files	yes
SWAP	S-{8|9|D}	Change primary address	yes
TIME READ ASCII	T-RA	Read Time/Date (ASCII)	no[4]
TIME READ BCD	T-RB	Read Time/Date (BCD)	no[4]
TIME READ DECIMAL	T-RD	Read Time/Date (Decimal)	no[4]
TIME READ ISO	T-RI	Read Time/Date (ISO)	no[4]
TIME WRITE ASCII	T-WA *dow mo/da/yr hr:mi:se ampm*	Write Time/Date (ASCII)	no[4]
TIME WRITE BCD	T-WB *b0 b1 b2 b3 b4 b5 b6 b7 b8*	Write Time/Date (BCD)	no[4]
TIME WRITE DECIMAL	T-WD *b0 b1 b2 b3 b4 b5 b6 b7*	Write Time/Date (Decimal)	no[4]
TIME WRITE ISO	T-WI *yyyy-mm-ddThh:mm:ss dow*	Write Time/Date (ISO)	no[4]
U1/UA	U1 *channel medium track sector*	Raw read of a block	not yet
U2/UB	U2 *channel medium track sector*	Raw write of a block	not yet
U3-U8/UC-UH	U3 - U8	Execute in user buffer	not yet
U9/UI	UI	Soft RESET	yes
U:/UJ	UJ	Hard RESET	yes
USER	U0> *pa*	Set unit primary address	yes
USER	U0>B *flag*	Enable/disable Fast Serial	yes[6]
USER	U0>D*val*	Set directory sector interleave	no[1]
USER	U0>H *number*	Select head 0/1	no[1]
USER	U0>L*flag*	Large REL file support on/off	no
USER	U0>M *flag*	Enable/disable 1541 emulation mode	no[1]

USER	`U0>R` *num*	Set number fo retries	no[1]
USER	`U0>S` *val*	Set sector interleave	no[1]
USER	`U0>T`	Test ROM checksum	no[5]
USER	`U0>V` *flag*	Enable/disable verify	no[1]
USER	`U0>` *pa*	Set unit primary address	yes
USER	`UI{+|-}`	Use C64/VIC-20 Serial protocol	no[1]
UTILITY LOADER	`&`[[*path*`:`]*name*	Load and execute program	no[1]
VALIDATE	`V`[*medium*]	Filesystem check	no[2]
WRITE PROTECT	`W-{0|1}`	Set/unset device write protect	yes

- [1]: outdated API, not useful, or can't be supported on FAT32
- [2]: is a no-op, returns `00, OK,00,00`
- [3]: third argument `FAT32` *has* to be passed
- [4]: CMDR-DOS was architected to run on the main computer, so it shouldn't be DOS that keeps track of the time
- [5]: Instead of testing the ROM, this command currently verifies that no buffers are allocated, otherwise it halts. This is used by unit tests to detect leaks.
- [6]: Repurposed for SD card read and write mode. *flag* selects whether fast read (auto_tx) and fast writes are enabled. 0=none, 1=auto_tx, 2=fast writes, 3=both

The following special file syntax and `OPEN` options are specific to CMDR-DOS:

Feature	Syntax	Description
Open for Read & Write	`,?,M`	Allows arbitrarily reading, writing and setting the position (`P`)[7]
Get current working directory	`$=C`	Produces a directory listing containing the name of the current working directory followed by all parent directory names all the way up to `/`

- [7]: once the EOF has been reached while reading, no further reads or writes are possible.

The following added command channel features are specific to CMDR-DOS:

Feature	Syntax	Description
POSITION	`P` *channel p0 p1 p2 p3*	Set position within file (like sd2iec); all args binary
TELL[8]	`T` *channel*	Return the current position within a file and the file's size; channel arg is binary

- [8]: available in ROM version R48 and later

To use the POSITION and TELL commands, you need to open two channels: a data channel and the command channel. The *channel* argument should be the same as the secondary address of the data channel.

If POSITION succeeds, `00, OK,00,00` is returned on the command channel.

If TELL succeeds, `07,pppppppp ssssssss,00,00` is returned on the command channel, where `pppppppp` is a hexadecimal representation of the position, and `ssssssss` is a hexadecimal represenation of the file's size.

Examples

```
OPEN 1,8,2,"LEVEL.DAT,S,R"
OPEN 15,8,15,"P"+CHR$(2)+CHR$(0)+CHR$(1)+CHR$(0)+CHR$(0)
```

The above opens LEVEL.DAT for reading and positions the read/write pointer at byte 256.

```
10 OPEN 2,8,5,"LEVEL.DAT,S,R"
20 OPEN 15,8,15,"T"+CHR$(5)
```

```
30 INPUT#15,A,A$,T,S
40 CLOSE 15
50 IF A>=20 THEN 90
60 SZ=VAL("$"+MID$(A$,9))
70 PRINT "SIZE=";SZ
80 GOTO 100
90 PRINT"ERROR"
100 CLOSE 2
```

This time, the secondary address is 5, and we're fetching only the file's size.

Current Working Directory

The $=C command will list the current working directory and its parent path. The current directory will be at the top of the listing, with each parent directory beneath, with / at the bottom.

```
DOS"$=C"

0 "/TEST            "
0    "TEST"             DIR
0    "/"                DIR
65535 BLOCKS FREE.
```

License

Chapter 14: Hardware Pinouts

This chapter covers pinout for the I/O ports and headers.

Port and Socket Listing

- VERA Connectors
- SNES Controller Ports (x2)
- IEC Port
- PS/2 Keyboard and mouse
- Expansion Slots (x4 in Gen1)
- User Port Header
- ATX Power Supply
- Front Panel

Chip sockets are not listed; pinouts are available on their respective data sheets.

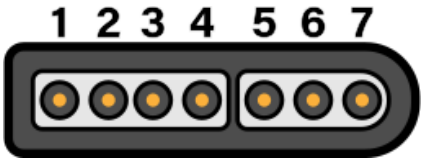
Disclaimer

The instructions and information in this document are the best available information at the time of writing. This information is subject to change, and no warranty is implied. We are not liable for damage or injury caused by use or misuse of this information, including damage caused by inaccurate information. Interfacing and modifying your Commander X16 is done solely at your own risk.

If you attempt to upgrade your firmware and the process fails, one of our community members may be able to help. Please visit the forums or the Discord community, both of which can be reached through https://commanderx16.com .

SNES Ports

The computer contains two SNES style ports and will work with Super Nintendo compatible game pads. An on-board pin header is accessible to connect two additional SNES ports.



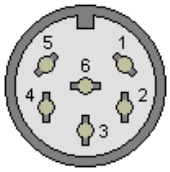
Pin #	Description	Wire Color
1	+5v	White
2	Data Clock	Yellow/Red
3	Data Latch	Orange
4	Serial Data	Red/Yellow
5	N/C	-
6	N/C	-
7	Ground	Brown

The Data Clock and Data Latch are generated by the computer and are shared across all SNES ports. The Serial Data line is unique per controller.

Thanks to Console Mods Wiki

IEC Port

The IEC port is a female 6 pin DIN 45322 connector. The pinout and specifications are the same as the Commodore 128 computer, with the required lines for Fast IEC, as used by the 1571 and 1581 diskette drives. 1541 drives are also compatible, using standard IEC mode at 400-600 bytes/sec.



Pin	Description	Signal Direction	Remark
1	SERIAL SRQ	IN	Serial Service Request In, at the C128 "Fast Serial Clock"
2	GND	-	Ground, signal ground (0V)
3	SERIAL ATN	OUT	Attention, for the selection of a device at beginning/end of a transmission
4	SERIAL CLK	IN/OUT	Clock (for data transmission)
5	SERIAL DATA	IN/OUT	Data
6	SERIAL RESET	OUT(/IN)	Reset

The IEC protocol is beyond the scope of this document. Please see Wikipedia for more information.

PS/2 Keyboard and Mouse

Pin	Name	Description
1	+DATA	Data
2	NC	Not connected
3	GND	Ground
4	Vcc	+5 VDC
5	+CLK	Clock
6	NC	Not Connected

Expansion Cards / Cartridges

The expansion slots can be used for I/O modules and RAM/ROM cartridges and expose the full CPU address and data bus, plus the ROM bank select lines, stereo audio, and 5 IO select lines.

The expansion/cartridge port is a 60-pin edge connector with 2.54mm pitch. Pin 1 is in the rear-left corner.

Desc	Pin		Pin	Desc
-12V	1	[ ]	2	+12V
GND	3	[ ]	4	+5V
AUDIO_L	5	[ ]	6	GND
AUDIO_R	7	[ ]	8	ROMB7
IO3	9	[ ]	10	ROMB0

IO4	11	[ ]	12	ROMB1
IO7	13	[ ]	14	ROMB6
IO5	15	[ ]	16	ROMB2
IO6	17	[ ]	18	ROMB5
RESB	19	[ ]	20	ROMB3
RDY	21	[ ]	22	ROMB4
IRQB	23	[ ]	24	PHI2
BE	25	[ ]	26	RWB
NMIB	27	[ ]	28	MLB
SYNC	29	[ ]	30	D0
A0	31	[ ]	32	D1
A1	33	[ ]	34	D2
A2	35	[ ]	36	D3
A3	37	[ ]	38	D4
A4	39	[ ]	40	D5
A5	41	[ ]	42	D6
A6	43	[ ]	44	D7
A7	45	[ ]	46	A15
A8	47	[ ]	48	A14
A9	49	[ ]	50	A13
A10	51	[ ]	52	A12
A11	53	[ ]	54	SDA
GND	55	[ ]	56	SCL
+5V	57	[ ]	58	GND
+12V	59	[ ]	60	-12V

To simplify address decoding, pins IO3-IO7 are active for specific, 32-byte memory mapped IO (MMIO) address ranges.

Address	Usage	Speed
$9F60-$9F7F	Expansion Card Memory Mapped IO3	8 MHz
$9F80-$9F9F	Expansion Card Memory Mapped IO4	8 MHz
$9FA0-$9FBF	Expansion Card Memory Mapped IO5	2 MHz
$9FC0-$9FDF	Expansion Card Memory Mapped IO6	2 MHz
$9FE0-$9FFF	Cartidge/Expansion Memory Mapped IO7	2 MHz

Expansion cards can use the IO3-IO6 lines as enable lines to provide their IO address range (s), or decode the address from the address bus directly. To prevent conflicts with other devices, expansion boards should allow the user to select their desired I/O bank with jumpers or DIP switches. IO7 is given priority to external cartridges that use MMIO and should be only used by an expansion card if there are no other MMIO ranges available. Doing so may cause a bus conflict with cartridges that make us of MMIO (such as those with expansion hardware). See below for more information on cartridges.

ROMB0-ROMB7 are connected to the ROM bank latch at address `$01`. Values 0-31 (`$00` - `$1F`) address the on-board ROM chips, and 32-255 are intended for expansion ROM or RAM chips (typically used by cartridges, see below). This allows for a total of 3.5MB of address space in the `$C000-$FFFF` address range.

SCL and SDA pins are shared with the i2c connector on J9 and can be used to access i2c peripherals on cartridges or expansion cards.

AUDIO_L and AUDIO_R are routed to J10, the audio option header.

The other pins are connected to the system bus and directly to the 65C02 processor.

Cartridges

Cartridges are essentially an expansion card housed in an external enclosure. Typically they are used for applications (e.g. games) with the X16 being able to boot directly from a cartridge at power on. They contain banked ROM and/or RAM and an optional I2C EEPROM (for storing game save states).

They can also function as an expansion card which means they can also use MMIO. Similarly an internal expansion card could contain RAM/ROM as well.

Because of this, while develoeprs are free to use the hardware as they please, to avoid conflcits, the banked ROM/RAM space is suggested to be used only by cartridges and cartridges should avoid using MMIO IO3-IO6. Instead, IO7 should be the default option for cartridges and the last option for expansion cards (only used if there are no other IO ranges available).

This helps avoid bus conflicts and an otherwise bad user experience given a cartridge should be simple to use from the standpoint of the user ("insert game -> play game").

These are soft guidelines. There is nothing physically preventing an expansion card from using banked ROM/RAM or a cartridge using any of the MMIO addresses. Doing so risks conflicts and compatibility issues.

Cartridges with additional hardware would be similar to expansion chips found on some NES and SNES cartridges (think VRC6, Super FX, etc.) and could be used for really anything, such as having a MIDI input for a cartridge that is meant as a music maker; some sort of hardware accelerator FPGA; network support, etc.

For more information about the memory map visit Chapter 8: Memory Map .

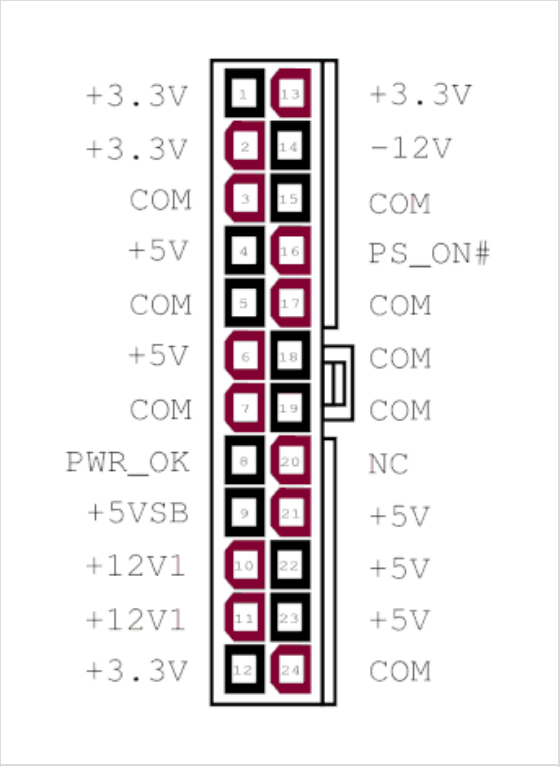
Booting from Cartridges

After the X16 finishes it's hardware initialization, the kernel checks bank 32 for the signature "CX16" at `$C000`. If found, it then jumps to `$C004` and leaves interrupts disabled.

ATX Power Supply

The Commander X16 has a socket for an industry standard 24-pin ATX power supply connector. Either a 24-pin or 20-pin PSU connector can be plugged in, though only the pins for the older 20-pin standard are used by the computer. You don't need an expensive power supply, but it must supply the -12v rail. Not all do, so check your unit to make sure. If you can't tell from the label, you can check Pin 12 and COM. If the clip side is facing away from you, pin 14 will be the second pin on the left on the clip side. For a 20-pin cable, -12v is on pin 12, but at the same relative position — the second pin on the left on the clip side.

24-pin ATX power connector, cable end



By CalvinTheMan - Own work, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=50881708

The Commander X16 does not use the 4-pin CPU power, GPU power, 4-pin drive power, or SATA power connectors.

To save space, when running a bare motherboard, we recommend a "Pico PSU" power supply, which derives all of the necessary power lines from a single 12V source.

J1 ROM Write Protect

Remove J1 to write protect system ROM. With J1 installed, users can program the system ROM using an appropriate ROM flash program.

J2 NMI

Connect a button here to generate an Non Maskable Interrupt (NMI) on the CPU. This will execute a BASIC warm start, which will stop any existing program, clear the screen, and print the READY prompt.

J3 Parallel/user port pullup resistors

When connected, activates 4.7k pullup resistors for PB0, PB4, PB6, PB7 and CA1 of the user port.

Printed on PCB: Connect J8 for LPT Compat. (TODO: Is this the Centronics parallel port mode Lorin hinted at early on?)

J4 Extra 65C22 Pins

PRxxxxx:

Pin	Desc
1	PB0
2	PB1
3	PB2
4	CB2

DEVxxxxx:

Pin	Desc

1	CA1
2	CA2
3	PB0
4	PB1
5	PB2
6	CB2

These pins are connected to VIA 1 at $9F00-$9F0F.

J5 SMC I2C (DEVxxxxx boards only)

DEVxxxxx boards: Remove jumpers from J5 to disconnect SMC from I2C bus. This allows serial programming of SMC via J9.

PRxxxxx boards: J5 is not present. On-board serial programming of SMC is not possible.

Desc	Pin		Pin	Desc
SCL_SMC	1	. .	2	SDA_SMC
SCL	3	. .	4	SDA

J6 System Speed

Pin	Desc
1 - 2	8 MHz
3 - 4	4 MHz
5 - 6	2 MHz

J7 SNES 3/4

Desc	Pin		Pin	Desc
CLC	1	. .	2	VCC
LATCH	3	. .	4	DAT4
DAT3	5	. .	6	GND

These pins will allow for two additional SNES controllers, for a total of four controllers on the system.

J8 Front Panel

Desc	Pin		Pin	Desc
HDD LED+	1	. .	2	POW LED +
HDD LED-	3	. .	4	POW LED -
RESET BUT	5	. .	6	POW BUT
RESET BUT	7	. .	7	POW BUT
+5VDC	9	. .	10	NC

This pinout is compatible with newer ATX style motherboards. AT motherboards and older ATX cases may still have a 3-pin power LED connector (with a blank pin in the middle.) You will need to move the + (red) wire on the power LED connector to the center pin, if this is the case. Or you can use two Male-Female breadboard cables to jumper the header to your power LED connector.

There is no on-board speaker header. Instead, all audio is routed to the rear panel headphone jack via the Audio Option header.

J9 I2C/SMC Header

There are two different layouts for the SMC header.

This is the layout on the production boards (PRxxxxx):

Desc	Pin		Pin	Desc
I2C SDA	1	. .	2	+5V
RTC MFP	3	. .	4	SMC TX
RESB	5	. .	6	SMC RX
I2C SCL	7	. .	8	GND
5VSB	9	. .	10	GND

This is the layout on the DEVxxxxx boards:

Desc	Pin		Pin	Desc
SMC MOSI/I2C SDA	1	. .	2	+5VSB
RTC MFP	3	. .	4	SMC TX
SMC Reset	5	. .	6	SMC RX
SMC SCK/I2C SCL	7	. .	8	GND
MISO	9	. .	10	GND

DEVxxxxx boards supports in-system serial programming using J9 and J5. This is not possible with PRxxxxx boards.

Note that pin 5 is connected to different SMC pins for DEV and PR boards, despite similar names. "SMC reset" (DEV) resets SMC, while "RESB" (PR) resets the rest of the system.

J10 Audio Option

Desc	Pin		Pin	Desc
SDA	1	. .	2	RESB
SCL	3	. .	4	VCC
	5	. .	6	
+12V	7	. .	8	-12V
	9	. .	10	
VERA_L	11	. .	12	BUS_L
	13	. .	14	
VERA_R	15	. .	16	BUS_R
	17	. .	18	
YM_L	19	. .	20	OUT_L
	21	. .	22	
YM_R	23	. .	24	OUT_R

5,6,9,10,13,14,17,18,21,22 - GND

Next to the audio header is a set of jumper pads, JP1-JP6. Cutting these traces allows you to extract isolated audio from each of the system devices or build a mixer to adjust the relative balance of the audio devices.

In order to avoid ground loop and power supply noise, we recommend installing a ground loop isolator when using an external mixer. 2 or 3 isolators will be required (one for each stereo pair.) (TODO: measure noise and test with pro audio gear.)

J12 User Port

Desc	Pin		Pin	Desc
PB0	1	. .	2	PB4
PA0	3	. .	4	PB5
PA1	5	. .	6	PB6/CB1
PA2	7	. .	8	PB7/CB2
PA3	9	. .	10	GND
PA4	11	. .	12	GND
PA5	13	. .	14	GND
PA6	15	. .	16	GND
PA7	17	. .	18	GND
CA1	19	. .	20	GND
PB1	21	. .	22	GND
PB2	23	. .	24	GND
PB3/CA2	25	. .	16	VCC

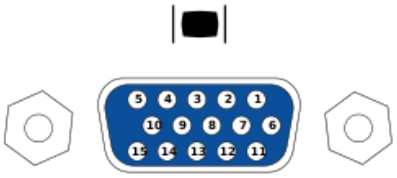
User port is connected to VIA 2 at address $9F10-$9F1F. This can be used for serial or parallel port I/O. Commander X16 does not have support for a serial port device in the KERNAL.

VERA Video Header (J11)

Desc	Pin		Pin	Desc
VCC	1	. .	2	GND
D7	3	. .	4	D6
D5	5	. .	6	D4
D3	7	. .	8	D2
D1	9	. .	10	D0
/IO1	11	. .	12	RESB
/MEMWE	13	. .	14	IRQB
A4	15	. .	16	/MEMOE
A2	17	. .	18	A3
A0	19	. .	20	A1
GND	21	. .	22	GND
VERA_L	23	. .	24	VERA_R

VERA is connected to I/O ports at $9F20-$9F3F. See Chapter 9: VERA Programmer's Reference for details.

VGA Connector



Pin	Desc
1	RED
2	GREEN
3	BLUE
4	
5	GND
6	RED_RTN
7	GREEN_RTN
8	BLUE_RTN
9	
10	GND
11	
12	
13	HSync
14	VSync
15	

The VGA connector is a female DE-15 jack.

The video resolution is 640x480 59.5FPS progressive scan, RGB color, and separated H/V sync.

In interlace mode, both horizontal and vertical sync pulses will appear on the HSync pin. (TODO: Test with OSSC).

VERA does not use the ID/DDC lines.

Composite Connector

The Composite video is a standard RCA connector. Center pin carries signal. Shield is signal ground.

The signal is NTSC Composite baseband video.

The video is 480 lines 59.97Hz interlaced. Composite is not available when VGA is running at 59.5Hz progressive scan.

S-Video Connector

Pin	Desc	
1	GND (Y)	
2	GND (C)	
3	Y	Intensity (Luminance)
4	C	Color (Chrominance)

The connector is a 4-pin Mini-DIN connector. While the same size as a PS/2 connector, the PS/2 connector has a plastic key at the bottom. Do not attempt to plug a keyboard or mouse into the S-Video port, or bent pins will occur.

The signal is NTSC baseband Y/C separated video. S-Video provides better resolution than composite, since the color and intensity are provided on separate pins. you can use a splitter cable to separate the Y and C signals to drive a Commodore 1702 or compatible monitor.

The video is 480 lines 59.97Hz interlaced. Composite is not available when VGA is running at 59.5Hz progressive scan.

J2 VERA Programming Interface

Pin	Desc
1	+5V
2	FPGA_CDONE
3	FPGA_CRESET_B
4	SPI_MISO
5	SPI_MOSI
6	SPI_SCK
7	SPI_SSEL_N
8	GND

VERA J7 Remote SD Card Option

Pin	Desc
1	CS
2	SCK
3	MOSI
4	MISO
5	+5V
6	GND

This requires an EEPROM programmer and an interface board to program. See Chapter 15 for the programming adapter and instructions.

Chapter 15: Upgrade Guide

This chapter provides tips for running upgrades on the various programmable chips.

WARNING: flashing any of these components has a risk of leading to an unbootable system. At the current time, doing hardware flash updates requires skill and knowledge beyond that of an ordinary end user and is not recommended without guidance from the community on the Commander X16 Discord.

Under the headings of each component is a matrix which indicates which software tools can be used to perform the flash of that component, depending on which flashing hardware you have access to and the operating system of the computer you have the device connected to. Some components of the Commander X16 can be self-flashed, but the risk of a failed flash rendering your X16 unbootable is high, in which case an external programmer must be used to flash the component and thus "unbrick" the system.

Flashable components

- System ROM
- SMC (PS/2 and Power controller)
- VERA

System ROM

Official community system ROMs will be posted as releases at X16Community/x16-emulator inside the distribution for the Emulator.

TODO: link to instructions for each solution in the matrix

↓ Hardware / OS →	Windows	Linux	Mac OS	Commander X16
Commander X16	-	-	-	x16-flash
XGecu TL866II+	Xgpro	minipro	minipro	-
XGecu TL866-3G / T48	Xgpro	-	-	-

SMC

Official community SMC ROMs will be posted as releases at X16Community/x16-smc .

TODO: link to instructions for each solution in the matrix

↓ Hardware / OS →	Windows	Linux	Mac OS	Commander X16
Commander X16	-	-	-	-
USBtinyISP	arduino	arduino	arduino	-
XGecu TL866II+	Xgpro	-	-	-
XGecu TL866-3G / T48	Xgpro	-	-	-

VERA

TODO: link to instructions for each solution in the matrix

Official community VERA bitstreams will be posted as releases at X16Community/vera-module

↓ Hardware / OS →	Windows	Linux	Mac OS	Commander X16
Commander X16	-	-	-	flashvera
XGecu TL866II+	Xgpro	minipro	minipro	-
XGecu TL866-3G / T48	Xgpro	-	-	-

Appendix A: Sound

FM instrument patch presets

#	Instrument Name		#	Instrument Name
0	Acoustic Grand Piano		64	Soprano Sax †
1	Bright Acoustic Piano		65	Alto Sax †
2	Electric Grand Piano		66	Tenor Sax †
3	Honky-tonk Piano		67	Baritone Sax
4	Electric Piano 1		68	Oboe †
5	Electric Piano 2		69	English Horn †
6	Harpsichord		70	Bassoon
7	Clavinet		71	Clarinet †
8	Celesta		72	Piccolo
9	Glockenspiel		73	Flute †
10	Music Box		74	Recorder
11	Vibraphone †		75	Pan Flute
12	Marimba		76	Blown Bottle
13	Xylophone		77	Shakuhachi
14	Tubular Bells		78	Whistle †
15	Dulcimer		79	Ocarina
16	Drawbar Organ †		80	Lead 1 (Square) †
17	Percussive Organ †		81	Lead 2 (Sawtooth) †
18	Rock Organ †		82	Lead 3 (Triangle) †
19	Church Organ		83	Lead 4 (Chiff+Sine) †
20	Reed Organ		84	Lead 5 (Charang) †
21	Accordion		85	Lead 6 (Voice) †
22	Harmonica		86	Lead 7 (Fifths) †
23	Bandoneon		87	Lead 8 (Solo) †
24	Acoustic Guitar (Nylon)		88	Pad 1 (Fantasia) †
25	Acoustic Guitar (Steel)		89	Pad 2 (Warm) †
26	Electric Guitar (Jazz)		90	Pad 3 (Polysynth) †
27	Electric Guitar (Clean)		91	Pad 4 (Choir) †
28	Electric Guitar (Muted)		92	Pad 5 (Bowed)
29	Electric Guitar (Overdriven)		93	Pad 6 (Metallic)
30	Electric Guitar (Distortion)		94	Pad 7 (Halo) †
31	Electric Guitar (Harmonics)		95	Pad 8 (Sweep) †
32	Acoustic Bass		96	FX 1 (Raindrop)

33	Electric Bass (finger)		97	FX 2 (Soundtrack) †
34	Electric Bass (picked)		98	FX 3 (Crystal)
35	Fretless Bass		99	FX 4 (Atmosphere) †
36	Slap Bass 1		100	FX 5 (Brightness) †
37	Slap Bass 2		101	FX 6 (Goblin)
38	Synth Bass 1		102	FX 7 (Echo)
39	Synth Bass 2		103	FX 8 (Sci-Fi) †
40	Violin †		104	Sitar
41	Viola †		105	Banjo
42	Cello †		106	Shamisen
43	Contrabass †		107	Koto
44	Tremolo Strings †		108	Kalimba
45	Pizzicato Strings		109	Bagpipe
46	Orchestral Harp		110	Fiddle †
47	Timpani		111	Shanai †
48	String Ensemble 1 †		112	Tinkle Bell
49	String Ensemble 2 †		113	Agogo
50	Synth Strings 1 †		114	Steel Drum
51	Synth Strings 2 †		115	Woodblock
52	Choir Aahs †		116	Taiko Drum
53	Voice Doos		117	Melodic Tom
54	Synth Voice †		118	Synth Drum
55	Orchestra Hit		119	Reverse Cymbal
56	Trumpet †		120	Fret Noise
57	Trombone		121	Breath Noise
58	Tuba		122	Seashore †
59	Muted Trumpet †		123	Bird Tweet
60	French Horn		124	Telephone Ring
61	Brass Section		125	Helicopter
62	Synth Brass 1		126	Applause †
63	Synth Brass 2		127	Gunshot

† Instrument is affected by the LFO, giving it a vibrato or tremolo effect.

FM extended instrument patch presets

These presets exist mainly to support playback of drum sounds, and many of them only work correctly or sound musical at certain pitches or within a small range of pitches.

#	Instrument Name		#	Instrument Name

128	Silent		146	Vibraslap
129	Snare Roll		147	Bongo
130	Snap		148	Maracas
131	High Q		149	Short Whistle
132	Scratch		150	Long Whistle
133	Square Click		151	Short Guiro
134	Kick		152	Long Guiro
135	Rim		153	Mute Cuica
136	Snare		154	Open Cuica
137	Clap		155	Mute Triangle
138	Tom		156	Open Triangle
139	Closed Hi-Hat		157	Jingle Bell
140	Pedal Hi-Hat		158	Bell Tree
141	Open Hi-Hat		159	Mute Surdo
142	Crash		160	Pure Sine
143	Ride Cymbal		161	Timbale
144	Splash Cymbal		162	Open Surdo
145	Tambourine			

Drum presets

These are the percussion instrument mappings for the drum number argument of the `ym_playdrum` and `ym_setdrum` API calls, and the `FMDRUM` BASIC command.

#	Instrument Name		#	Instrument Name
			56	Cowbell
25	Snare Roll		57	Crash Cymbal 2
26	Finger Snap		58	Vibraslap
27	High Q		59	Ride Cymbal 2
28	Slap		60	High Bongo
29	Scratch Pull		61	Low Bongo
30	Scratch Push		62	Mute High Conga
31	Sticks		63	Open High Conga
32	Square Click		64	Low Conga
33	Metronome Bell		65	High Timbale
34	Metronome Click		66	Low Timbale
35	Acoustic Bass Drum		67	High Agogo
36	Electric Bass Drum		68	Low Agogo
37	Side Stick		69	Cabasa

38	Acoustic Snare		70	Maracas
39	Hand Clap		71	Short Whistle
40	Electric Snare		72	Long Whistle
41	Low Floor Tom		73	Short Guiro
42	Closed Hi-Hat		74	Long Guiro
43	High Floor Tom		75	Claves
44	Pedal Hi-Hat		76	High Woodblock
45	Low Tom		77	Low Woodblock
46	Open Hi-Hat		78	Mute Cuica
47	Low-Mid Tom		79	Open Cuica
48	High-Mid Tom		80	Mute Triangle
49	Crash Cymbal 1		81	Open Triangle
50	High Tom		82	Shaker
51	Ride Cymbal 1		83	Jingle Bell
52	Chinese Cymbal		84	Belltree
53	Ride Bell		85	Castanets
54	Tambourine		86	Mute Surdo
55	Splash Cymbal		87	Open Surdo

BASIC FMPLAY and PSGPLAY string macros

Overview

The play commands use a string of tokens to define sequences of notes to be played on a single voice of the corresponding sound chip. Tokens cause various effects to happen, such as triggering notes, changing the playback speed, etc. In order to minimize the amount of text required to specify a sequence of sound, the player maintains an internal state for most note parameters.

Stateful Player Behavior:

Playback parameters such as tempo, octave, volume, note duration, etc do not need to be specified for each note. These states are global between all voices of both the FM and PSG sound chips. The player maintains parameter state during and after playback. For instance, setting the octave to 5 in an `FMPLAY` command will result in subsequent `FMPLAY` and `PSGPLAY` statements beginning with the octave set to 5.

The player state is reset to default values whenever `FMINIT` or `PSGINIT` are used.

Parameter	Default	Equivalent Token
Tempo	120	T120
Octave	4	O4
Length	4	L4
Note Spacing	1	S1

Using Tokens:

The valid tokens are: `A-G,I,K,L,O,P,R,S,T,V,<,>`.

Each token may be followed by optional modifiers such as numbers or symbols. Options to a token must be given in the order they are expected, and must have no spacing between them. Tokens may have spaces between them as desired. Any unknown characters are ignored.

Example:

```
FMPLAY 0,"L4"      : REM DEFAULT LENGTH = QUARTER NOTE
FMPLAY 0,"A2. C+." : REM VALID
FMPLAY 0,"A.2 C.+" : REM INVALID
```

The valid command plays A as a dotted half, followed by C♯ as a dotted quarter.

The invalid example would play A as a dotted quarter (not half) because length must come before dots. Next, it would ignore the 2 as garbage. Then it would play natural C (not sharp) as a dotted quarter. Finally, it would ignore the + as garbage, because sharp/flat must precede length and dot.

Token definitions:

Musical notes

- Synopsis: Play a musical note, optionally setting the length.
- Syntax: `<A-G>[<+/->][<length>][.]`

Example:

```
FMPLAY 0,"A+2A4C.G-8."
```

On the YM2151 using channel 0, plays in the current octave an **A**♯ half note[?] followed by an **A** quarter note[?], followed by **C** dotted quarter note, followed by **G**♭ dotted eighth note[?].

Lengths and dots after the note name or rest set the length just for the current note or rest. To set the default length for subsequent notes and rests, use the `L` macro.

Rests

- Synopsis: Wait for a period of silence equal to the length of a note, optionally setting the length.
- Syntax: `R[<length>][.]`

Example:

```
PSGPLAY 0,"CR2DRE"
```

On the VERA PSG using voice 0, plays in the current octave a **C** quarter note, followed by a half rest (silence), followed by a quarter **D**, followed by a quarter rest (silence), and finally a quarter **E**.

The numeral `2` in `R2` sets the length for the `R` itself but does not alter the default note length (assumed as 4 - quarter notes in this example).

Note Length

- Synopsis: Set the default length for notes and rests that follow
- Syntax: `L[<length>][.]`

Example values:

- L4 = quarter note (crotchet)
- L16 = sixteenth note (semiquaver)
- L12 = 8th note triplets (quaver triplet)
- L4. = dotted quarter note (1.5x the length)
- L4.. = double-dotted quarter note (1.75x the length)

Example program:

```
10 FMPLAY 0,"L4"
20 FOR I=1 TO 2
30 FMPLAY 0,"CDECL8"
40 NEXT
```

On the YM2151 using channel 0, this program, when RUN, plays in the current octave the sequence **C D E C** first as quarter notes, then as eighth notes the second time around.

Articulation

- Synopsis: Set the spacing between notes, from legato to extreme staccato
- Syntax: `S<0-7>`

`S0` indicates legato. For FMPLAY, this also means that notes after the first in a phrase don't implicitly retrigger.

`S1` is the default value, which plays a note for 7/8 of the duration of the note, and releases the note for the remaining 1/8 of the note's duration.

You can think of `S` is, out of 8, how much space is put between the notes.

Example:

```
FMPLAY 0,"L4S1CDES0CDES4CDE"
```

On the YM2151 using channel 0, plays in the current octave the sequence **C D E** three times, first with normal articulation, next with legato (notes all run together and without retriggering), and finally with a moderate staccato.

Explicit retrigger

- Synopsis: on the YM2151, when using `S0` legato, retrigger on the next note.
- Syntax: `K`

Example:

```
FMPLAY 0,"S0CDEKFGA"
```

On the YM2151 using channel 0, plays in the current octave the sequence **C D E** using legato, only triggering on the first note, then the sequence **F G A** the same way. The note **F** is triggered without needing to release the previous note early.

Octave

- Synopsis: Explictly set the octave number for notes that follow
- Syntax: `O<0-7>`

Example:

```
PSGPLAY 0,"O4AO2AO6CDE"
```

On the VERA PSG using voice 0, changes to octave 4 and plays **A** (440Hz), then switches to octave 2, and plays **A** (110Hz), then switches to octave 6 and plays the sequence **C D E**

Octave Up

- Synopsis: Increases the octave by 1
- Syntax: `>`

If the octave would go above 7, this macro has no effect.

Example:

```
PSGPLAY 0,"O4AB>C+DE"
```

On the VERA PSG using voice 0, changes to octave 4 and plays the first five notes of the **A major** scale by switching to octave 5 starting at the **C♯**

Octave Down

- Synopsis: Decreases the octave by 1
- Syntax: `<`

If the octave would go below 0, this macro has no effect. Example:

```
PSGPLAY 0,"O5GF+EDC<BAG"
```

On the VERA PSG using voice 0, changes to octave 5 and plays the **G major** scale from the top down by switching to octave 4 starting at the **B**

Tempo

- Synopsis: Sets the BPM, the number of quarter notes per minute
- Syntax: `T<1-255>`

High tempo values and short notes tend to have inaccurate lengths due to quantization error. Delays within a string do keep track of fractional frames so the overall playback length should be relatively consistent.

Low tempo values that cause delays (lengths) to exceed 255 frames will also end up being inaccurate. For very long notes, it may be better to use legato to string several together.

Example:

```
10 FMPLAY 0,"T120C4CGGAAGR"
20 FMPLAY 0,"T180C4CGGAAGR"
```

On the YM2151 using channel 0, plays in the current octave the first 7 notes of *Twinkle Twinkle Little Star*, first at 120 beats per minute, then again 1.5 times as fast at 180 beats per minute.

Volume

- Synopsis: Set the channel or voice volume
- Syntax: `V<0-63>`

This macro mirrors the `PSGVOL` and `FMVOL` BASIC commands for setting a channel or voice's volume. 0 is silent, 63 is maximum volume.

Example:

```
FMPLAY 0,"V40ECV45ECV50ECV55ECV60ECV63EC"
```

On the YM2151 using channel 0, starting at a moderate volume, plays the sequence **E C**, repeatedly, increasing the volume steadily each time.

Panning

- Synopsis: Sets the stereo output of a channel or voice to left, right, or both.
- Syntax: `P<1-3>`

1 = Left
2 = Right
3 = Both

Example:

```
10 FOR I=1 TO 4
20 PSGPLAY 0,"P1CP2B+"
30 NEXT I
40 PSGPLAY 0,"P3C"
```

On the VERA PSG using voice 0, in the current octave, repeatedly plays a **C** out of the left speaker, then a **B**♯ (effectively a **C** one octave higher) out of the right speaker. After 4 such loops, it plays a **C** out of both speakers.

Instrument change

- Synopsis: Sets the FM instrument (like FMINST) or PSG waveform (like PSGWAV)
- Syntax: `I<0-255>` (0-162 for FM)

Note: This macro is available starting in ROM version R43.

Example:

```
10 FMINIT
20 FMVIB 200,15
30 FMCHORD 0,"I11CI11EI11G"
```

This program sets up appropriate vibrato/tremolo and plays a C major chord with the vibraphone patch across FM channels 0, 1, and 2.

Appendix B: VERA Firmware Recovery

WARNING: This is a draft that may contain errors or omissions that could damage your hardware.

Using a Windows PC to upgrade or recover a VERA

Target Component: VERA
Programmer: TL866-3G/T48
Software: Xgpro
Host OS: Windows

Before You Start

Before starting, it is recommended to disconnect the Commander X16's PSU's power from the wall socket. You will need to reconnect power later, but while connecting the programmer to the system, it is safer to disconnect mains power from the power supply. Power is supplied to parts of the main board even when the computer is turned off.use_directory_urls To perform the upgrade, you will need the following:

- A TL866-3G/T48 programmer
- The Xgpro software
- Female-to-female jumper wires

Programmer Wiring Setup

The VERA 8-pin header should be connected as follows:

VERA J2 Pin	Connect to
1 (+5V)	Not connected
2 (CDONE)	Not connected
3 (CRESET_B)	VERA, J7 GND pin
4 (SPI_MISO)	TL866-3G/T48, ICSP pin 5 (MISO)
5 (SPI_MOSI)	TL866-3G/T48, ICSP pin 15 (MOSI)
6 (SPI_SCK)	TL866-3G/T48, ICSP pin 7 (SCK)
7 (SPI_SEL_N)	TL866-3G/T48, ICSP pin 1 (/CS)
8 (GND)	TL866-3G/T48, ICSP pin 16 (GND)

Image 1: Vera J2 programming header and J7 header.

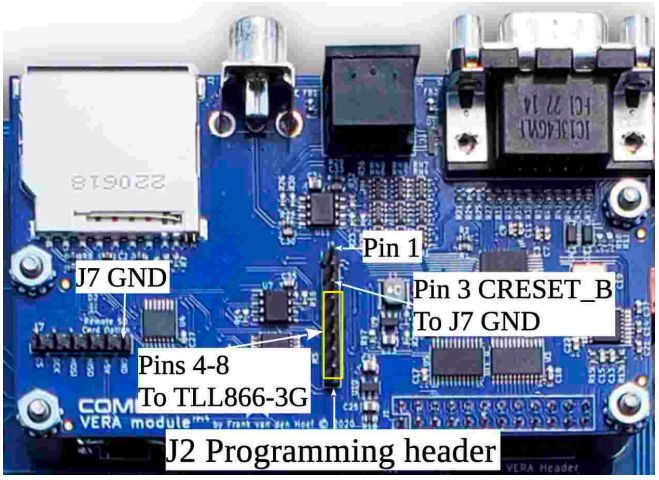
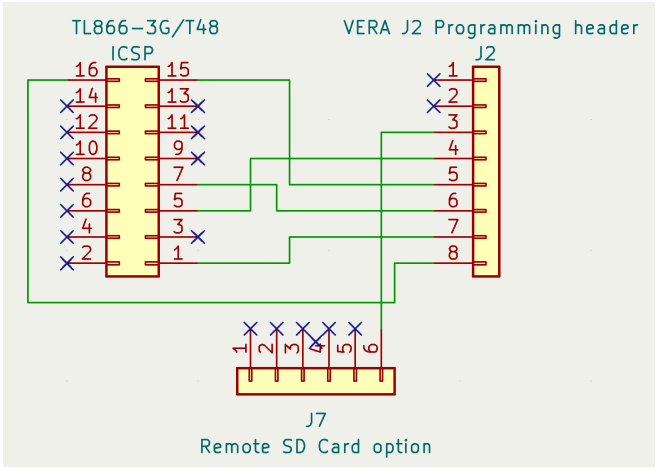


Image 2: TL866-3G/T48 ICSP header.

Image 3: Schematics for connection between the VERA board and the TL866-3G/T48.



Powering the Target Component

The VERA board is programmed while it is still mounted in the Commander X16 and will be powered by the computer's PSU, not by the programmer.

Before proceeding with the firmware upgrade, ensure that the wiring is correct. Then, connect the Commander X16 to the wall socket and press the computer's power button to ensure that 5V is supplied to the VERA board.

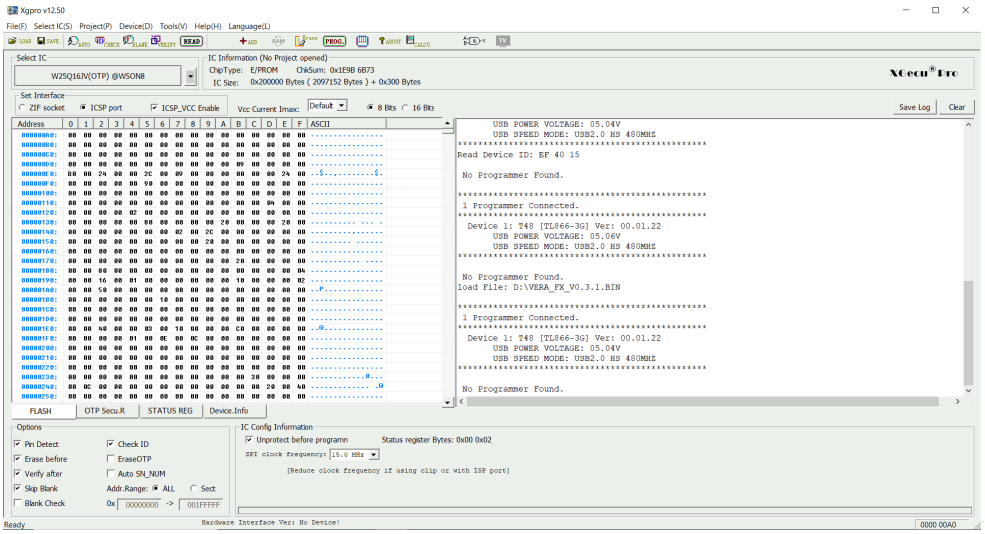
Please note that the VERA's FPGA is held in reset because VERA pin 3 (CRESET_B) is connected to ground. As a result, you will not see any screen output during the upgrade process.

Programmer Software Setup

Open the Xgpro software and configure the following settings:

- Select target chip: W25Q16JV
- Setup interface: Choose ICSP port and uncheck ICSP_VCC_Enable

- Click on "ID Check" to verify the connection
  - The response value should be EF 40 15
  - If it is not, double-check the wiring before proceeding



Update/Flash Procedure

In the Xgpro software, follow these steps:

- Click on "Load" to load the firmware into the software buffer
- After loading the firmware into the software buffer, click on "Prog." to upload the firmware to the VERA board.

Once the update is complete, press the power button to turn off the Commander X16. Then, disconnect the computer from the wall socket. Finally, remove all wires from the VERA pin header.

Congratulations! The firmware update for VERA is now complete.

Appendix C: The 65C02 Processor

This is not meant to be a complete manual on the 65C02 processor, though is meant to serve as a convenient quick reference. Much of this information comes from 6502.org and pagetable.com. It is been placed here for convenience though further information can be found at those (and other) sources.

Overview

The WDC65C02 CPU is a modern version of the MOS6502 with a few additional instructions and addressing modes and is capable of running at up to 14 MHz. On the Commander X16, it is clocked at 8 MHz.

A note about 65C816 Compatibilty

The Commander X16 may be upgraded at some point to use the WDC 65C816 CPU. The 65C816 is mostly compatible with the 65C02, except for 4 instructions (`BBRx` , `BBSx` , `RMBx` , and `SMBx`).

These instructions *may* be deprecated in a future release of the emulator, and so we suggest not using these instructions. Some people are already using the 65C816 in their X16 systems, and so using these instructions will cause your programs to malfunction on these computers.

Instruction Tables

Instructions By Number

	x0	x1	x2	x3	x4	x5	x6	x7	x8	x9	xA	xB	xC	xD	xE	xF
0x	BRK	ORA			TSB	ORA	ASL	RMB0	PHP	ORA	ASL		TSB	ORA	ASL	BBR0
1x	BPL	ORA	ORA		TRB	ORA	ASL	RMB1	CLC	ORA	INC		TRB	ORA	ASL	BBR1
2x	JSR	AND			BIT	AND	ROL	RMB2	PLP	AND	ROL		BIT	AND	ROL	BBR2
3x	BMI	AND	AND		BIT	AND	ROL	RMB3	SEC	AND	DEC		BIT	AND	ROL	BBR3
4x	RTI	EOR				EOR	LSR	RMB4	PHA	EOR	LSR		JMP	EOR	LSR	BBR4
5x	BVC	EOR	EOR			EOR	LSR	RMB5	CLI	EOR	PHY			EOR	LSR	BBR5
6x	RTS	ADC			STZ	ADC	ROR	RMB6	PLA	ADC	ROR		JMP	ADC	ROR	BBR6
7x	BVS	ADC	ADC		STZ	ADC	ROR	RMB7	SEI	ADC	PLY		JMP	ADC	ROR	BBR7
8x	BRA	STA			STY	STA	STX	SMB0	DEY	BIT	TXA		STY	STA	STX	BBS0
9x	BCC	STA	STA		STY	STA	STX	SMB1	TYA	STA	TXS		STZ	STA	STZ	BBS1
Ax	LDY	LDA	LDX		LDY	LDA	LDX	SMB2	TAY	LDA	TAX		LDY	LDA	LDX	BBS2
Bx	BCS	LDA	LDA		LDY	LDA	LDX	SMB3	CLV	LDA	TSX		LDY	LDA	LDX	BBS3
Cx	CPY	CMP			CPY	CMP	DEC	SMB4	INY	CMP	DEX	WAI	CPY	CMP	DEC	BBS4
Dx	BNE	CMP	CMP			CMP	DEC	SMB5	CLD	CMP	PHX	STP		CMP	DEC	BBS5
Ex	CPX	SBC			CPX	SBC	INC	SMB6	INX	SBC	NOP		CPX	SBC	INC	BBS6
Fx	BEQ	SBC	SBC			SBC	INC	SMB7	SED	SBC	PLX			SBC	INC	BBS7

Instructions By Name

ADC	AND	ASL	BBRx	BBSx	BCC	BCS	BEQ	BIT	BMI	BNE	BPL	BRA	BRK	BVC	BVS
CLC	CLD	CLI	CLV	CMP	CPX	CPY	DEC	DEX	DEY	EOR	INC	INX	INY	JMP	JSR
LDA	LDX	LDY	LSR	NOP	ORA	PHA	PHP	PHX	PHY	PLA	PLP	PLX	PLY	RMBx	ROL
ROR	RTI	RTS	SBC	SEC	SED	SEI	SMBx	STA	STP	STX	STY	STZ	TAX	TAY	TRB
TSB	TSX	TXA	TXS	TYA	WAI										

Instructions By Category

Arithmetic	ADC	SBC						
Boolean	AND	EOR	ORA					
Bit Shift	ASL	LSR	ROL	ROR				
Branch	BBRx	BBSx						
Test Bit	BIT	TRB	TSB					
Branching	BCC	BCS	BEQ	BMI	BNE	BPL	BVC	BVS	BRA
Misc	BRK	NOP	STP	WAI				
Flags	CLC	CLD	CLI	CLV	SEC	SED	SEI		
Compare	CMP	CPX	CPY					
Increment/Decrement	DEC	DEX	DEY	INX	INY	INC		
Flow	JMP	JSR	RTI	RTS				
Load Data	LDA	LDX	LDY					
Stack	PHA	PHP	PHX	PHY	PLA	PLP	PLX	PLY
Bit Operations	RMBx	SMBx						
Store Data	STA	STX	STY	STZ				
Transfer	TAX	TXA	TAY	TYA	TSX	TXS		

ADC

Add with Carry

```
SYNTAX       MODE           HEX  LEN  CYCLES  FLAGS
ADC #$20     Immediate      $69   2     2     NV----ZC
ADC $20      Zero Page      $65   2     3     NV----ZC
ADC $20,X    Zero Page,X    $75   2     4     NV----ZC
ADC $8080    Absolute       $6D   3     4     NV----ZC
ADC $8080,X  Absolute,X     $7D   3     4+    NV----ZC +p
ADC $8080,Y  Absolute,Y     $79   3     4+    NV----ZC +p
ADC ($20,X)  Indirect,X     $61   2     6     NV----ZC
ADC ($20),Y  Indirect,Y     $71   2     5+    NV----ZC +p
ADC ($20)    ZP Indirect    $72   2     5     NV----ZC +c
```

Add a number to the Accumulator and stores the result in A.

Use the Carry (C) or Overflow (V) flags to determine whether the result was too large for an 8 bit number.

If C is set before operation, then 1 will be added to the result.

C is set when result is more than 255 ($FF)
Z is set when result is zero
V is set when signed result is too large. (Goes below -128 or above 127).
N is set when result is negative (bit 7=1)

+p: Add 1 cycle if a page boundary is crossed when forming address.
+c: New for the 65C02

[Opcodes] | [By Name] | [By Category]

AND

Logical And

```
SYNTAX       MODE           HEX  LEN  CYCLES  FLAGS
AND #$20     Immediate      $29   2     2     N-----Z-
AND $20      Zero Page      $25   2     3     N-----Z-
AND $20,X    Zero Page,X    $35   2     4     N-----Z-
AND $8080    Absolute       $2D   3     4     N-----Z-
AND $8080,X  Absolute,X     $3D   3     4+    N-----Z- +p
AND $8080,Y  Absolute,Y     $39   3     4+    N-----Z- +p
AND ($20,X)  Indirect,X     $21   2     6     N-----Z-
AND ($20),Y  Indirect,Y     $31   2     5+    N-----Z- +p
AND ($20)    ZP Indirect    $32   2     5     N-----Z- +c
```

Bitwise AND the provided value with the Accumulator.

- Sets N (Negative) flag if the bit 7 of the result is 1, and otherewise clears it.
- Sets Z (Zero) is the result is zero, and otherwise clears it

`AND #$FF` will leave A unaffected (but still set the flags).
`AND #$00` will clear A.
`AND #$0F` will clear the high nibble of A, leaving a value of $00 to $0F in A.

M	A	Result
0	0	0
0	1	0
1	0	0
1	1	1

Other Boolean Instructions:
EOR exclusive-OR
ORA bitwise OR

+p: Add 1 cycle if a page boundary is crossed when forming address.
+c: New for the 65C02

[Opcodes] | [By Name] | [By Category]

ASL

Arithmetic Shift Left

```
SYNTAX       MODE           HEX  LEN  CYCLES  FLAGS
ASL A        Accumulator    $0A   1     2     N-----ZC
ASL $20      Zero Page      $06   2     5     N-----ZC
ASL $20,X    Zero Page,X    $16   2     6     N-----ZC
ASL $8080    Absolute       $0E   3     6     N-----ZC
ASL $8080,X  Absolute,X     $1E   3     6+    N-----ZC +p
```

Shifts all bits to the left by one position, moving 0 into the low bit.

0 is shifted into bit 0.
Bit 7 is shifted to Carry.

Similar instructions:
LSR is the opposite instruction and shifts to the right.
ROL shifts left through Carry.

+p: Add 1 cycle if a page boundary is crossed when forming address.

[Opcodes] | [By Name] | [By Category]

BBRx

Branch on Bit Reset

```
SYNTAX       MODE           HEX  LEN  CYCLES  FLAGS
BBR0 $20,$8080 ZP Relative   $0F   3     5     -------- +c -816
BBR1 $20,$8080 ZP Relative   $1F   3     5     -------- +c -816
BBR2 $20,$8080 ZP Relative   $2F   3     5     -------- +c -816
BBR3 $20,$8080 ZP Relative   $3F   3     5     -------- +c -816
BBR4 $20,$8080 ZP Relative   $4F   3     5     -------- +c -816
BBR5 $20,$8080 ZP Relative   $5F   3     5     -------- +c -816
BBR6 $20,$8080 ZP Relative   $6F   3     5     -------- +c -816
BBR7 $20,$8080 ZP Relative   $7F   3     5     -------- +c -816
```

Branch to LABEL if bit x of zero page address is 0 where x is the number of the specific bit (0-7).

+c: New for the 65C02 -816: *Not available* on the 65C816

BBR Example

```
check_flag:
  BBR3 zeropage_flag, flag_not_set
flag_set:
  NOP
  ...
flag_not_set:
  NOP
  ...
```

The above BBR3 looks at value in zeropage_flag (here it's a label to an actual zero page address) and if bit 3 of the value is *zero* the branch would be taken to `@flag_not_set`.

[Opcodes] | [By Name] | [By Category]

BBSx

Branch on Bit Set

```
SYNTAX       MODE           HEX  LEN  CYCLES  FLAGS
BBS0 $20,$8080 ZP Relative    $8F   3     5     -------- +c -816
BBS1 $20,$8080 ZP Relative    $9F   3     5     -------- +c -816
BBS2 $20,$8080 ZP Relative    $AF   3     5     -------- +c -816
BBS3 $20,$8080 ZP Relative    $BF   3     5     -------- +c -816
BBS4 $20,$8080 ZP Relative    $CF   3     5     -------- +c -816
BBS5 $20,$8080 ZP Relative    $DF   3     5     -------- +c -816
BBS6 $20,$8080 ZP Relative    $EF   3     5     -------- +c -816
BBS7 $20,$8080 ZP Relative    $FF   3     5     -------- +c -816
```

Branch to LABEL if bit x of zero page address is 1 where x is the number of the specific bit (0-7).

+c: New for the 65C02 -816: *Not available* on the 65C816

BBS Example

```
check_flag:
    BBS3 zeropage_flag, flag_set
flag_not_set:
    NOP
    ...
flag_set:
    NOP
    ...
```

The above BBR3 looks at value in zeropage_flag (here it's a label to an actual zero page address) and if bit 3 of the value is *zero* the branch would be taken to `@flag_set` .

[Opcodes] | [By Name] | [By Category]

BIT

Test Bit

```
SYNTAX       MODE           HEX  LEN  CYCLES  FLAGS
BIT $20      Zero Page      $24   2     3     NV----Z-
BIT $8080    Absolute       $2C   3     4     NV----Z-
BIT #$20     Immediate      $89   2     2     ------Z- +c
BIT $20,X    Zero Page,X    $34   2     4     NV----Z- +c
BIT $8080,X  Absolute,X     $3C   3     4+    NV----Z- +c +p
```

- Sets Z (Zero) flag based on an AND of value provided to the Accumulator.
- Sets N (Negative) flag to the value of bit 7 at the provided address (NOTE: not with immediate).
- Sets V (Overflow) flag to the value of bit 6 at the provided addres (NOTE: not with immediate).

+p: Add 1 cycle if a page boundary is crossed when forming address.
+c: New for the 65C02

[Opcodes] | [By Name] | [By Category]

Bcc

Branch Instructions

```
SYNTAX       MODE           HEX  LEN  CYCLES  FLAGS
BCC $8080    Relative       $90   2    2/3+   -------- +p Carry Clear
BCS $8080    Relative       $B0   2    2/3+   -------- +p Carry Set
```

```
BEQ $8080    Relative       $F0   2    2/3+   -------- +p Equal: Zero bit set
BMI $8080    Relative       $30   2    2/3+   -------- +p Negative bit set
BNE $8080    Relative       $D0   2    2/3+   -------- +p Not Equal: Zero bit clear
BPL $8080    Relative       $10   2    2/3+   -------- +p Negative bit clear
BVC $8080    Relative       $50   2    2/3+   -------- +p oVerflow Clear
BVS $8080    Relative       $70   2    2/3+   -------- +p oVerflow Set
BRA $8080    Relative       $80   2    3/4+   -------- +p +c Always
```

The branch instructions take the branch when the related flag is Set (1) or Clear (0).

When combined with CMP, this is the 6502's "IF THEN" construct.

```
LDA $1234  ; Reads the value of address $1234
CMP #$20   ; Compares it with the literal $20 (32)
BEQ Match  ; If they are equal, move to the label "Match".
```

The operand is a *relative* address, based on the Program Counter at the start of the next opcode. As a result, you can only branch 127 bytes forward or 128 bytes back. However, most assemblers take a label or an address literal. So the assembled value will be computed based on the PC and the entered value.

For example, if the PC is `$1000`, the statement `BCS $1023` will be `$B0 $21`.

`BCC` also functions as "branch less-than" (`<`) after a comparison (some assemblers support a `BLT` macro/alias). Similarly, `BCS` also functions as "branch greater-than-or-equal" (`>=`) after a comparison (some assemblers support a `BGE` macro/alias).

+p: Execution takes one additional cycle when branching crosses a page boundary. +c: New for the 65C02

[Opcodes] | [By Name] | [By Category]

BRK

Break: Software Interrupt

```
SYNTAX       MODE           HEX  LEN  CYCLES  FLAGS
BRK          Implied        $00   1     7     ---BD---
```

BRK is a software interrupt. With any interrupt several things happen:

1. The Program Counter is incremented by 2 bytes.
2. The new PC and flags are pushed onto the stack (pushed flags has B set on BRK).
3. The B flag is set (but only valid in stack memory flags interrupt pushed).
4. The D (Decimal) flag is cleared, forcing the CPU into binary mode.
5. The CPU reads the address from the IRQ vector at $FFFE and jumps there.

On the X16, BRK will jump out of the running program to the machine monitor. You can then examine the state of the CPU registers and memory.

The B flag (as pushed on the stack) is used to distinguish a BRK from an NMI. An interrupt triggered by asserting the NMI pin does not set the B flag, and so the X16 does a warm boot of BASIC, rather than jumping to MONitor.

[Opcodes] | [By Name] | [By Category]

CLC

Clear Carry

```
SYNTAX       MODE           HEX  LEN  CYCLES  FLAGS
CLC          Implied        $18   1     2     -------C
```

Clears the Carry flag. This is useful before ADC to prevent an extra 1 during addition. C is also often used in KERNAL routines to alter the operation of the routine or return certain information.

[Opcodes] | [By Name] | [By Category]

CLD

Clear Decimal Flag

```
SYNTAX       MODE           HEX  LEN  CYCLES  FLAGS
CLD          Implied        $D8   1     2     ----D---
```

Clears the Decimal flag. This switches the CPU back to binary operation if it was previously in BCD mode.

[Opcodes] | [By Name] | [By Category]

CLI

Clear Interrupt Disable

```
SYNTAX       MODE           HEX  LEN  CYCLES  FLAGS
CLI          Implied        $58   1     2     -----I--
```

Clear Interrupt disable. This allows IRQ interrupts to proceed normally. NMI and RST are always enabled.

Use SEI to disable interrupts

[Opcodes] | [By Name] | [By Category]

CLV

Clear oVerflow

```
SYNTAX       MODE           HEX  LEN  CYCLES  FLAGS
CLV          Implied        $B8   1     2     -V------
```

Clear the Overflow (V) flag after an arithmetic operation, such as ADC or SBC.

[Opcodes] | [By Name] | [By Category]

CMP

Compare A to memory

```
SYNTAX       MODE           HEX  LEN  CYCLES  FLAGS
CMP #$20     Immediate      $C9   2     2     N-----ZC
CMP $20      Zero Page      $C5   2     3     N-----ZC
CMP $20,X    Zero Page,X    $D5   2     4     N-----ZC
CMP $8080    Absolute       $CD   3     4     N-----ZC
CMP $8080,X  Absolute,X     $DD   3     4+    N-----ZC +p
CMP $8080,Y  Absolute,Y     $D9   3     4+    N-----ZC +p
CMP ($20,X)  Indirect,X     $C1   2     6     N-----ZC
CMP ($20),Y  Indirect,Y     $D1   2     5+    N-----ZC +p
CMP ($20)    ZP Indirect    $D2   2     5     N-----ZC +c
```

Compares the value in the Accumulator (A) with the given value. It sets flags based on subtracting A - *Value*.

- Sets C (Carry) flag if the value in A is >= given value
- Clears C (Carry) flag if the value in A is < given value
- Sets Z (Zero) flag if the values are equal
- Clears Z (Zero) flag if the values are not equal
- Sets N (Negative) flag if value in A is < given value

+p: Add 1 cycle if a page boundary is crossed when forming address.
+c: New for the 65C02

[Opcodes] | [By Name] | [By Category]

CPX

Compare X to memory

```
SYNTAX       MODE           HEX  LEN  CYCLES  FLAGS
CPX #$20     Immediate      $E0   2     2     N-----ZC
CPX $20      Zero Page      $E4   2     3     N-----ZC
CPX $8080    Absolute       $EC   3     4     N-----ZC
```

Compares the value in the X register with the given value. It sets flags based on subtracting X - *Value*.

- Sets C (Carry) flag if the value in X is >= given value
- Clears C (Carry) flag if the value in X is < given value
- Sets Z (Zero) flag if the values are equal
- Clears Z (Zero) flag if the values are not equal
- Sets N (Negative) flag if value in X is < given value

[Opcodes] | [By Name] | [By Category]

CPY

Compare Y to memory

```
SYNTAX       MODE           HEX  LEN  CYCLES  FLAGS
CPY #$20     Immediate      $C0   2     2     N-----ZC
CPY $20      Zero Page      $C4   2     3     N-----ZC
CPY $8080    Absolute       $CC   3     4     N-----ZC
```

Compares the value in the Y register with the given value. It sets flags based on subtracting Y - *Value*.

- Sets C (Carry) flag if the value in Y is >= given value
- Clears C (Carry) flag if the value in Y is < given value
- Sets Z (Zero) flag if the values are equal
- Clears Z (Zero) flag if the values are not equal
- Sets N (Negative) flag if value in Y is < given value

[Opcodes] | [By Name] | [By Category]

DEC

Decrement Value

```
SYNTAX       MODE           HEX  LEN  CYCLES  FLAGS
DEC A        Accumulator    $3A   1     2     N-----Z- +c
DEC $20      Zero Page      $C6   2     5     N-----Z-
DEC $20,X    Zero Page,X    $D6   2     6     N-----Z-
DEC $8080    Absolute       $CE   3     6     N-----Z-
DEC $8080,X  Absolute,X     $DE   3     7     N-----Z-
DEX          Implied        $CA   1     2     N-----Z-
DEY          Implied        $88   1     2     N-----Z-
```

Decrement value by one: this subtracts 1 from memory or the designated register, leaving the new value in its place.

`DEC` with an operand operates on memory.

`DEX` operates on the X register
`DEY` operates on the Y register
`DEC A` or `DEC` operates on the Accumulator.

- Sets N (Negative) flag if the two's compliment value is negative
- Sets Z (Zero) flag is the value is zero

+c: New for the 65C02

16-bit DEC Example

You can peform a 16-bit DEC by chaining two DECs together, testing the low byte before decrementing the high byte:

```
;16 bit decrement
      LDA Num_Low
      BNE skip
      DEC Num_High
skip: DEC Num_Low
```

[Opcodes] | [By Name] | [By Category]

EOR

Exclusive OR

```
SYNTAX       MODE           HEX  LEN  CYCLES  FLAGS
EOR #$20     Immediate      $49   2     2     N-----Z-
EOR $20      Zero Page      $45   2     3     N-----Z-
EOR $20,X    Zero Page,X    $55   2     4     N-----Z-
EOR $8080    Absolute       $4D   3     4     N-----Z-
EOR $8080,X  Absolute,X     $5D   3     4+    N-----Z- +p
EOR $8080,Y  Absolute,Y     $59   3     4+    N-----Z- +p
EOR ($20,X)  Indirect,X     $41   2     6     N-----Z-
EOR ($20),Y  Indirect,Y     $51   2     5+    N-----Z- +p
EOR ($20)    ZP Indirect    $52   2     5     N-----Z- +c
```

Perform an exclusive OR of the given value in A (the accumulator), storing the result in A.

The exclusive OR version of ORA .

- Sets N (Negative) flag if the two's compliment value is negative
- Sets Z (Zero) flag is the value is zero

Exclusive OR returns a 1 bit for each bit that is different in the values tested. It returns a 0 for each bit that is the same.

`EOR #$00` has no effect on A, but still sets the Z and N flags.
`EOR #$FF` inverts the bits in A.

M	A	Result
0	0	0
0	1	1
1	0	1
1	1	0

Other Boolean Instructions:
ORA bitwise OR
AND bitwise AND

+p: Add 1 cycle if a page boundary is crossed when forming address.
+c: New for the 65C02

[Opcodes] | [By Name] | [By Category]

INC

Increment Value

```
SYNTAX       MODE           HEX  LEN  CYCLES  FLAGS
INC A        Accumulator    $1A   1     2     N-----Z- +c
INC $20      Zero Page      $E6   2     5     N-----Z-
INC $20,X    Zero Page,X    $F6   2     6     N-----Z-
INC $8080    Absolute       $EE   3     6     N-----Z-
```

```
INC $8080,X  Absolute,X     $FE   3     6/7   N-----Z-
INX          Implied        $E8   1     2     N-----Z-
INY          Implied        $C8   1     2     N-----Z-
```

Increment by one: this adds 1 to memory or the designated register, leaving the new value in its place.

- Sets N (Negative) flag if the two's compliment value is negative
- Sets Z (Zero) flag is the value is zero

`INC oper` operates on memory.
`INX` operates on the X register.
`INY` operates on the Y register.
`INC A` or `INC` with no operand operates on the Accumulator.

+c: New for the 65C02

16-bit INC Example

You can peform a 16-bit INC by chaining two INCs together, testing the low byte after incrementing it.

```
;16 bit increment
        INC Addr_Low
        BNE skip
        INC Addr_High
skip:   ...
```

[Opcodes] | [By Name] | [By Category]

JMP

Jump to new address

```
SYNTAX       MODE           HEX  LEN  CYCLES  FLAGS
JMP $8080    Absolute       $4C   3     3     --------
JMP ($8080)  Indirect       $6C   3     5     --------
JMP $8080,X  Absolute,X     $7C   3     6     -------- +c
```

Jump to specified memory location and begin execution from this point.

Note for indirect jumps: The CPU does not correctly retrieve the second byte of the pointer from the next page, so you should never use a pointer address on the last byte of a page. ie: $12FF. *[Issue is fixed on 65C02]*

+c: New for the 65C02

(Absolute,X) and Jump Tables

(Absolute,X) is an additional mode for the 65C02 and is commonly used for implementing jump tables.

So we might have something like:

```
important_jump_table:
  .word routine1
  .word routine2
...

LDX #$02     ; table index * 2
JMP (important_jump_table,x)
```

The above would jump to the address of `routine2`, and is much faster than the old 6502 method of pushing the two bytes onto the stack and performing an RTS.

[Opcodes] | [By Name] | [By Category]

JSR

Jump to Subroutine

```
SYNTAX       MODE           HEX  LEN  CYCLES  FLAGS
JSR $8080    Absolute       $20   3     6     --------
```

Stores the address of the Program Counter to the stack.
Jump to specified memory location and begin execution from this point.

This is used to run subroutines in user programs, as well as running KERNAL routines. RTS is used at the end of the routine to return to the instruction immediately after the JSR.

Be careful to always match JSR and RTS, as imbalanced JSR/RTS operations will either overflow or underflow the stack.

[Opcodes] | [By Name] | [By Category]

LDA

Read memory to Accumulator

```
SYNTAX       MODE           HEX  LEN  CYCLES  FLAGS
LDA #$20     Immediate      $A9   2     2     N-----Z-
LDA $20      Zero Page      $A5   2     3     N-----Z-
LDA $20,X    Zero Page,X    $B5   2     4     N-----Z-
LDA $8080    Absolute       $AD   3     4     N-----Z-
LDA $8080,X  Absolute,X     $BD   3     4+    N-----Z- +p
LDA $8080,Y  Absolute,Y     $B9   3     4+    N-----Z- +p
LDA ($20,X)  Indirect,X     $A1   2     6     N-----Z-
LDA ($20),Y  Indirect,Y     $B1   2     5+    N-----Z- +p
LDA ($20)    ZP Indirect    $B2   2     5     N-----Z- +c
```

Place the given value from memory into the accumulator (A).

- Sets N (Negative) flag if the two's compliment value is negative
- Sets Z (Zero) flag is the value is zero

+p: Add 1 cycle if a page boundary is crossed when forming address.
+c: New for the 65C02

[Opcodes] | [By Name] | [By Category]

LDX

Read memory to X Index Register

```
SYNTAX       MODE           HEX  LEN  CYCLES  FLAGS
LDX #$20     Immediate      $A2   2     2     N-----Z-
LDX $20      Zero Page      $A6   2     3     N-----Z-
LDX $20,Y    Zero Page,Y    $B6   2     4     N-----Z-
LDX $8080    Absolute       $AE   3     4     N-----Z-
LDX $8080,Y  Absolute,Y     $BE   3     4+    N-----Z- +p
```

Place the given value from memory into the X register.

- Sets N (Negative) flag if the two's compliment value is negative
- Sets Z (Zero) flag is the value is zero

+p: Add 1 cycle if a page boundary is crossed when forming address.

[Opcodes] | [By Name] | [By Category]

LDY

Read memory to Y Index Register

```
SYNTAX       MODE           HEX  LEN  CYCLES  FLAGS
LDY #$20     Immediate      $A0   2     2     N-----Z-
LDY $20      Zero Page      $A4   2     3     N-----Z-
```

```
LDY $20,X    Zero Page,X    $B4   2     4     N-----Z-
LDY $8080    Absolute       $AC   3     4     N-----Z-
LDY $8080,X  Absolute,X     $BC   3     4+    N-----Z- +p
```

Place the given value from memory into the Y register.

- Sets N (Negative) flag if the two's compliment value is negative
- Sets Z (Zero) flag is the value is zero

+p: Add 1 cycle if a page boundary is crossed when forming address.

[Opcodes] | [By Name] | [By Category]

LSR

Logical Shift Right

```
SYNTAX       MODE           HEX  LEN  CYCLES  FLAGS
LSR A        Accumulator    $4A   1     2     N-----Z-
LSR $20      Zero Page      $46   2     5     N-----Z-
LSR $20,X    Zero Page,X    $56   2     6     N-----Z-
LSR $8080    Absolute       $4E   3     6     N-----Z-
LSR $8080,X  Absolute,X     $5E   3    6/7    N-----Z-
```

Shifts all bits to the right by one position.

Bit 0 is shifted into Carry.
0 shifted into bit 7.

Similar instructions:
ASL is the opposite instruction, shifting to the left.
ROR rotates bit 0 through Carry to bit 7.

[Opcodes] | [By Name] | [By Category]

NOP

No Operation

```
SYNTAX       MODE           HEX  LEN  CYCLES  FLAGS
NOP          Implied        $EA   1     2     --------
```

NOP simply does nothing for 2 clock cycles. No registers are affected, and no memory reads or writes occur. This can be used to delay the clock by 2 ticks.

It's also a useful way to blank out unwanted instructions in memory or in a machine language program on disk. By changing the byte values of the opcode and operands to $EA, you can effectively cancel out an instruction.

It is also useful for adding small delays to your code. For instance, to add a bit of delay when writing to the YM2151 chip (see Chapter 11 - YM Write Procedure).

[Opcodes] | [By Name] | [By Category]

ORA

Logical OR

```
SYNTAX       MODE           HEX  LEN  CYCLES  FLAGS
ORA #$20     Immediate      $09   2     2     N-----Z-
ORA $20      Zero Page      $05   2     3     N-----Z-
ORA $20,X    Zero Page,X    $15   2     4     N-----Z-
ORA $8080    Absolute       $0D   3     4     N-----Z-
ORA $8080,X  Absolute,X     $1D   3     4+    N-----Z- +p
ORA $8080,Y  Absolute,Y     $19   3     4+    N-----Z- +p
ORA ($20,X)  Indirect,X     $01   2     6     N-----Z-
```

```
ORA ($20),Y  Indirect,Y     $11   2     5+    N-----Z- +p
ORA ($20)    ZP Indirect    $12   2     5     N-----Z- +c
```

Perform a logical OR of the given value in A (the Accumulator), storing the result in A.

- Sets N (Negative) flag if the two's compliment value is negative
- Sets Z (Zero) flag is the value is zero

`OR #$00` has no effect on A, but still sets the Z and N flags.
`OR #$FF` results in $FF.

M	A	Result
0	0	0
0	1	1
1	0	1
1	1	1

Other Boolean Instructions:
EOR exclusive-OR
AND bitwise AND

+p: Add 1 cycle if a page boundary is crossed when forming address.
+c: New for the 65C02

[Opcodes] | [By Name] | [By Category]

PHA

Push to stack

```
SYNTAX       MODE           HEX  LEN  CYCLES  FLAGS
PHA          Implied        $48   1     3     --------
PHP          Implied        $08   1     3     --------
PHX          Implied        $DA   1     3     -------- +c
PHY          Implied        $5A   1     3     -------- +c
```

Pushes a register to the stack.

This instruction copies the value in the affected register to the address of the stack pointer, then moves the stack pointer downward by one byte.

Be careful to match Push and Pull operations so that you don't accidentally overflow or underflow the stack.

PHP pushes the Flags, also called P for Program Status Register.

The corresponding "Pull" instructions are PLA , PHP , PHX , and PHY .

+c: New for the 65C02

[Opcodes] | [By Name] | [By Category]

PLA

Pull from stack

```
SYNTAX       MODE           HEX  LEN  CYCLES  FLAGS
PLA          Implied        $68   1     4     N-----Z-
PLP          Implied        $28   1     4     NV--DIZC
PLX          Implied        $FA   1     4     N-----Z- +c
PLY          Implied        $7A   1     4     N-----Z- +c
```

Pulls a value from the stack into a register.

This instruction moves the stack pointer up by one byte, then copies the value from the address of the stack pointer to the affected register.

Be careful to match Push and Pull operations so that you don't accidentally overflow or underflow the stack.

PLP pulls the Flags, also called P for Program Status Register.

Use TXS or TSX to directly manage the stack pointer.

The corresponding "Push" instructions are PHA , PHP , PHX , and PHY .

+c: New for the 65C02

[Opcodes] | [By Name] | [By Category]

RMBx

Memory Bit Operations

SYNTAX	MODE	HEX	LEN	CYCLES	FLAGS
RMB0 $20	Zero Page	$07	2	5	-------- +c -816
RMB1 $20	Zero Page	$17	2	5	-------- +c -816
RMB2 $20	Zero Page	$27	2	5	-------- +c -816
RMB3 $20	Zero Page	$37	2	5	-------- +c -816
RMB4 $20	Zero Page	$47	2	5	-------- +c -816
RMB5 $20	Zero Page	$57	2	5	-------- +c -816
RMB6 $20	Zero Page	$67	2	5	-------- +c -816
RMB7 $20	Zero Page	$77	2	5	-------- +c -816

Set bit x to 0 at the given zero page address where x is the number of the specified bit (0-7).

Often used in conjunction with BBR and BBS .

+c: New for the 65C02 -816: *Not available* on the 65C816

[Opcodes] | [By Name] | [By Category]

ROL

Rotate Left

SYNTAX	MODE	HEX	LEN	CYCLES	FLAGS
ROL A	Accumulator	$2A	1	2	N-----ZC
ROL $20	Zero Page	$26	2	5	N-----ZC
ROL $20,X	Zero Page,X	$36	2	6	N-----ZC
ROL $8080	Absolute	$2E	3	6	N-----ZC
ROL $8080,X	Absolute,X	$3E	3	6/7	N-----ZC +p

Rotate all bits to the left one position. The value in the carry (C) flag is shifted into bit 0 and the original bit 7 is shifted into the carry (C).

ASL shifts left, moving 0 into bit 0
ROR rotates to the right.

+p: Add 1 cycle if a page boundary is crossed when forming address.

[Opcodes] | [By Name] | [By Category]

ROR

Rotate Right

SYNTAX	MODE	HEX	LEN	CYCLES	FLAGS
ROR A	Accumulator	$6A	1	2	N-----ZC
ROR $20	Zero Page	$66	2	5	N-----ZC
ROR $20,X	Zero Page,X	$76	2	6	N-----ZC
ROR $8080	Absolute	$7E	3	6	N-----ZC
ROR $8080,X	Absolute,X	$6E	3	6/7	N-----ZC +p

Rotate all bits to the right one position. The value in the carry (C) flag is shifted into bit 7 and the original bit 0 is shifted into the carry (C).

LSR shifts right, placing 0 into bit 7.
ROL rotates to the left.

+p: Add 1 cycle if a page boundary is crossed when forming address.

[Opcodes] | [By Name] | [By Category]

RTI

Return from Interrupt

```
SYNTAX       MODE           HEX  LEN  CYCLES  FLAGS
RTI          Implied        $40   1     6     --------
```

Return from an interrupt by popping three values off the stack. The first is for the status register (P) followed by the two bytes of the program counter.

Note that unlike RTS, the popped address is the actual return address (rather than address-1).

[Opcodes] | [By Name] | [By Category]

RTS

Return from Subroutine

```
SYNTAX       MODE           HEX  LEN  CYCLES  FLAGS
RTS          Implied        $60   1     6     --------
```

Typically used at the end of a subroutine. It jumps back to the address after the JSR that called it by popping the top 2 bytes off the stack and transferring control to that address +1.

[Opcodes] | [By Name] | [By Category]

SBC

Subtract With Carry

```
SYNTAX       MODE           HEX  LEN  CYCLES  FLAGS
SBC #$20     Immediate      $E9   2     2     NV----ZC
SBC $20      Zero Page      $E5   2     3     NV----ZC
SBC $20,X    Zero Page,X    $F5   2     4     NV----ZC
SBC $8080    Absolute       $ED   3     4     NV----ZC
SBC $8080,X  Absolute,X     $FD   3     4+    NV----ZC +p
SBC $8080,Y  Absolute,Y     $F9   3     4+    NV----ZC +p
SBC ($20,X)  Indirect,X     $E1   2     6     NV----ZC
SBC ($20),Y  Indirect,Y     $F1   2     5+    NV----ZC +p
SBC ($20)    ZP Indirect    $F2   2     5     NV----ZC +c
```

Subtract the operand from A and places the result in A.

When Carry is 0, an additional 1 is subtracted.

There is no "Subtract without carry". To do that, use SEC first to set the Carry flag.

If D=1, subtraction is Binary Coded Decimal. If D=0 then subtraction is binary.

C is clear when result is less than 0. (ie: Borrow took place)
Z is set when result is zero
V is set when signed result goes below -128 or above 127.
N is set when result is negative (bit 7=1)

+p: Add 1 cycle if a page boundary is crossed when forming address.
+c: New for the 65C02

[Opcodes] | [By Name] | [By Category]

SEC

Set Carry

```
SYNTAX       MODE           HEX  LEN  CYCLES  FLAGS
SEC          Implied        $38   1     2     -------C
```

Sets the Carry flag. This is used before SBC to prevent an extra subtract. C is also often used in KERNAL routines to alter the operation of the routine or return certain information.

[Opcodes] | [By Name] | [By Category]

SED

Set Decimal

```
SYNTAX       MODE           HEX  LEN  CYCLES  FLAGS
SED          Implied        $F8   1     2     ----D---
```

Sets the Decimal flag. This will put the CPU in BCD mode, which affects the behavior of ADC and SBC.

In binary mode, adding 1 to $09 will set the Accumulator to $0F.
In BCD mode, adding 1 to $09 will set the Accumulator to $10.

Using BCD allows for easier conversion of binary numbers to decimal. BCD also allows for storing decimal numbers without loss of precision due to power-of-2 rounding.

[Opcodes] | [By Name] | [By Category]

SEI

Set Interrupt Disable

```
SYNTAX       MODE           HEX  LEN  CYCLES  FLAGS
SEI          Implied        $78   1     2     -----I--
```

Sets or clears the Interrupt Disable flag. When I is set, the CPU will not execute IRQ interrupts, even if the line is asserted. Use CLI to re-enable interrupts.

[Opcodes] | [By Name] | [By Category]

SMBx

Set Memory Bit

```
SYNTAX       MODE           HEX  LEN  CYCLES  FLAGS
SMB0 $20     Zero Page      $87   2     5     -------- +c -816
SMB1 $20     Zero Page      $97   2     5     -------- +c -816
SMB2 $20     Zero Page      $A7   2     5     -------- +c -816
SMB3 $20     Zero Page      $B7   2     5     -------- +c -816
SMB4 $20     Zero Page      $C7   2     5     -------- +c -816
SMB5 $20     Zero Page      $D7   2     5     -------- +c -816
SMB6 $20     Zero Page      $E7   2     5     -------- +c -816
SMB7 $20     Zero Page      $F7   2     5     -------- +c -816
```

Set bit x to 1 at the given zero page address where x is the number of the specific bit (0-7).

Often used in conjunction with BBR and BBS .

Specific to the 65C02 (*unavailable on the 65C816*)

+c: New for the 65C02 -816: *Not available* on the 65C816

[Opcodes] | [By Name] | [By Category]

STA

Store Accumulator contents to memory

```
SYNTAX       MODE           HEX  LEN  CYCLES  FLAGS
STA $20      Zero Page      $85   2     3     --------
STA $20,X    Zero Page,X    $95   2     4     --------
STA $8080    Absolute       $8D   3     4     --------
STA $8080,X  Absolute,X     $9D   3     5+    -------- +p
STA $8080,Y  Absolute,Y     $99   3     5+    -------- +p
STA ($20,X)  Indirect,X     $81   2     6     --------
STA ($20),Y  Indirect,Y     $91   2     6+    -------- +p
STA ($20)    ZP Indirect    $92   2     5     -------- +c
```

Place the given value from the accumulator (A) into memory.

+p: Add 1 cycle if a page boundary is crossed when forming address.
+c: New for the 65C02

[Opcodes] | [By Name] | [By Category]

STP

Stop

```
SYNTAX       MODE           HEX  LEN  CYCLES  FLAGS
STP          Implied        $DB   1     3     -------- +c
```

Stops (or halts) the processor and places it in a lower power state until a hardware reset occurs. For the X16 emulator, when the debugger is enabled using the `-debug` command-line parameter, the STP instruction will break into the debugger automatically.

If debugging is not enabled, the emulator will prompt the user to close the emulator or reset the emulation.

+c: New for the 65C02

[Opcodes] | [By Name] | [By Category]

STX

Save X Index Register contents to memory

```
SYNTAX       MODE           HEX  LEN  CYCLES  FLAGS
STX $20      Zero Page      $86   2     3     --------
STX $20,Y    Zero Page,Y    $96   2     4     --------
STX $8080    Absolute       $8E   3     4     --------
```

[Opcodes] | [By Name] | [By Category]

STY

Save Y Index Register contents to memory

```
SYNTAX       MODE           HEX  LEN  CYCLES  FLAGS
STY $20      Zero Page      $84   2     3     --------
STY $20,X    Zero Page,X    $94   2     4     --------
STY $8080    Absolute       $8C   3     4     --------
```

[Opcodes] | [By Name] | [By Category]

STZ

Set memory to zero

```
SYNTAX       MODE           HEX  LEN  CYCLES  FLAGS
STZ $20      Zero Page      $64   2     3     -------- +c
STZ $20,X    Zero Page,X    $74   2     4     -------- +c
STZ $8080    Absolute       $9C   3     4     -------- +c
STZ $8080,X  Absolute,X     $9E   3     5     -------- +c
```

+c: New for the 65C02

[Opcodes] | [By Name] | [By Category]

TRB

Test and reset bit

```
SYNTAX       MODE           HEX  LEN  CYCLES  FLAGS
TRB $20      Zero Page      $14   2     5     ------Z- +c
TRB $8080    Absolute       $1C   3     5     ------Z- +c
```

Effectively an inverted AND between memory and the Accumulator. The bits that are 1 in the Accumulator are set to 0 in memory.

- Sets Z (Zero) flag if all bits from the AND are zero.

+c: New for the 65C02

TRB Example

```
          ; Assume location $20 has a value of $11.
LDA #$01  ; Load a bit mask of 0000 0001
TRB $20   ; Apply the mask and reset bit 0
          ; Location $20 now has a value of $10.
```

This is conceptually similar to

```
LDA #$01 ; We want to clear bit 1 of the data
EOR #$FF ; Invert the mask, so $01 becomes $FE (1111 1110)
AND $20  ; AND with memory, saving the result in .A
STA $20  ; Store it back to memory.
```

[Opcodes] | [By Name] | [By Category]

TSB

Test and set bit

```
SYNTAX       MODE           HEX  LEN  CYCLES  FLAGS
TSB $20      Zero Page      $04   2     5     ------Z- +c
TSB $8080    Absolute       $0C   3     5     ------Z- +c
```

Performs an OR with each bit in the accumulator and memory. Each bit that is 1 in the Accumulator is set to 1 in memory. This is similar to an ORA operation, execpt that the result is stored in memory, not in A.

The Z flag is set based on the final result of the operation, ie: the memory data is 0.

+c: New for the 65C02

[Opcodes] | [By Name] | [By Category]

Txx

Transfer between registers

```
SYNTAX       MODE           HEX  LEN  CYCLES  FLAGS
TAX          Implied        $AA   1     2     N-----Z- Copy from .A to .X
TXA          Implied        $8A   1     2     N-----Z- Copy from .X to .A
TAY          Implied        $A8   1     2     N-----Z- Copy from .A to .Y
TYA          Implied        $98   1     2     N-----Z- Copy from .Y to .A
TSX          Implied        $BA   1     2     N-----Z- Copy from Stack Pointer to .X
TXS          Implied        $9A   1     2     -------- Copy from .X to Stack Pointer
```

Copies data from one register to anohter.

TSX and TSX copy between the Stack Pointer and the X register. This is the only way to directly control the Stack Pointer. To initialize the Stack Pointer to a specific address, you can use the following instructions.

```
LDX #$FF
TXS
```

[Opcodes] | [By Name] | [By Category]

WAI

Wait

```
SYNTAX       MODE           HEX  LEN  CYCLES  FLAGS
WAI          Implied        $CB   1     3     -------- +c
```

Effectively stops the processor until a hardware interrupt occurs. The intterupt is processed immediately, and execution resumes in the Interrupt handler.

NMI, IRQ, and RST (Reset) will recover from the WAI condition.

Normally, an instruction completes its operation before actually handling an interrupt. But if WAI has executed, the CPU does not need to defer the interrupt, and so the interrupt can be handled immediately.

+c: New for the 65C02

[Opcodes] | [By Name] | [By Category]

Status Flags

Flags are stored in the P register. PHP and PLP can be used to directly manipulate this register. Otherwise the flags are used to indicate certain statuses and changed by various instructions.

P-Register:

`NV1B DIZC`

N = Negative
V = oVerflow
1 = Always 1
B = Interrupt Flag
D = Decimal Mode
I = Interupts Disabled
Z = Zero
C = Carry

Replacement Macros for Bit Instructions

Since `BBRx` , `BBSx` , `RMBx` , and `SMBx` should not be used, to maintain compatibility with the 65C816, here are some example macros that can be used to help convert existing software that may have been using these instructions:

```
.macro bbs bit_position, data, destination
 .if (bit_position = 7)
  bit data
```

```
   bmi destination
  .else
   .if (bit_position = 6)
    bit data
    bvs destination
   .else
    lda data
    and #1 << bit_position
    bne destination
   .endif
   .endif
.endmacro

.macro bbr bit_position, data, destination
 .if (bit_position = 7)
  bit data
  bpl destination
 .else
  .if (bit_position = 6)
   bit data
   bvc destination
  .else
   lda data
   and #1 << bit_position
   beq destination
  .endif
 .endif
.endmacro

.macro rmb bit, destination
 lda #$1 << bit
 trb destination
.endmacro

.macro smb bit, destination
 lda #$1 << bit
 tsb destination
.endmacro
```

The above is CA65 specific but the code should work similarly for other languages. The logic can also be used to if using an assembly language tool that does not have macro support with small changes.

Further Reading

- http://www.6502.org/tutorials/6502opcodes.html
- http://6502.org/tutorials/65c02opcodes.html
- https://www.pagetable.com/c64ref/6502/?cpu=65c02
- http://www.oxyron.de/html/opcodesc02.html
- https://www.nesdev.org/wiki/Status_flags
- https://skilldrick.github.io/easy6502/
- https://www.westerndesigncenter.com/wdc/documentation/w65c02s.pdf
- https://www.westerndesigncenter.com/wdc/documentation/w65c816s.pdf

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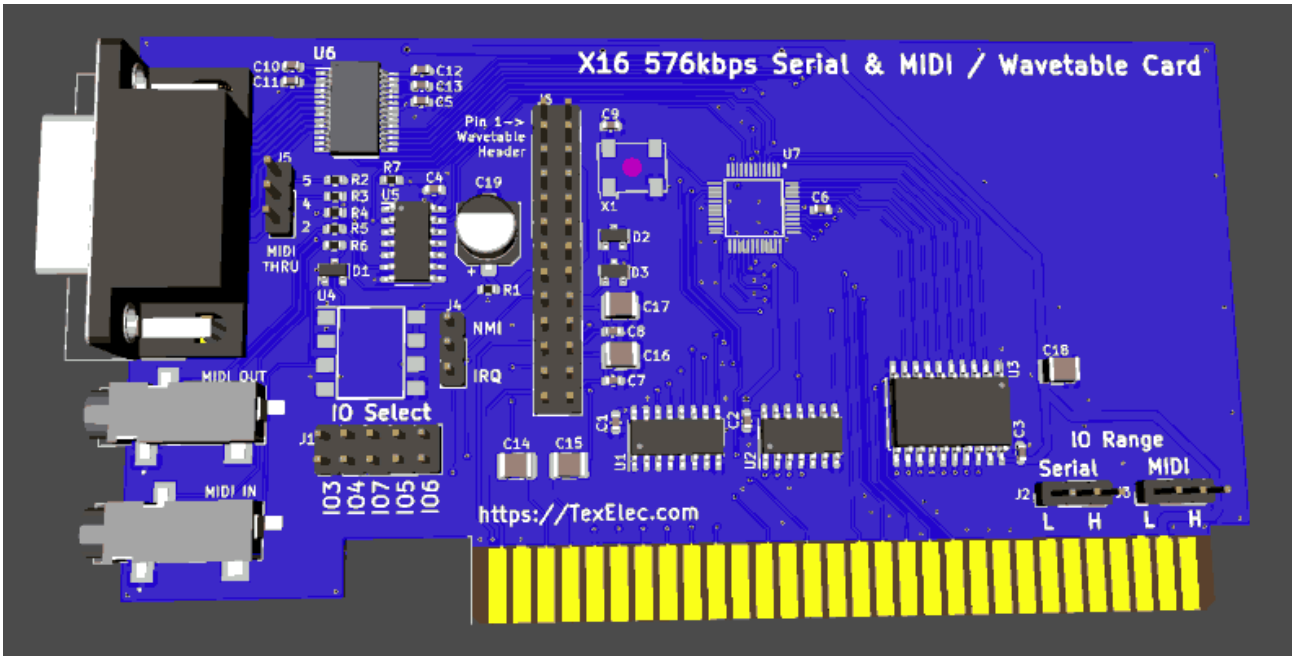
Appendix D: Official Expansion Cards

This is just a stub as a proposal for how to document official expansion cards (namely those made by the core X16 team).

Serial/MIDI UART/Wavetable Expansion Card

Kevin is desinging an EIA compliant UART expansion card which is capable of supporting standard serial as well as MIDI and even has a header to install wavetable cards. It uses the Texas Instruments TL16C2550 .



As the card is still in development there are not any demos or code examples available, though the datasheet contains informaiton on how to set things up (see below). Kevin also provied some information on how to setup the card in his original announcement on the community Discord.

Appendix E: Diagnostic Bank

The Diagnostic ROM bank can run a full diagnostic on the system memory (base + 512K-2048K extended) of the Commander X16.

Index

Running Diagnostics

Functional system

The memory diagnostics can be started in two different ways. If the system is functional enough to actually boot into BASIC, the diagnostics can be started from there with the following:

```
BANK 0,7: SYS $C000
```

It is also possible to jump directly to the diagnostic ROM bank from assembly.

```
    lda #$07    ; ROM bank 7 is the diagnostic bank
    sta $01     ; Write ROM bank to ROM bank registers
    jmp $C000   ; Jump to beginning of diagnostic ROM
```

NOTE: The Diagnostic ROM is not able to return to BASIC or any program that has called. The only way to exit the Diagnostic ROM is by resetting or powercycling the system.

Non functional system

If the Commander X16 is not able to boot into BASIC, the memory diagnostics can be started by keeping the power button pressed for about a second when powering on the system.
This will make the Commander X16 boot directly into the diagnostic ROM bank and start the memory diagnostics.

Progress indicators

Without screen

When the diagnostic ROM bank starts, it will use the activity LED to indicate the progress.

- ON - while zero-page memory is tested (very brief)
- OFF - for 1st test of base memory ($0100-$9EFF)
- ON - for 2nd test of base memory ($0100-$9EFF)
- OFF - for 3rd test of base memory ($0100-$9EFF)
- ON - for 4th test of base memory ($0100-$9EFF)

After the inital test of base memory, the number of available memory banks is tested, VERA is initialized and both the activity LED and the keyboard LEDs are used to indicate the progress.
The keyboard LEDs are used as a binary counter:

Num	Binary	Num Lock	Caps Lock	Scroll Lock
0	000	0	0	0
1	001	0	0	1
2	010	0	1	0

3	011	0	1	1
4	100	1	0	0
5	101	1	0	1
6	110	1	1	0
7	111	1	1	1

Main test loop

During the first test iteration, the keyboard LEDs will display 0 0 1
When the test is done, the activity light will blink once.
During the second test iteration, the keyboard LEDS will display 0 1 0
When the test is done, the activity light will blink once.
During the third test iteration, the keyboard LEDs will display 0 1 1
When the test is done, the activity light will blink once.
During the fourth test iteration, the keyboard LEDs will display 1 0 0
When the test is done, the activity light will blink once.

As the last part of the test loop, the base memory is tested. Keyboard LEDs will show 1 0 1
When the test loop is done, keyboard LEDs will show 1 1 1 and the activity LED will blink 3 times before starting over.

With screen

When the base memory has been tested the first time, VERA is initialized with output to VGA.
On the screen there is detailed information about the progress of each test iteration.
Each time through the main test loop, the output of VERA will be switched between VGA and Composite/S-Video.

Error communication

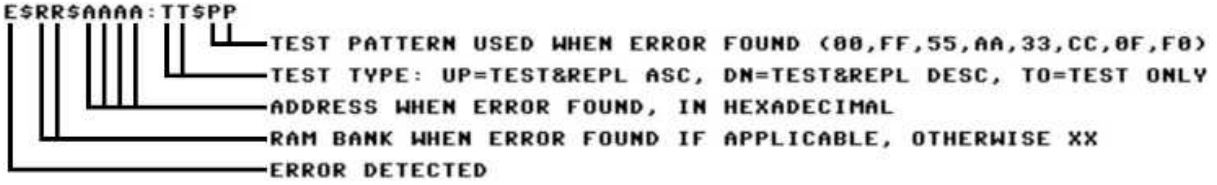
If an error is detected before VERA is initialized, the error will be reported with the activity LED by blinking every half second 3 times, staying off for 1 second and repeating. - All tests stop.

This means that if an error occurs before VERA is initialized, you have no way of figuring out exactly where the error is, but you do know that the error has happened in base memory.

When the initial test of base memory has succeeded and VERA is initialized, any errors will be reported to the display. Only if more than 32 errors are encountered, will the tests stop and the activity LED will flash the same way as when an error is encountered before VERA initialization.

Even when tests are stopped, VERA output will still be switched between VGA and Composite/S-Video about every minute.

The errorcodes on screen are as follows:



Test algorithm

Theory

RAM diagnostics are performed with the March C- algorithm. This algorithm should be fairly godd at finding most common memory errors.

In short, he aslgorithm is described as follows:

1. Write 0 to all memory cells
2. For each cell, check that it contains 0 and write 1 in ascending order
3. For each cell, check that it contains 1 and write 0 in ascending order
4. For each cell, check that it contains 0 and write 1 in descending order
5. For each cell, check that it contains 1 and write 0 in descending order

6. Check that all cells contain 0

On the Commander X16 and most other 6502 based computers, above algorithm would take a very long time to complete. For this reason, the algorithm has been modified slightly to write and compare entire bytes instead of single bits. To catch most memory errors, the following bit patterns are tested:

- 0000 0000
- 0101 0101
- 0011 0011
- 0000 1111

The algorithm is then implemented in the following way:

1. Write pattern to all memory addresses
2. For each addres, check the patterna and write the inverted patterin in ascending order
3. For each address, check the inverted pattern and write the original pattern in ascending order
4. For each address, check the original pattern and write the inverted pattern in descending order
5. For eac address, check the inverted pattern and write the original pattern in descending order
6. Check all addresses contain the original pattern

Implementation

When memory test starts, the first thing that happens is that zero-page is tested by it self. If this test passes, the rest of base memory is tested from $0100-$9EFF while ensuring that these tests do not affect zero-page memory.

When basememory has passed the initial test, zero-page is used for variables and stack pointer is initialized to enable pushing and popping of registers and function calls.
VERA is initialized and the number of memory banks is tested.

All available memory banks are tested together as opposed to checking and clearing a single memory page at a time.
When all memory banks have been tested, the base memory $0200-$9EFF is tested again.

Memory banks and base memory is tested in continous loop.

If an error is detected, this is either communicated through the activity LED, if VERA has not yet been initialized, or by writing information about the error on the display.

Appendix F: The 65C816 Processor

Table Of Contents

Overview

This document is a brief introduction and quick reference for the 65C816 Microprocessor. For more details, see the 65C816 data sheet or Programming the 65816: Including the 6502, 65C02, and 65802 .

The WDC65C816 CPU is an 8/16 bit CPU and a follow-up to the 65C02 processor. The familiar 65C02 instructions and address modes are retained, and some new ones are added.

The CPU can optionally operate in 16-bit mode, extending the utility of math instruction (16-bit adds!) and the coverage of .X and .Y indexed modes to 64KB.

Zero Page has been renamed to Direct Page, and Direct Page can now be relocated anywhere in the first 64K of RAM. As a result, all of the Zero Page instructions are now "Direct" instructions and can operate anywhere in the X16's address range.

Likewise, the Stack can also be relocated, and the stack pointer is now 16 bits. This allows for a much larger stack, and the combination of stack and DP relocation offer interesting multitasking opportunities.

Compatibility with the 65C02

The 65C916 CPU is generally compatible with the 65C02 instruction set, with the exception of the `BBRx` , `BBSx` , `RMBx` , and `SMBx` instructions. We recommend programmers avoid these instructions when writing X16 softwware, using the more conventional Boolean logic instructions, instead.

Registers

Notation	Name	Description
A	Accumulator	The accumulator. It stores the result of moth math and logical operations.
X	X Index	.X is mostly used as a counter and to offset addresses with X indexed modes
Y	Y Index	.Y is mostly used as a counter and to offset addresses with Y indexed modes
S	Stack Pointer	SP points to the next open position on the stack.
DB or DBR	Data Bank	Data bank is the default bank for operations that use a 16 bit address.
K or PBR	Program Bank	The default address for 16 bit JMP and JSR oprerations. Can only be set with a 24 bit JMP or JSR.
P	Processor Status	The flags.
PC	Program Counter	The address of the current CPU instruction

.A, .X, and .Y can be 8 or 16 bits wide, based on the flag settings (see below).

The Stack Pointer (.S) is 16 bits wide in Native mode and 8 bits wide (and fixed to the $100-1FF range) in Emulation mode.

.DB and .K are the bank registers, allowing programs and data to occupy separate 64K banks on computers with more than 64K of RAM. (The X16 does not use the bank registers, instead using addresses $00 and $01 for banking.)

Status Flags

The native mode flags are as follows:

`nvmx dizc e`

n = Negative
v = oVerflow
m = Memory width (0=16 bit, 1=8 bit)
x = Index register width (0=16 bit, 1=8 bit)
d = Decimal Mode
i = Interupts Disabled
z = Zero
c = Carry
e = Emulation Mode (0=65C02 mode, 1=65C816 mode)

In emulation mode, the **m** and **x** flags are always set to 1.

Here are the 6502 and 65C02 registers, for comparison:

`nv1b dizc`

n = Negative
v = oVerflow
1 = this bit is always 1
b = brk: set during a BRK instruction interrupt
d = Decimal Mode
i = Interupts Disabled
z = Zero
c = Carry

Note the missing **b** flag on the 65C816. This is no longer needed in native mode, since the BRK instruction now has its own vector.

The **e** flag can only accessed via the XCE instruction, which swaps Carry and the Emulation flag.

The other flags can all be manipulated with SEP and REP, and the various branch instructions (BEQ, BCS, etc) test some of the flags. The rest can only be tested indirectly through the stack.

When a BRK or IRQ is triggered in *emulation* mode, a ghost **b** flag will be pushed to the stack instead of the **x** flag. This can be used to test for a BRK vs IRQ in the Interrupt handler.

16 bit mode

The 65C816 CPU boots up in emulation mode. This locks the register width to 8 bits and locks out certain operations.

If you want to use the '816 features, including 16-bit operation, you will need to enable *native* mode. Clearing **e** switches the CPU to native mode. However, it's not as simple as just setting a flag. The **e** flag can only be accessed through the XCE instruction, which swaps the Carry and Emulation flags.

To switch to native mode, use the following steps:

```
CLC  ; clear the Carry bit
XCE  ; swap the Emulation and Carry bit
```

To switch back to emulation mode, *set* the Carry flag and perform an XCE again.

```
SEC  ; Set Carry
XCE  ; and push the 1 into the Emulation flag.
```

Once **e** is cleared, the **m** and **x** flags can be set to 1 or 0 to control the register width.

When the **m** flag is *clear*, Accumulator operations and memory reads and writes will be 16-bit operations. The CPU reads two bytes at a time with LDA, writes two bytes at a time with STA, and all math involving .A is 16 bits wide.

Likewise, whenn **x** is clear, the .X and .Y index registers are 16 bits wide. INX and INY will now count up to 65535, and indexed instructions like `LDA addr,X` can now cover 64K.

You can use `REP #$10` to enable 16-bit index registers, and `REP #$20` to enable 16-bit memory and Accumulator. `SEP #$10` or `SEP #$20` will switch back to 8-bit operation. You can also combine the operand and use `SEP #$30` or `REP #$30` to flip both bits at once.

And now we reach the 16-bit assembly trap: the actual assembly opcodes are the same, regardless of the **x** and **m** flags. This means the assembler needs to track the state of these flags internally, so it can correctly write one or two bytes when assembling immediate mode

instructions like LDA #$01.

You can help the assembler out by using *hints*. Different assemblers have different hinting systems, so we will focus on 64TASS and cc65.

64TASS accepts `.as` (.A short) and `.al` (.A long) to tell the assembler to store 8 bits or 16 bits in an immediate mode operand. For LDX and LDY, use the `.xs` and `.xl` hints.

The hints for ca65 are `.a8`, `.a16`, `.i8`, and `.i16`

Note that this has no effect on *absolute* or *indirect* addressing modes, such as `LDA $1234` and `LDA ($1000)`, since the operand for these modes is always 16 bits.

To make it easy to remember the modes, just remember that **e**, **m**, and **x** all *emulate* 65C02 behavior when *set*.

Address Modes

The 65C816 now has 24 discinct address modes, although most are veriations on a theme. Make note of the new syntax for Stack relative instructions (,S), the use of brackets for [24 bit indirect] addressing, and the fact that Zero Page has been renamed to Direct Page. This means that $0001 and $01 are now two different addresses (although they would be the same if .DP is set to $00.

Mode	Syntax	Description
Immediate	#$12	Value is supplied in the program stream
Absolute	$1234	Data is at this address.
Absolute X Indexed	$1234,X	Address is offset by X. If X=2 this is $1236.
Absolute Y Indexed	$1234,Y	Address is offset by X. If Y=2 this is $1236.
Direct	$12	Direct Page address. Operand is 1 byte.
Direct X Indexed	$12,X	Address on Direct Page is offset by .X
Direct Y Indexed	$12,Y	Address on Direct Page is offset by .Y
Direct Indirect	($12)	Value at $12 is a 16-bit address.
Direct Indirect Y Indexed	($12),Y	Resolve pointer at $12 then offset by Y.
Direct X Indexed Indirect	($12,X)	Start at $12, offset by X, then read that address.
Direct Indirect Long	[$12]	24 bit pointer on Direct Page.
Direct Indrect Long Y Indexed	[$12],Y	Resolve address at $12, then offset by Y.
Indirect	($1234)	Read pointer at $1234 and get data from the resultant address
Indirect X Indexed	($1234,X)	Read pointer at $1234 offset by X, get data from resultant address
Indirect Long	[$1234]	Pointer is a 24-bit address.
Absolute Long	$123456	24 bit address.
Absolute Indexed Long	$123456,X	24 bit address, offset by X.
Stack Relative Indexed	$12,S	Stack relative.
Stack Relative Indirect Indexed	($12,S),Y	Resolve Pointer at $12, then offset by Y.
Accumulator (implied)		Operation acts on .A
Implied		Target is part of the opcode name.
Relative Address (8 bit signed)	$1234	Branches can only jump by -128 to 127 bytes.
16 bit relative address	$1234	BRL can jump by 32K bytes.
Block Move	#$12,#$34	Operands are the bank numbers for block move/copy.

Vectors

The 65816 has two different sets of interrupt vectors. In emulation mode, the vectors are the same as the 65C02. In native mode (.e = 0), the native vectors are used. This allows you to switch to the desired operation mode, based on the operating mode of your interrupt handlers.

The Commander X16 operates mostly in emulation mode, so native mode interrupts on the X16 will switch to emulation mode, then simply call the 8-bit interrupt handlers.

The vectors are:

Name	Emu	Native
COP	FFF4	00FFE4
BRK	FFFE	00FFE6
ABORT	FFF8	00FFE8
NMI	FFFA	00FFEA
RESET	FFFC	
IRQ	FFFE	00FFEE

The 65C02 shares the same interrupt for BRK and IRQ, and the **b** flag tells the interrupt handler whether to execute a break or interrupt.

In emulation mode, the 65C816 pushes a modified version of the flags to the stack. The BRK instruction actually pushes a 1 in bit 4, which can then be tested in the Interrupt Service Routine. In native mode, however, the flags are pushed verbatim, since BRK has its own handler.

There is also no native RESET vector, since the CPU always boots to emulation mode. The CPU always starts at the address stored in $FFFC.

Decimal Mode

When the **d** flag is set, the CPU operates in Decimal mode. In this mode, a byte is treated as two decimal digits, rather than a binary number. As a result, you can easily add, subtract, and display decimal numbers.

While in Decimal mode, the lower nibble of a byte contains the 1s digit, and the upper nibble contains the 10s digit. Each nibble can only contain value from 0-9, and addition will wrap from 9 to 0. Subtraction works similarly, wrapping down from 0 to 9.

SED enables Decimal mode. At that point, ADC and SBC will perform base-10 addition and subtraction. CLD clears Decimal mode and returns to binary mode.

When adding, the Carry bit will be set if the result is 100 or greater. The total result can never exceed 199, so two digits plus Carry is all that is needed to represent values from 0 to 199.

If you perform an ADC with the Carry bit set, this will add an extra 1 to the result.

Examples

Operation	.A	Result	Notes
ADC #$01	$09	$10	
ADC #$01	$99	$00	Carry is set, indicating 100.

When subtracting, the Carry bit operates as a *borrow* bit, and the sense is inverted: 0 indicates a borrow took place, and 1 means it did not.

Operation	.A	Result	Notes
SBC #$01	$10	$09	Carry is set, indicating no borrow.
SBC #$01	$00	$99	Carry is clear, indicating a borrow.

In the second example ($00 - $01), the final result was $99 with a borrow.

Note that the **n** flag tracks the high bit, but two's complement doesn't work as expected in Decimal mode. Instead, we have to use *Ten's complement*.

Simply put, $00 - $01 gives you $99. So when working in signed BCD, any value where the high digit is 5-9 is actually a negative value. To convert negative values to positive values for printing, you would subtract from 99 and add 1.

For example: the integer -49 is $51 in BCD. `99 - 51 + 1 = 49`. You'd print that as `-49`.

Instruction Tables

Instructions By Opcode

	x0	x1	x2	x3	x4	x5	x6	x7	x8	x9	xA	xB	xC	xD	xE	xF
0x	BRK	ORA	COP	ORA	TSB	ORA	ASL	ORA	PHP	ORA	ASL	PHD	TSB	ORA	ASL	ORA
1x	BPL	ORA	ORA	ORA	TRB	ORA	ASL	ORA	CLC	ORA	INC	TCS	TRB	ORA	ASL	ORA
2x	JSR	AND	JSL	AND	BIT	AND	ROL	AND	PLP	AND	ROL	PLD	BIT	AND	ROL	AND
3x	BMI	AND	AND	AND	BIT	AND	ROL	AND	SEC	AND	DEC	TSC	BIT	AND	ROL	AND
4x	RTI	EOR	WDM	EOR	MVP	EOR	LSR	EOR	PHA	EOR	LSR	PHK	JMP	EOR	LSR	EOR
5x	BVC	EOR	EOR	EOR	MVN	EOR	LSR	EOR	CLI	EOR	PHY	TCD	JML	EOR	LSR	EOR
6x	RTS	ADC	PER	ADC	STZ	ADC	ROR	ADC	PLA	ADC	ROR	RTL	JMP	ADC	ROR	ADC
7x	BVS	ADC	ADC	ADC	STZ	ADC	ROR	ADC	SEI	ADC	PLY	TDC	JMP	ADC	ROR	ADC
8x	BRA	STA	BRL	STA	STY	STA	STX	STA	DEY	BIT	TXA	PHB	STY	STA	STX	STA
9x	BCC	STA	STA	STA	STY	STA	STX	STA	TYA	STA	TXS	TXY	STZ	STA	STZ	STA
Ax	LDY	LDA	LDX	LDA	LDY	LDA	LDX	LDA	TAY	LDA	TAX	PLB	LDY	LDA	LDX	LDA
Bx	BCS	LDA	LDA	LDA	LDY	LDA	LDX	LDA	CLV	LDA	TSX	TYX	LDY	LDA	LDX	LDA
Cx	CPY	CMP	REP	CMP	CPY	CMP	DEC	CMP	INY	CMP	DEX	WAI	CPY	CMP	DEC	CMP
Dx	BNE	CMP	CMP	CMP	PEI	CMP	DEC	CMP	CLD	CMP	PHX	STP	JML	CMP	DEC	CMP
Ex	CPX	SBC	SEP	SBC	CPX	SBC	INC	SBC	INX	SBC	NOP	XBA	CPX	SBC	INC	SBC
Fx	BEQ	SBC	SBC	SBC	PEA	SBC	INC	SBC	SED	SBC	PLX	XCE	JSR	SBC	INC	SBC

Instructions By Name

ADC	AND	ASL	BCC	BCS	BEQ	BIT	BMI	BNE	BPL
BRA	BRK	BRL	BVC	BVS	CLC	CLD	CLI	CLV	CMP
COP	CPX	CPY	DEC	DEX	DEY	EOR	INC	INX	INY
JMP	JML	JSL	JSR	LDA	LDX	LDY	LSR	MVN	MVP
NOP	ORA	PEA	PEI	PER	PHA	PHB	PHD	PHK	PHP
PHX	PHY	PLA	PLB	PLD	PLP	PLX	PLY	REP	ROL
ROR	RTI	RTL	RTS	SBC	SEC	SED	SEI	SEP	STA
STP	STX	STY	STZ	TAX	TAY	TCD	TCS	TDC	TRB
TSB	TSC	TSX	TXA	TXS	TXY	TYA	TYX	WAI	WDM
XBA	XCE								

Instructions By Category

Category	Instructions
Arithmetic	ADC , SBC

Boolean	AND , EOR , ORA
Shift	ASL , LSR , ROL , ROR
Branch	BCC , BCS , BEQ , BMI , BNE , BPL , BRA , BRK , BRL , BVC , BVS
Test	BIT , TRB , TSB
Flags	CLC , CLD , CLI , CLV , REP , SEC , SED , SEI , SEP
Compare	CMP , CPX , CPY
Interrupt	COP , WAI
Inc/Dec	DEC , DEX , DEY , INC , INX , INY
Flow	JMP , JML , JSL , JSR , NOP , RTI , RTL , RTS , WDM
Load	LDA , LDX , LDY
Block Move	MVN , MVP
Stack	PEA , PEI , PER , PHA , PHB , PHD , PHK , PHP , PHX , PHY , PLA , PLB , PLD , PLP , PLX , PLY
Store	STA , STP , STX , STY , STZ
Register Swap	TAX , TAY , TCD , TCS , TDC , TSC , TSX , TXA , TXS , TXY , TYA , TYX , XBA , XCE

ADC

Add with Carry

```
SYNTAX           MODE       HEX LEN CYCLES      FLAGS
ADC #$20/#$1234  imm        69  3-m 3-m         nv....zc .
ADC $20          dir        65  2   4-m+w       nv....zc .
ADC $20,X        dir,X      75  2   5-m+w       nv....zc .
ADC $20,S        stk,S      63  2   5-m         nv....zc .
ADC $1234        abs        6D  3   5-m         nv....zc .
ADC $1234,X      abs,X      7D  3   6-m-x+x*p   nv....zc .
ADC $1234,Y      abs,Y      79  3   6-m-x+x*p   nv....zc .
ADC $FEDBCA      long       6F  4   6-m         nv....zc .
ADC $FEDCBA,X    long,X     7F  4   6-m         nv....zc .
ADC ($20)        (dir)      72  2   6-m+w       nv....zc .
ADC ($20),Y      (dir),Y    71  2   7-m+w-x+x*p nv....zc .
ADC ($20,X)      (dir,X)    61  2   7-m+w       nv....zc .
ADC ($20,S),Y    (stk,S),Y  73  2   8-m         nv....zc .
ADC [$20]        [dir]      67  2   7-m+w       nv....zc .
ADC [$20],Y      [dir],Y    77  2   7-m+w       nv....zc .
```

ADC adds the accumulator (.A), the supplied operand, and the Carry bit (0 or 1). The result is stored in .A.

Since Carry is always added in, you should always remember to use CLC (Clear Carry) before performing an addition operation. When adding larger numbers (16, 24, 32, or more bits), you can use the Carry flag to chain additions.

Here is an example of a 16-bit add, when in 8 bit mode:

```
CLC
LDA Addend1
ADC Addend2
STA Result1
LDA Addend1+1  ; Reads the high byte of the addend
ADC Addend2+1  ; (the +1 refers to the *address* of Addend, not the value)
STA Result1+1  ;
done:
; the final result is at Result1
```

Flags:

- **n** is set when the high bit of .A is set. This indicates a negative number when using Two's Complement signed values.
- **v** (overflow) is set when the sum exceeds the maximum *signed* value for .A. (More on that below). * **n** is set when the high bit is 1.
- **z** is set when the result is zero. This is useful for loop counters and can be tested with BEQ and BNE. (BEQ and BNE test the Zero bit, which is also the "equal" bit when performing subtraction or Compare operations.)
- **c** is set when the unsigned result exceeds the register's capacity (255 or 65535).

Overflow vs Carry

The CPU detects addition that goes past the 7 or 15 bit boundary of a signed number, as well as the 8 bit boundary of an unsigned number.

In 8-bit mode, when you add two positive numbers that result in a sum higher than 127 or add two negative numbers that result in a sum below -128, you will get a signed overflow, and the v flag will be set.

When the sum of the two numbers exceeeds 255 or 65535, then the Carry flag will be set. This bit can be added to the next higher byte with ADC #0.

```
CLC
LDA #$7F
ADC #$10
BRK
```

[Opcodes] [By Name] [By Category]

AND

Boolean AND

```
SYNTAX           MODE       HEX LEN CYCLES      FLAGS
AND #$20/#$1234  imm        29  3-m 3-m         n.....z. .
AND $20          dir        25  2   4-m+w       n.....z. .
AND $20,X        dir,X      35  2   5-m+w       n.....z. .
AND $20,S        stk,S      23  2   5-m         n.....z. .
AND $1234        abs        2D  3   5-m         n.....z. .
AND $1234,X      abs,X      3D  3   6-m-x+x*p   n.....z. .
AND $1234,Y      abs,Y      39  3   6-m-x+x*p   n.....z. .
AND $FEDBCA      long       2F  4   6-m         n.....z. .
AND $FEDCBA,X    long,X     3F  4   6-m         n.....z. .
AND ($20)        (dir)      32  2   6-m+w       n.....z. .
AND ($20),Y      (dir),Y    31  2   7-m+w-x+x*p n.....z. .
AND ($20,X)      (dir,X)    21  2   7-m+w       n.....z. .
AND ($20,S),Y    (stk,S),Y  33  2   8-m         n.....z. .
AND [$20]        [dir]      27  2   7-m+w       n.....z. .
AND [$20],Y      [dir],Y    37  2   7-m+w       n.....z. .
```

Perform a logical AND operation with the operand and .A

AND compares each bit of the operands and sets the result bit to 1 only when the matching bit of each operand is 1.

AND is useful for reading a group of bits from a byte. For example, `AND #$0F` will clear the top nibble of .A, returning the bits from the lower nibble.

Truth table for AND:

```
Operand 1: 1100
Operand 2: 1010
Result:    1000
```

Flags:

- **n** is set when the high bit of the result is 1
- **z** is set when the result is Zero

See also: ORA , EOR

[Opcodes] [By Name] [By Category]

ASL

Arithmetic Shift Left

```
SYNTAX          MODE       HEX LEN CYCLES      FLAGS
ASL             acc        0A  1   2           n.....zc .
ASL $20         dir        06  2   7-2*m+w     n.....zc .
ASL $20,X       dir,X      16  2   8-2*m+w     n.....zc .
ASL $1234       abs        0E  3   8-2*m       n.....zc .
ASL $1234,X     abs,X      1E  3   9-2*m       n.....zc .
```

ASL shifts the target left one place. It shifts the high bit of the operand into the Carry flag and a zero into the low bit.

See also: LSR , ROL , ROR

[Opcodes] [By Name] [By Category]

BCC

Branch on Carry Clear

```
SYNTAX          MODE       HEX LEN CYCLES      FLAGS
BCC LABEL       rel8       90  2   2+t+t*e*p   ........ .
```

Jumps to the target address when the Carry flag (**c**) is Zero.

BCC can be used after add, subtract, or compare operations. After a compare, **c** is as follows:

- When A < Operand, **c** is clear.
- When A >= Operand, **c** is set.

A branch operation uses an 8 bit signed value internally, starting from the instruction after the branch. So the branch destination can be 126 bytes before or 128 bytes after the branch instruction.

[Opcodes] [By Name] [By Category]

BCS

Branch on Carry Set

```
SYNTAX          MODE       HEX LEN CYCLES      FLAGS
BCS LABEL       rel8       B0  2   2+t+t*e*p   ........ .
```

Jumps to the target address when the Carry flag is 1.

BCC can be used after add, subtract, or compare operations. After a compare, **c** is as follows:

- When A < Operand, **c** is clear.
- When A >= Operand, **c** is set.

A branch operation uses an 8 bit signed value internally, starting from the instruction after the branch. So the branch destination can be 126 bytes before or 128 bytes after the branch instruction.

[Opcodes] [By Name] [By Category]

BEQ

Branch on Equal.

```
SYNTAX          MODE       HEX LEN CYCLES      FLAGS
BEQ LABEL       rel8       F0  2   2+t+t*e*p   ........ .
```

Jumps to the target address when the Zero flag is 1. While this is most commonly used after a compare (see CMP) operation, it's also useful to test if a number is zero after a Load operation, or to test if a loop is complete after a DEC operation.

A branch operation uses an 8 bit signed value internally, starting from the instruction after the branch. So the branch destination can be 126 bytes before or 128 bytes after the branch instruction.

[Opcodes] [By Name] [By Category]

BIT

Bit Test

```
SYNTAX           MODE       HEX LEN CYCLES      FLAGS
BIT #$20/#$1234  imm        89  3-m 3-m         ......z. .
BIT $20          dir        24  2   4-m+w       nv....z. .
BIT $20,X        dir,X      34  2   5-m+w       nv....z. .
BIT $1234        abs        2C  3   5-m         nv....z. .
BIT $1234,X      abs,X      3C  3   6-m-x+x*p   nv....z. .
```

Tests the operand against the Accumulator. The ALU does an AND operation internally, setting **z** if the result is 0.

When **m**=1, **n** and **v** are set based on the value of bits 7 and 6 in memory.

When **m**=0, **n** and **v** are set based on the value of bits 15 and 14 in memory.

[Opcodes] [By Name] [By Category]

BMI

Branch on Minus

```
SYNTAX           MODE       HEX LEN CYCLES      FLAGS
BMI LABEL        rel8       30  2   2+t+t*e*p   ........ .
```

Jumps to the specified address when the Negative flag (**n**) is set.

n is set when ALU operations result in a negative number, or when the high bit of an ALU operation is 1.

A branch operation uses an 8 bit signed value internally, starting from the instruction after the branch. So the branch destination can be 126 bytes before or 128 bytes after the branch instruction.

[Opcodes] [By Name] [By Category]

BNE

Branch on Not Equal.

```
SYNTAX           MODE       HEX LEN CYCLES      FLAGS
BNE LABEL        rel8       D0  2   2+t+t*e*p   ........ .
```

Jumps to the target address when the Zero flag is 0. While this is most commonly used after a compare (CMP) operation, it's also useful to test if a number is zero after a Load operation, or to test if a loop is complete after a DEC operation.

A branch operation uses an 8 bit signed value internally, starting from the instruction after the branch. So the branch destination can be 126 bytes before or 128 bytes after the branch instruction.

[Opcodes] [By Name] [By Category]

BPL

Branch on Plus

```
SYNTAX           MODE       HEX LEN CYCLES      FLAGS
BPL LABEL        rel8       10  2   2+t+t*e*p   ........ .
```

Jumps to the specified address when the Negative flag (**n**) is clear.

n is clear when ALU operations result in a positive number, or when the high bit of an ALU operation is 0.

A branch operation uses an 8 bit signed value internally, starting from the instruction after the branch. So the branch destination can be 126 bytes before or 128 bytes after the branch instruction.

[Opcodes] [By Name] [By Category]

BRA

Branch Always

```
SYNTAX          MODE       HEX LEN CYCLES      FLAGS
BRA LABEL       rel8       80  2   3+e*p       ........ .
```

Jumps to the specified address.

A branch operation uses an 8 bit signed value internally, starting from the instruction after the branch. So the branch destination can be 126 bytes before or 128 bytes after the branch instruction.

[Opcodes] [By Name] [By Category]

BRK

Break

```
SYNTAX          MODE       HEX LEN CYCLES      FLAGS
BRK #$20        imm        00  1   8-e         ....di.. .
```

Perform a break interrupt. The exact behavior changes slightly, based on whether the CPU is in native or emulation mode. (e is 1 in emulation mode.)

Since the Program Counter is incremented

In emulation mode:

1. .PC (Program Counter) is incremented by 1 byte.
2. If the CPU is in Native mode, the Program Bank is pushed to the stack.
3. .PC is pushed onto the stack.
4. .P (flags) is pushed to the stack. (the **b** bit, bit 4, is set to 1.)
5. The **d** (Decimal) flag is cleared, forcing the CPU into binary mode.
6. The CPU reads the address from the IRQ vector at $FFFE and jumps there.

An IRQ is similar, except that IRQ clears bit 4 (**b**) during the push to the stack. So an Interrupt Service Routine can read the last byte on the stack to determine whether an emulation-mode interrupt is a BRK or IRQ.

On the X16, the IRQ services the keyboard, mouse, game pads, updates the clock, blinks the cursor, and updates the LEDs.

In native mode:

1. .PC is incremented by 1 byte.
2. .X (Program Bank) is pushed the stack
3. .PC is pushed to the stack
4. .P (flags) is pushed to the stack
5. The **d** (Decimal) flag is cleared, forcing the CPU into binary mode.
6. The CPU reads the address from the BRK vector at $00FFE6 and jumps there.

Since the Native Mode has a distinct BRK vector, you do not need to query the stack to dispatch a BRK vs IRQ interrupt. You can just handle each immediately.

The RTI instruction is used to return from an interrupt. It pulls the values back off the stack (this varies, depending on the CPU mode) and returns to the pushed PC address.

RTI

See the Vectors section for the break vector.

[Opcodes] [By Name] [By Category]

BRL

Branch Long

```
SYNTAX          MODE       HEX LEN CYCLES      FLAGS
BRL LABEL       rel16      82  3   4           ........ .
```

BRL is a 16 bit *branch* instruction, meaning assembly creates a relative address. Unlike BRA and the other branch instructions, BRL uses a 16-bit address, which allows for an offset of -32768 to 32767 bytes away from the instruction *following* The BRL.

Of course, due to wrapping of the 64K bank, this means that the entire 64K region is accessible. Values below 0 will simply wrap around and start from $FFFF, and values above $FFFF will wrap around to 0.

Since this is a *relatve* branch, that means code assembled with BRL, instead of JMP, can be moved around in memory without the need for re-assembly.

[Opcodes] [By Name] [By Category]

BVC

Branch on Overflow Clear

```
SYNTAX          MODE       HEX LEN CYCLES      FLAGS
BVC LABEL       rel8       50  2   2+t+t*e*p   ........ .
```

Branches to the specified address when the Overflow bit is 0.

A branch operation uses an 8 bit signed value internally, starting from the instruction after the branch. So the branch destination can be 126 bytes before or 128 bytes after the branch instruction.

[Opcodes] [By Name] [By Category]

BVS

Branch on Overflow Set

```
SYNTAX          MODE       HEX LEN CYCLES      FLAGS
BVS LABEL       rel8       70  2   2+t+t*e*p   ........ .
```

Branches to the specified address when the Overflow bit is 1.

A branch operation uses an 8 bit signed value internally, starting from the instruction after the branch. So the branch destination can be 126 bytes before or 128 bytes after the branch instruction.

[Opcodes] [By Name] [By Category]

CLC

Clear Carry

```
SYNTAX          MODE       HEX LEN CYCLES      FLAGS
CLC             imp        18  1   2           .......c .
```

Clears the Carry bit in the flags. You'll usually use CLC before addition and SEC before subtraction. You'll also want to use CLC or SEC appropriately before calling certain KERNAL routines that use the **c** bit as an input value.

[Opcodes] [By Name] [By Category]

CLD

Clear Decimal

```
SYNTAX          MODE       HEX LEN CYCLES      FLAGS
CLD             imp        D8  1   2           ....d... .
```

Clears the Decimal flag, returning the CPU to 8-bit or 16-bit binary operation.

When Decimal is set, the CPU will store numbers in Binary Coded Decimal format. Clearing this flag restores the CPU to binary operation. See Decimal Mode for more information.

[Opcodes] [By Name] [By Category]

CLI

Clear Interrupt Flag

```
SYNTAX          MODE       HEX LEN CYCLES      FLAGS
CLI             imp        58  1   2           .....i.. .
```

Clears the **i** flag, *allowing interrupts to be handled*.

The **i** flag operates somewhat non-intuitively: when **i** is set (1), IRQ is suppressed. When **i** is clear (0), interrupts are handled. So CLI *allows* interrupts to be handled.

See [BRK}(#brk) for more information on interrupt handling.

[Opcodes] [By Name] [By Category]

CLV

Clear Overflow

```
SYNTAX          MODE       HEX LEN CYCLES      FLAGS
CLV             imp        B8  1   2           .v...... .
```

Overflow is *set* when the result of an addition operation goes up through $80 or subtraction goes down through $80.

CLV clears the overflow flag. There is no "SEV" instruction, but overflow can be set with SEP #$40.

[Opcodes] [By Name] [By Category]

CMP

Compare

```
SYNTAX          MODE       HEX LEN CYCLES      FLAGS
CMP #$20/#$1234 imm        C9  3-m 3-m         n.....zc .
CMP $20         dir        C5  2   4-m+w       n.....zc .
CMP $20,X       dir,X      D5  2   5-m+w       n.....zc .
CMP $20,S       stk,S      C3  2   5-m         n.....zc .
CMP $1234       abs        CD  3   5-m         n.....zc .
CMP $1234,X     abs,X      DD  3   6-m-x+x*p   n.....zc .
CMP $1234,Y     abs,Y      D9  3   6-m-x+x*p   n.....zc .
CMP $FEDBCA     long       CF  4   6-m         n.....zc .
CMP $FEDCBA,X   long,X     DF  4   6-m         n.....zc .
CMP ($20)       (dir)      D2  2   6-m+w       n.....zc .
CMP ($20),Y     (dir),Y    D1  2   7-m+w-x+x*p n.....zc .
CMP ($20,X)     (dir,X)    C1  2   7-m+w       n.....zc .
CMP ($20,S),Y   (stk,S),Y  D3  2   8-m         n.....zc .
CMP [$20]       [dir]      C7  2   7-m+w       n.....zc .
CMP [$20],Y     [dir],Y    D7  2   7-m+w       n.....zc .
```

Compares the Accumulator with memory. This performs a subtract operation between .A and the operand and sets the **n**, **z**, and **c** flags based on the result. The Accumulator is not altered.

- WHen A = Operand, **z** is set.
- When A < Operand, **c** is clear.
- When A <> Operand, **z** is clear.
- When A >= Operand, **c** is set.

You can use the Branch instructions (BEQ, BNE, BPL, BMI, BCC, BCS) to jump to different parts of your program based on the results of CMP. Here are some BASIC comparisons and the equivalent assembly language steps.

```
; IF A = N THEN 1000
CMP N
BEQ $1000

; IF A <> N THEN 1000
CMP N
BNE $1000

; IF A < N THEN 1000
CMP N
BCC $1000

; IF A >= N THEN 1000
CMP N
BCS $1000

; IF A > N THEN 1000
CMP N
BEQ skip
BCS $1000
skip:

; IF A <= N THEN 1000
CMP N
BEQ $1000
BCC $1000
```

As you can see, some comparisons will require two distinct branch instructions.

Also, note that the Branch instructions (except BRL) require that the target address be within 128 bytes of the instruciton after the branch. If you need to branch further, the usual method is to invert the branch instruction and use a JMP to take the branch.

For example, the following two branches behave the same, but the second one can jump to any address on the computer, whereas the first can only jump -128/+127 bytes away:

```
short_branch:
CMP N
BEQ target

longer_branch:
CMP N
BNE skip
JMP target
skip:
```

[Opcodes] [By Name] [By Category]

COP

COP interrupt.

```
SYNTAX          MODE       HEX LEN CYCLES      FLAGS
COP #$20        imm        02  2   8-e         ....di.. .
```

COP is similar to BRK, but uses the FFE4 or FFF4 vectors. The intent is to COP is to switch to a Co-Processor, but this can be used for any purpose on the X16 (including triggering a DMA controller, if that's what you want to do.)

[Opcodes] [By Name] [By Category]

CPX

Compare X Register

```
SYNTAX          MODE       HEX LEN CYCLES      FLAGS
CPX #$20/#$1234 imm        E0  3-x 3-x         n.....zc .
CPX $20         dir        E4  2   4-x+w       n.....zc .
CPX $1234       abs        EC  3   5-x         n.....zc .
```

This compares the X register to an operand and sets the flags accordingly.

See CMP for more information.

[Opcodes] [By Name] [By Category]

CPY

Compare Y Register

```
SYNTAX          MODE       HEX LEN CYCLES      FLAGS
CPY #$20/#$1234 imm        C0  3-x 3-x         n.....zc .
CPY $20         dir        C4  2   4-x+w       n.....zc .
CPY $1234       abs        CC  3   5-x         n.....zc .
```

This compares the Y register to an operand and sets the flags accordingly.

See CMP for more information.

[Opcodes] [By Name] [By Category]

DEC

Decrement

```
SYNTAX          MODE       HEX LEN CYCLES      FLAGS
DEC             acc        3A  1   2           n.....z. .
DEC $20         dir        C6  2   7-2*m+w     n.....z. .
DEC $20,X       dir,X      D6  2   8-2*m+w     n.....z. .
DEC $1234       abs        CE  3   8-2*m       n.....z. .
DEC $1234,X     abs,X      DE  3   9-2*m       n.....z. .
```

Decrement .A or memory. The **z** flag is set when the value reaches zero. This makes DEC, DEX, and DEY useful as a loop counter, by setting the number of iterations, the repeated operation, then DEX followed by BNE.

z is set when the counter reaches zero. **n** is set when the high bit gets set.

[Opcodes] [By Name] [By Category]

DEX

Decrement .X

```
SYNTAX          MODE       HEX LEN CYCLES      FLAGS
DEX             imp        CA  1   2           n.....z. .
```

Decrement .X The **z** flag is set when the value reaches zero. This makes DEC, DEX, and DEY useful as a loop counter, by setting the number of iterations, the repeated operation, then DEX followed by BNE.

z is set when the counter reaches zero. **n** is set when the high bit gets set.

[Opcodes] [By Name] [By Category]

DEY

Decrement .Y

```
SYNTAX          MODE       HEX LEN CYCLES      FLAGS
DEY             imp        88  1   2           n.....z. .
```

Decrement .X The **z** flag is set when the value reaches zero. This makes DEC, DEX, and DEY useful as a loop counter, by setting the number of iterations, the repeated operation, then DEX followed by BNE.

z is set when the counter reaches zero. **n** is set when the high bit gets set.

[Opcodes] [By Name] [By Category]

EOR

Exclusive OR

```
SYNTAX           MODE       HEX LEN CYCLES      FLAGS
EOR #$20/#$1234  imm        49  3-m 3-m         n.....z. .
EOR $20          dir        45  2   4-m+w       n.....z. .
EOR $20,X        dir,X      55  2   5-m+w       n.....z. .
EOR $20,S        stk,S      43  2   5-m         n.....z. .
EOR $1234        abs        4D  3   5-m         n.....z. .
EOR $1234,X      abs,X      5D  3   6-m-x+x*p   n.....z. .
EOR $1234,Y      abs,Y      59  3   6-m-x+x*p   n.....z. .
EOR $FEDBCA      long       4F  4   6-m         n.....z. .
EOR $FEDCBA,X    long,X     5F  4   6-m         n.....z. .
EOR ($20)        (dir)      52  2   6-m+w       n.....z. .
EOR ($20),Y      (dir),Y    51  2   7-m+w-x+x*p n.....z. .
EOR ($20,X)      (dir,X)    41  2   7-m+w       n.....z. .
EOR ($20,S),Y    (stk,S),Y  53  2   8-m         n.....z. .
EOR [$20]        [dir]      47  2   7-m+w       n.....z. .
EOR [$20],Y      [dir],Y    57  2   7-m+w       n.....z. .
```

Perform an Exclusive OR operation with the operand and .A

EOR compares each bit of the operands and sets the result bit to 1 if one of the two bits is 1. If both bits are 1, the result is 0. If both bits are 0, the result is 0.

EOR is useful for *inverting* the bits in a byte. `EOR #$FF` will flip an entire byte. (This will always flip the low byte in .A. To flip both bytes when **m** is 0, you would use `EOR #$FFFF` .)

Truth table for EOR:

```
Operand 1: 1100
Operand 2: 1010
Result:    0110
```

[Opcodes] [By Name] [By Category]

INC

Increment

```
SYNTAX           MODE       HEX LEN CYCLES      FLAGS
INC              acc        1A  1   2           n.....z. .
INC $20          dir        E6  2   7-2*m+w     n.....z. .
INC $20,X        dir,X      F6  2   8-2*m+w     n.....z. .
INC $1234        abs        EE  3   8-2*m       n.....z. .
INC $1234,X      abs,X      FE  3   9-2*m       n.....z. .
```

Increment .A or memory

Adds 1 to the value in .A or the specified memory address. The **n** and **z** flags are set, based on the resultant value.

INC is useful for reading strings and operating on large areas of memory, especially with indirect and indexed addressing modes.

[Opcodes] [By Name] [By Category]

INX

Increment .X

```
SYNTAX          MODE       HEX LEN CYCLES      FLAGS
INX             imp        E8  1   2           n.....z. .
```

Increment the X register.

The following routine prints a null-terminated string (**a** should be 1.)

```
LDX #$0
loop:
LDA string_addr, X
BEQ done
JSR CHROUT
INX
BRA loop
done:
```

See [INC}(#inc)

[Opcodes] [By Name] [By Category]

INY

Increment .Y

```
SYNTAX          MODE       HEX LEN CYCLES      FLAGS
INY             imp        C8  1   2           n.....z. .
```

Increment the Y register.

See [INC}(#inc)

[Opcodes] [By Name] [By Category]

JMP

Jump

```
SYNTAX          MODE       HEX LEN CYCLES      FLAGS
JMP $2034       abs        4C  3   3           ........ .
JMP ($2034)     (abs)      6C  3   5           ........ .
JMP ($2034,X)   (abs,X)    7C  3   6           ........ .
```

Jump to a differnent address in memory, continuing program execution at the specified address.

Instructions like `JMP ($1234,X)` make it possible to branch to a selectable subroutine by setting X to the indesx into the vector table.

[Opcodes] [By Name] [By Category]

JML

Jump Long

```
SYNTAX          MODE       HEX LEN CYCLES      FLAGS
JML $FEDCBA     long       5C  4   4           ........ .
JMP [$2034]     [abs]      DC  3   6           ........ .
```

Jump to a differnent address in memory, continuing program execution at the specified address. JML accepts a 24-bit address, allowing the program to change program banks.

[Opcodes] [By Name] [By Category]

JSL

Jmp to Subroutine Long

```
SYNTAX          MODE       HEX LEN CYCLES      FLAGS
JSL $203456     long       22  4   8           ........ .
```

This is a 24-bit instruction, which can jump to a subroutine located in another program bank.

Use the RTL instruction to return to the instruction following the JSL.

[Opcodes] [By Name] [By Category]

JSR

Jump to Subroutine

```
SYNTAX          MODE       HEX LEN CYCLES      FLAGS
JSR $2034       abs        20  3   6           ........ .
JSR ($2034,X)   (abs,X)    FC  3   8           ........ .
```

Jumps to a new operating address in memory. Also pushes the return address to the stack, allowing an RTS insruction to pick up at the address following the JSR.

The RTS instruction returns to the instruction following JSR.

The actual address pushed to the stack is the *before* the next instruction. This means that the CPU still needs to increment the PC by 1 step during the RTS.

[Opcodes] [By Name] [By Category]

LDA

Load Accumulator

```
SYNTAX          MODE       HEX LEN CYCLES      FLAGS
LDA #$20/#$1234 imm        A9  3-m 3-m         n.....z. .
LDA $20         dir        A5  2   4-m+w       n.....z. .
LDA $20,X       dir,X      B5  2   5-m+w       n.....z. .
LDA $20,S       stk,S      A3  2   5-m         n.....z. .
LDA $1234       abs        AD  3   5-m         n.....z. .
LDA $1234,X     abs,X      BD  3   6-m-x+x*p   n.....z. .
LDA $1234,Y     abs,Y      B9  3   6-m-x+x*p   n.....z. .
LDA $FEDBCA     long       AF  4   6-m         n.....z. .
LDA $FEDCBA,X   long,X     BF  4   6-m         n.....z. .
LDA ($20)       (dir)      B2  2   6-m+w       n.....z. .
LDA ($20),Y     (dir),Y    B1  2   7-m+w-x+x*p n.....z. .
LDA ($20,X)     (dir,X)    A1  2   7-m+w       n.....z. .
LDA ($20,S),Y   (stk,S),Y  B3  2   8-m         n.....z. .
LDA [$20]       [dir]      A7  2   7-m+w       n.....z. .
LDA [$20],Y     [dir],Y    B7  2   7-m+w       n.....z. .
```

Reads a value from memory into .A. This sets **n** and **z** appropriately, allowing you to use BMI, BPL, BEQ, and BNE to act based on the value being read.

[Opcodes] [By Name] [By Category]

LDX

Load X Register

```
SYNTAX          MODE       HEX LEN CYCLES      FLAGS
LDX #$20/#$1234 imm        A2  3-x 3-x         n.....z. .
LDX $20         dir        A6  2   4-x+w       n.....z. .
LDX $20,Y       dir,Y      B6  2   5-x+w       n.....z. .
```

```
LDX $1234        abs        AE  3   5-x         n.....z. .
LDX $1234,Y      abs,Y      BE  3   6-2*x+x*p   n.....z. .
```

Read a value into .X. This sets **n** and **z** appropriately, allowing you to use BMI, BPL, BEQ, and BNE to act based on the value being read.

[Opcodes] [By Name] [By Category]

LDY

Load X Register

```
SYNTAX           MODE       HEX LEN CYCLES      FLAGS
LDY #$20/#$1234  imm        A0  3-x 3-x         n.....z. .
LDY $20          dir        A4  2   4-x+w       n.....z. .
LDY $20,X        dir,X      B4  2   5-x+w       n.....z. .
LDY $1234        abs        AC  3   5-x         n.....z. .
LDY $1234,X      abs,X      BC  3   6-2*x+x*p   n.....z. .
```

Read a value into .Y. This sets **n** and **z** appropriately, allowing you to use BMI, BPL, BEQ, and BNE to act based on the value being read.

[Opcodes] [By Name] [By Category]

LSR

Logical Shift Right

```
SYNTAX           MODE       HEX LEN CYCLES      FLAGS
LSR              acc        4A  1   2           n.....zc .
LSR $20          dir        46  2   7-2*m+w     n.....zc .
LSR $20,X        dir,X      56  2   8-2*m+w     n.....zc .
LSR $1234        abs        4E  3   8-2*m       n.....zc .
LSR $1234,X      abs,X      5E  3   9-2*m       n.....zc .
```

Shifts all bits to the right by one position.

Bit 0 is shifted into Carry.; 0 shifted into the high bit (7 or 15, depending on the **m** flag.)

Similar instructions:; ASL is the opposite instruction, shifting to the left.; ROR rotates bit 0 through Carry to bit 7.;

+p Adds a cycle if ,X crosses a page boundary.; +c New for the 65C02;

[Opcodes] [By Name] [By Category]

MVN

Block Copy/Move Negative

```
SYNTAX           MODE       HEX LEN CYCLES      FLAGS
MVN #$20,#$34    src,dest   54  3   7           ........ .
```

This performs a block copy. Use MVN when the source and destination ranges overlap and dest < source.

Copying anything other than page zero requires 16-bit index registers, so it's wise to clear **m** and **x** with `REP #$30`.

- Set .X to the source address
- Set .Y to the destination address
- Set .A to size-1
- MVN #source_bank, #dest_bank

[Opcodes] [By Name] [By Category]

MVP

Block Copy/Move Positive

```
SYNTAX          MODE       HEX LEN CYCLES      FLAGS
MVP #$20,#$34   src,dest   44  3   7           ........ .
```

This performs a block copy. Use MVP when the source and destination ranges overlap and dest > source.

Copying anything other than page zero requires 16-bit index registers, so it's wise to clear **m** and **x** with `REP #$30`.

- Set .X to the source_address + size - 1
- Set .Y to the destination_address
- Set .A to size-1
- MVP #source_bank, #dest_bank

[Opcodes] [By Name] [By Category]

NOP

No Operation

```
SYNTAX          MODE       HEX LEN CYCLES      FLAGS
NOP             imp        EA  1   2           ........ .
```

The CPU performs no operation. This is useful when blocking out instructions, or reserving space for later use.

[Opcodes] [By Name] [By Category]

ORA

Boolean OR

```
SYNTAX          MODE       HEX LEN CYCLES      FLAGS
ORA #$20/#$1234 imm        09  3-m 3-m         n.....z. .
ORA $20         dir        05  2   4-m+w       n.....z. .
ORA $20,X       dir,X      15  2   5-m+w       n.....z. .
ORA $20,S       stk,S      03  2   5-m         n.....z. .
ORA $1234       abs        0D  3   5-m         n.....z. .
ORA $1234,X     abs,X      1D  3   6-m-x+x*p   n.....z. .
ORA $1234,Y     abs,Y      19  3   6-m-x+x*p   n.....z. .
ORA $FEDBCA     long       0F  4   6-m         n.....z. .
ORA $FEDCBA,X   long,X     1F  4   6-m         n.....z. .
ORA ($20)       (dir)      12  2   6-m+w       n.....z. .
ORA ($20),Y     (dir),Y    11  2   7-m+w-x+x*p n.....z. .
ORA ($20,X)     (dir,X)    01  2   7-m+w       n.....z. .
ORA ($20,S),Y   (stk,S),Y  13  2   8-m         n.....z. .
ORA [$20]       [dir]      07  2   7-m+w       n.....z. .
ORA [$20],Y     [dir],Y    17  2   7-m+w       n.....z. .
```

Perform a Boolean OR operation with the operand and .A

ORA compares each bit of the operands and sets the result bit to 1 if either or both of the two bits is 1. If both bits are 0, the result is 0.

ORA is useful for *setting* a specific bit in a byte.

Truth table for ORA:

```
Operand 1: 1100
Operand 2: 1010
Result:    1110
```

[Opcodes] [By Name] [By Category]

PEA

Push Absolute

```
SYNTAX          MODE       HEX LEN CYCLES      FLAGS
PEA $2034       abs        F4  3   5           ........ .
```

PEA, PEI, and PER push values to the stack *without* affecting registers.

PEA pushes the operand value onto the stack. The literal operand is used, rather than an address.

This seems inconsistent with the absolute address syntax, as PEA and PEI follow their own syntax rules.

[Opcodes] [By Name] [By Category]

PEI

Push Effecive Indirect Address

```
SYNTAX          MODE       HEX LEN CYCLES      FLAGS
PEI ($20)       (dir)      D4  2   6+w         ........ .
```

PEI takes a *pointer* as an operand. The value written to the stack is the two bytes at the supplied address.

Example:

```
; data at $20 is $1234
PEI ($20)
; pushes $1234 onto the stack.
```

The written form of PEI is inconsistent with the usual indirect mode syntax, as PEI and PEA follow their own syntax rules.

[Opcodes] [By Name] [By Category]

PER

Push Effective PC Relative Indirect Address

```
SYNTAX          MODE       HEX LEN CYCLES      FLAGS
PER LABEL       rel16      62  3   6           ........ .
```

PER pushes the address *relative to the program counter*. This allows you to mark the current executing location and push that to the stack.

When used in conjunctin with BRL, PER can form a reloatable JSR instruction.

Consider the following ca65 macro:

```
.macro bsr addr
per .loword(:+ - 1)
brl addr
:
.endmacro
```

This gets the address following the BRL instruction and pushes that to the stack. See JSR to understand why the -1 is required.

[Opcodes] [By Name] [By Category]

PHA

Push Accumulator

```
SYNTAX          MODE       HEX LEN CYCLES      FLAGS
PHA             imp        48  1   4-m         ........ .
```

Pushes the Accumulator to the stack. This will push 1 byte when **m** is 1 and two bytes when **m** is 0 (16-bit memory/.A mode.)

An 8-bit stack push writes data at the Stack Pointer address, then moves SP down by 1 byte.

A 16-bit push writes the high byte first, decrements the PC, then writes the low byte, and decrements the PC again.

In Emulation mode, the Stack Pointer will always be an address in the $100-$1FF range, so there is only room for 256 bytes on the stack. In native mode, the stack can be anywhere in the first 64KB of RAM.

[Opcodes] [By Name] [By Category]

PHB

Push Data Bank register.

```
SYNTAX          MODE       HEX LEN CYCLES      FLAGS
PHB             imp        8B  1   3           ........ .
```

The data bank register sets the top 8 bits used when reading data with LDA, LDX, and LDY.

This is always an 8-bit operation.

[Opcodes] [By Name] [By Category]

PHD

Push Direct Page

```
SYNTAX          MODE       HEX LEN CYCLES      FLAGS
PHD             imp        0B  1   4           ........ .
```

Pushes the 16-bit Direct Page register to the stack. This is useful for preserving the location of .D before relocating Direct Page for another use (such as an operating system routine.)

[Opcodes] [By Name] [By Category]

PHK

Push Program Bank

```
SYNTAX          MODE       HEX LEN CYCLES      FLAGS
PHK             imp        4B  1   3           ........ .
```

Pushes the Program Bank register to the stack. The Program Bank is the top 8 bits of the 24-bit Program Counter address.

[Opcodes] [By Name] [By Category]

PHP

Push Program Status (Flags)

```
SYNTAX          MODE       HEX LEN CYCLES      FLAGS
PHP             imp        08  1   3           ........ .
```

The CPU writes the flags in the order `nvmx dizc`. (**e** does not get written to the stack.)

Note: the 6502 and 65C02 use bit 4 (**x** on the '816) for the Break flag. While **b** does get written to the stack in a BRK operation, bit 4 in .P always reflects the state of the 8-bit-index flag. Since the flags differ slightly in behavior, make sure your Interrupt handler code reads from the stack, not the .P bits, when dispatching a IRQ/BRK interrupt.

[Opcodes] [By Name] [By Category]

PHX

Push X Register

```
SYNTAX          MODE       HEX LEN CYCLES      FLAGS
PHX             imp        DA  1   4-x         ........ .
```

Pushes the X register to the stack. This will push 1 byte when **x** is 1 and two bytes when **x** is 0 (16-bit index mode.)

An 8-bit stack push writes data at the Stack Pointer address, then moves SP down by 1 byte. A 16-bit stack push moves the stack pointer down 2 bytes.

[Opcodes] [By Name] [By Category]

PHY

Push Y Register

```
SYNTAX          MODE       HEX LEN CYCLES      FLAGS
PHY             imp        5A  1   4-x         ........ .
```

Pushes the Y register to the stack. This will push 1 byte when **y** is 1 and two bytes when **y** is 0 (16-bit index mode.)

An 8-bit stack push writes data at the Stack Pointer address, then moves SP down by 1 byte. A 16-bit stack push moves the stack pointer down 2 bytes.

[Opcodes] [By Name] [By Category]

PLA

Pull Accumulator

```
SYNTAX          MODE       HEX LEN CYCLES      FLAGS
PLA             imp        68  1   5-m         n.....z. .
```

Pulls the Accumulator from the stack.

In the opposite of PHA, the PLA instruction reads the current value from the stack and *increments* the stack pointer by 1 or 2 bytes.

The number of bytes read is based on the value of the **m** flag.

[Opcodes] [By Name] [By Category]

PLB

Pull Data Bank Register

```
SYNTAX          MODE       HEX LEN CYCLES      FLAGS
PLB             imp        AB  1   4           n.....z. .
```

Pull the Data Bank register from the stack.

In the opposite of PHB, the PLB instruction reads the current value from the stack and *increments* the stack pointer by 1 byte.

[Opcodes] [By Name] [By Category]

PLD

Pull Direct Page Register

```
SYNTAX          MODE       HEX LEN CYCLES      FLAGS
PLD             imp        2B  1   5           n.....z. .
```

This pulls a word from the stack and loads it into the Direct Page register.

That value can be placed on the stack in several ways, such as PHA, PHX, or PEA.

[Opcodes] [By Name] [By Category]

PLP

Pull Prgram Status Byte (flags)

```
SYNTAX          MODE       HEX LEN CYCLES      FLAGS
```

```
PLP             imp         28  1   4           nvmxdizc .
```

This reads the flags back from the stack. Since the flags affect the state of the **m** and **x** register-width flags, this should be performed *before* a PLA, PLX, or PLY operation.

[Opcodes] [By Name] [By Category]

PLX

Pull X Register

```
SYNTAX          MODE        HEX LEN CYCLES      FLAGS
PLX             imp         FA  1   5-x         n.....z. .
```

Pulls the X Register from the stack.

In the opposite of PHX, the PLX instruction reads the current value from the stack and *increments* the stack pointer by 1 or 2 bytes.

The number of bytes read is based on the value of the **x** flag.

[Opcodes] [By Name] [By Category]

PLY

Pull Y Register

```
SYNTAX          MODE        HEX LEN CYCLES      FLAGS
PLY             imp         7A  1   5-x         n.....z. .
```

Pulls the Y Register from the stack.

In the opposite of PHY, the PLY instruction reads the current value from the stack and *increments* the stack pointer by 1 or 2 bytes.

The number of bytes read is based on the value of the **x** flag.

[Opcodes] [By Name] [By Category]

REP

Reset Program Status Bit

```
SYNTAX          MODE        HEX LEN CYCLES      FLAGS
REP #$20/#$1234 imm         C2  2   3           nvmxdizc .
```

This clears (to 0) flags in the Program Status Byte. The 1 bits in the will be cleared in the flags, so REP #$30 will set the **a** and **x** bits low.

[Opcodes] [By Name] [By Category]

ROL

Rotate Left

```
SYNTAX          MODE        HEX LEN CYCLES      FLAGS
ROL             acc         2A  1   2           n.....zc .
ROL $20         dir         26  2   7-2*m+w     n.....zc .
ROL $20,X       dir,X       36  2   8-2*m+w     n.....zc .
ROL $1234       abs         2E  3   8-2*m       n.....zc .
ROL $1234,X     abs,X       3E  3   9-2*m       n.....zc .
```

Shifts bits in the accumulator or memory left one bit. The Carry bit (**c**) is shifted into bit 0. The high bit (7 or 15) is shifted into **c**.

[Opcodes] [By Name] [By Category]

ROR

Rotate Right

```
SYNTAX          MODE       HEX LEN CYCLES      FLAGS
ROR             acc        6A  1   2           n.....zc .
ROR $20         dir        66  2   7-2*m+w     n.....zc .
ROR $20,X       dir,X      76  2   8-2*m+w     n.....zc .
ROR $1234       abs        6E  3   8-2*m       n.....zc .
ROR $1234,X     abs,X      7E  3   9-2*m       n.....zc .
```

Shifts bits in the accumulator or memory right one bit. The Carry bit (**c**) is shifted into the high bit (15 or 7). The low bit (0) is shifted into **c**.

[Opcodes] [By Name] [By Category]

RTI

Return From Interrupt

```
SYNTAX          MODE       HEX LEN CYCLES      FLAGS
RTI             imp        40  1   7-e         nvmxdizc .
```

This returns control to the executing program. The following steps happen, in order:

1. The CPU pulls the flags from the stack (including **m** and **x**, which switch to 8/16 bit mode, as appropriate.
2. The CPU pulls the Program Counter from the stack.
3. If the CPU is in native mode, the CPU pulls the Program Bank register.

[Opcodes] [By Name] [By Category]

RTL

Return From Subroutine Long

```
SYNTAX          MODE       HEX LEN CYCLES      FLAGS
RTL             imp        6B  1   6           ........ .
```

This returns to the caller at the end of a subroutine. This should be used to return to the instruction following a JSL instruction.

This reads 3 bytes from the stack and loads them into the Program Counter and Program Bank register. The next instruction executed will then be the instruction after the JSL that jumped to the subroutine.

[Opcodes] [By Name] [By Category]

RTS

Return From Subroutine

```
SYNTAX          MODE       HEX LEN CYCLES      FLAGS
RTS             imp        60  1   6           ........ .
```

Return to to a calling routine after a JSR .

RTS reads a 2 byte address from the stack and loads that address into the Program Counter. The next instruction executed will then be the instruction after the JSR that jumped to the subroutine.

[Opcodes] [By Name] [By Category]

SBC

Subtract With Carry

```
SYNTAX          MODE       HEX LEN CYCLES      FLAGS
SBC #$20/#$1234 imm        E9  3-m 3-m         nv....zc .
SBC $20         dir        E5  2   4-m+w       nv....zc .
SBC $20,X       dir,X      F5  2   5-m+w       nv....zc .
SBC $20,S       stk,S      E3  2   5-m         nv....zc .
```

```
SBC $1234        abs        ED  3   5-m          nv....zc .
SBC $1234,X      abs,X      FD  3   6-m-x+x*p    nv....zc .
SBC $1234,Y      abs,Y      F9  3   6-m-x+x*p    nv....zc .
SBC $FEDBCA      long       EF  4   6-m          nv....zc .
SBC $FEDCBA,X    long,X     FF  4   6-m          nv....zc .
SBC ($20)        (dir)      F2  2   6-m+w        nv....zc .
SBC ($20),Y      (dir),Y    F1  2   7-m+w-x+x*p  nv....zc .
SBC ($20,X)      (dir,X)    E1  2   7-m+w        nv....zc .
SBC ($20,S),Y    (stk,S),Y  F3  2   8-m          nv....zc .
SBC [$20]        [dir]      E7  2   7-m+w        nv....zc .
SBC [$20],Y      [dir],Y    F7  2   7-m+w        nv....zc .
```

Subtract a value from .A. The result is left in .A.

When performing subtraction, the Carry bit indicates a Borrow and operates in reverse from addition: when **c** is 0, SBC subtracts one from the final result, to account for the borrow.

After the operation, **c** will be set to 0 if a borrow took place and 1 if it did not.

When **m** is 0, this will be a 16 bit add, and the CPU will read two bytes from memory.

Since there is no "subtract with no carry", you should always use SEC before the first SBC in a sequence, to ensure that the Carry bit is *set*, going into a subtraction.

[Opcodes] [By Name] [By Category]

SEC

Set Carry

```
SYNTAX           MODE       HEX LEN CYCLES      FLAGS
SEC              imp        38  1   2           .......c .
```

Sets the Carry bit to 1

[Opcodes] [By Name] [By Category]

SED

Set Decimal

```
SYNTAX           MODE       HEX LEN CYCLES      FLAGS
SED              imp        F8  1   2           ....d... .
```

Sets the Decimal bit to 1, setting the CPU to BCD mode.

When Decimal is set, the CPU will store numbers in Binary Coded Decimal format. Clearing this flag restores the CPU to binary operation. See Decimal Mode for more information.

In binary mode, adding 1 to $09 will set the Accumulator to $0A. In BCD mode, adding 1 to $09 will set the Accumulator to $10.

Using BCD allows for easier conversion of binary numbers to decimal. BCD also allows for storing decimal numbers without loss of precision due to power-of-2 rounding.

An add or subtract (ADC or SBC) is required to actually trigger BCD conversion. So if you have a number like $1A on the accumulator and you SED, you can convert .A to $20 with the instruction `ADC #$00`.

[Opcodes] [By Name] [By Category]

SEI

Set IRQ Disable

```
SYNTAX           MODE       HEX LEN CYCLES      FLAGS
SEI              imp        78  1   2           .....i.. .
```

Sets **i**, which inhibits IRQ handling. When **i** is set, the CPU will not respond to the IRQ pin. When **i** is clear, the CPU will perform an interrupt when the IRQ pin is asserted.

The **i** flag operates somewhat non-intuitively: when **i** is set (1), IRQ is suppressed. When **i** is clear (0), interrupts are handled. So CLI *allows* interrupts to be handled and SEI *blocks* interrupt handling.

See BRK for a brief description of interrupts.

[Opcodes] [By Name] [By Category]

SEP

Set Processor Status Bit

```
SYNTAX           MODE       HEX LEN CYCLES      FLAGS
SEP #$20/#$1234  imm        E2  2   3           nvmxdizc .
```

Reset Program Status Bit

This sets (to 1) a flag in the Program Status Byte. The operand value will be loaded into the flags, so SEP #$30 will set the **a** and **x** bits high.

[Opcodes] [By Name] [By Category]

STA

Store Accumulator to Memory

```
SYNTAX           MODE       HEX LEN CYCLES      FLAGS
STA $20          dir        85  2   4-m+w       ........ .
STA $20,X        dir,X      95  2   5-m+w       ........ .
STA $20,S        stk,S      83  2   5-m         ........ .
STA $1234        abs        8D  3   5-m         ........ .
STA $1234,X      abs,X      9D  3   6-m         ........ .
STA $1234,Y      abs,Y      99  3   6-m         ........ .
STA $FEDBCA      long       8F  4   6-m         ........ .
STA $FEDCBA,X    long,X     9F  4   6-m         ........ .
STA ($20)        (dir)      92  2   6-m+w       ........ .
STA ($20),Y      (dir),Y    91  2   7-m+w       ........ .
STA ($20,X)      (dir,X)    81  2   7-m+w       ........ .
STA ($20,S),Y    (stk,S),Y  93  2   8-m         ........ .
STA [$20]        [dir]      87  2   7-m+w       ........ .
STA [$20],Y      [dir],Y    97  2   7-m+w       ........ .
```

Stores the value in .A to a memory address.

When **m** is 0, the value saved will be a 16-bit number, using two bytes of memory. When **m** is 1, the value will be an 8-bit number, using one byte of RAM.

[Opcodes] [By Name] [By Category]

STP

Stop the Clock

```
SYNTAX           MODE       HEX LEN CYCLES      FLAGS
STP              imp        DB  1   3           ........ .
```

Halts the CPU. The CPU will no longer process instructions until the Reset pin is asserted.

[Opcodes] [By Name] [By Category]

STX

Store Index X to Memory

```
SYNTAX          MODE       HEX LEN CYCLES      FLAGS
STX $20         dir        86  2   4-x+w       ........ .
STX $20,Y       dir,Y      96  2   5-x+w       ........ .
STX $1234       abs        8E  3   5-x         ........ .
```

Stores the value in .X to a memory address.

When the flag **x** is 0, the value saved will be a 16-bit number, using two bytes of memory. When **x** is 1, the value will be an 8-bit number, using one byte of RAM.

[Opcodes] [By Name] [By Category]

STY

Store Index Y to Memory

```
SYNTAX          MODE       HEX LEN CYCLES      FLAGS
STY $20         dir        84  2   4-x+w       ........ .
STY $20,X       dir,X      94  2   5-x+w       ........ .
STY $1234       abs        8C  3   5-x         ........ .
```

Stores the value in .Y to a memory address.

When the flag **x** is 0, the value saved will be a 16-bit number, using two bytes of memory. When **x** is 1, the value will be an 8-bit number, using one byte of RAM.

[Opcodes] [By Name] [By Category]

STZ

Store Sero to Memory

```
SYNTAX          MODE       HEX LEN CYCLES      FLAGS
STZ $20         dir        64  2   4-m+w       ........ .
STZ $20,X       dir,X      74  2   5-m+w       ........ .
STZ $1234       abs        9C  3   5-m         ........ .
STZ $1234,X     abs,X      9E  3   6-m         ........ .
```

Stores a zero to a memory address.

When **m** is 0, the value saved will be a 16-bit number, using two bytes of memory. When **m** is 1, the value will be an 8-bit number, using one byte of RAM.

[Opcodes] [By Name] [By Category]

TAX

Transfer Accumulator to Index X

```
SYNTAX          MODE       HEX LEN CYCLES      FLAGS
TAX             imp        AA  1   2           n.....z. .
```

Copies the contents of .A to .X.

[Opcodes] [By Name] [By Category]

TAY

Transfer Accumulator to Index Y

```
SYNTAX          MODE       HEX LEN CYCLES      FLAGS
TAY             imp        A8  1   2           n.....z. .
```

Copies the contents of .A to .Y.

[Opcodes] [By Name] [By Category]

TCD

Transfer C Accumulator to Direct Register

```
SYNTAX          MODE       HEX LEN CYCLES      FLAGS
TCD             imp        5B  1   2           n.....z. .
```

This copies the 16-bit value from the 16-bit Accumulator to the Direct Register, allowing you to relocate Direct Page anywhere in the first 64K of RAM.

This is one of the times that the 16-bit Accumulator is called .C, as it always operates on a 16-bit value, regardless of the state of the **m** flag.

[Opcodes] [By Name] [By Category]

TCS

Transfer C Accumulator to Stack Pointer

```
SYNTAX          MODE       HEX LEN CYCLES      FLAGS
TCS             imp        1B  1   2           ........ .
```

This copies the 16-bit value from the 16-bit Accumulator to the Stack Pointer, allowing you to relocate the stack anywhere in the first 64K of RAM.

This is one of the times that the 16-bit Accumulator is called .C, as it always operates on a 16-bit value, regardless of the state of the **m** flag.

[Opcodes] [By Name] [By Category]

TDC

Transfer Direct Register to C Accumulator

```
SYNTAX          MODE       HEX LEN CYCLES      FLAGS
TDC             imp        7B  1   2           n.....z. .
```

Copies the value of the Direct Register to the Accumulator.

This is one of the times that the 16-bit Accumulator is called .C, as it always operates on a 16-bit value, regardless of the state of the **m** flag.

[Opcodes] [By Name] [By Category]

TRB

Test and Reset Bit

```
SYNTAX          MODE       HEX LEN CYCLES      FLAGS
TRB $20         dir        14  2   7-2*m+w     ......z. .
TRB $1234       abs        1C  3   8-2*m       ......z. .
```

TRB does two things with one operation: it tests specified bits in a memory location, and it clears (resets) those bits after the test.

First, TRB performs a logical AND between the memory address specified and the Accmulator. If the result of the AND is zero, the **z** flag will be set.

Second, TRB clears bits in the memory value based on the bit mask in the accmulator. Any bit that is 1 in .A will be changed to 0 in memory.

So to *clear* a bit in a memory value, set that value to 1 in .A, like this:

```
; memory at $2000 contains $84
LDA #$80
TRB $2000
; memory at $2000 now contains $04, and z flag is clear
```

```
; memory at $1234 contains $20
LDA #$01
TRB $1234
; memory at $1234 contains $20 and z flag is set
; because $20 AND $01 == 0.
```

[Opcodes] [By Name] [By Category]

TSB

Test and Set Bit

```
SYNTAX          MODE       HEX LEN CYCLES      FLAGS
TSB $20         dir        04  2   7-2*m+w     ......z. .
TSB $1234       abs        0C  3   8-2*m       ......z. .
```

TSB does two things with one operation: it tests specified bits in a memory location, and it clears (resets) those bits after the test.

First, TSB performs a logical AND between the memory address specified and the Accmulator. If the result of the AND is zero, the **z** flag will be set.

TSB also *sets* the bits that are 1 in the accumulator, similar to an OR operation.

[Opcodes] [By Name] [By Category]

TSC

Transfer Stack Pointer to C accumulator

```
SYNTAX          MODE       HEX LEN CYCLES      FLAGS
TSC             imp        3B  1   2           n.....z. .
```

Copies the Stack Pointer to the 16-bit Accumulator.

This is one of the times that the 16-bit Accumulator is called .C, as it always operates on a 16-bit value, regardless of the state of the **m** flag.

[Opcodes] [By Name] [By Category]

TSX

Transfer Stack Pointer X Register

```
SYNTAX          MODE       HEX LEN CYCLES      FLAGS
TSX             imp        BA  1   2           n.....z. .
```

Copies the Stack Pointer to the X register.

[Opcodes] [By Name] [By Category]

TXA

Transfer X Register to Accumulator

```
SYNTAX          MODE       HEX LEN CYCLES      FLAGS
TXA             imp        8A  1   2           n.....z. .
```

Copies the value in .X to .A

[Opcodes] [By Name] [By Category]

TXS

Transfer X Register to Stack Pointer

```
SYNTAX          MODE       HEX LEN CYCLES      FLAGS
TXS             imp        9A  1   2           ........ .
```

Copies the X register to the Stack Pointer. This is used to reset the stack to a known location, usually at boot or when context-switching.

[Opcodes] [By Name] [By Category]

TXY

Transfer X Register to Accumulator

```
SYNTAX          MODE       HEX LEN CYCLES      FLAGS
TXY             imp        9B  1   2           n.....z. .
```

Copies the value in .X to .Y

[Opcodes] [By Name] [By Category]

TYA

Transfer Y Register to Accumulator

```
SYNTAX          MODE       HEX LEN CYCLES      FLAGS
TYA             imp        98  1   2           n.....z. .
```

Copies the value in .Y to .A

[Opcodes] [By Name] [By Category]

TYX

Transfer Y Register to X Register

```
SYNTAX          MODE       HEX LEN CYCLES      FLAGS
TYX             imp        BB  1   2           n.....z. .
```

Copies the value in .Y to .X

[Opcodes] [By Name] [By Category]

WAI

Wait For Interrupt

```
SYNTAX          MODE       HEX LEN CYCLES      FLAGS
WAI             imp        CB  1   3           ........ .
```

Stops the CPU until the next interrupt is triggered. This allows the CPU to respond to an interrupt immediately, rather than waiting for an instruction to complete.

[Opcodes] [By Name] [By Category]

WDM

WDM

```
SYNTAX          MODE       HEX LEN CYCLES      FLAGS
WDM             imm        42  2   2           ........ .
```

WDM is a 2 byte NOP: the WDM opcode and the operand byte following are both read, but not executed.

The WDM opcode is reserved for future use and should be avoided in 65C816 programs.

[Opcodes] [By Name] [By Category]

XBA

Exchange B and A Accumulator

```
SYNTAX          MODE       HEX LEN CYCLES      FLAGS
XBA             imp        EB  1   3           n.....z. .
```

Swaps the values in .A and .B. This exchanges the high and low bytes of the Accumulator. XBA functions the same in both 8 and 16 bit modes.

[Opcodes] [By Name] [By Category]

XCE

Exchange Carry and Emulation Flags

```
SYNTAX          MODE       HEX LEN CYCLES      FLAGS
XCE             imp        FB  1   2           .......c e
```

This allows the CPU to switch between Native and Emulation modes.

To switch into native mode:

```
CLC
XCE
```

To switch to 65C02 emulation mode:

```
SEC
XCE
```

[Opcodes] [By Name] [By Category]
