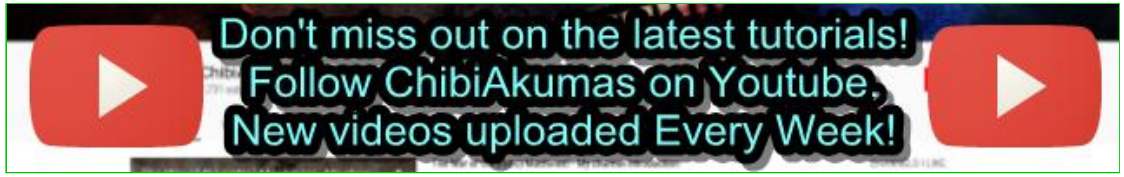

Learn Multi platform 6502 Assembly Programming... For Monsters!

Platform Specific Lessons

Lesson P31 - Hardware Sprites on the Atari 800 / 5200

The Atari 5200 and 800 have some limited hardware sprite support... capable of 8 pixel wide sprites - but that are the entire height of the screen!

Lets learn about them!

SpriteTest.asm

Compared to other systems, the 'Hardware Sprites' of the atari are pretty limited, and may not be very useful as they are just 8 pixels wide and one color

That said, they may be useful in some cases, you could combine them together to make a 32x32 player sprite - or use them for parallax effects or something!

View Options
Default Dark
Simple (Hide this menu)
Print Mode (white background)

Top Menu
Main Menu
Youtube channel
Forum
AkuSprite Editor
Dec/Bin/Hex/Oct/Ascii Table

Z80 Content
Z80 Tutorial List
Learn Z80 Assembly
Hello World
Advanced Series
Multiplatform Series
Platform Specific Series
ChibiAkumas Series
Grime Z80
Z80 Downloads
Z80 Cheatsheet
Sources.7z
DevTools kit
Z80 Platforms
Amstrad CPC
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Gameboy & Gameboy Color
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Atari 800 / 5200 Sprites

The Atari's hardware sprites are very weird!

Basically each sprite is 8 pixels wide and just 2 colors (1+transparent)... there are 4 'normal' ones that are 8 pixels wide.... and 4 missile sprites that are just 2(!) pixels wide... but we can position them together to give us 5 sprites.

Despite being 8 pixels wide... each sprite is up to 128 pixels tall (or 256 in hires mode) - the entire height of the screen!... if you can't guess this is because the systems is changing the data each rasterline.

The data used to draw the sprite is taken from a single pointer at **$D407**... if this pointer is set to $18 then all the sprites will use the $1800-$1FFF range - the exact address differs depending on whether the Resolution bit of $D400 is set to 0 or 1... in Res1 Sprites will be at $1800+$400 - $1C00 ... or in Res0 $1800+$200 = $1A00

On an Atari 800 where the GTIA is at $D000 this would give the following addresses for the sprite settings GTIA is at $C000 on the 5200)

The addresses controling the sprite are shown below... note we cannot set vertical position - we just write the sprite bitmap to a different address in the 'strip' of memory (eg between $1C00-$1CFF)

Player	Res0 Data	Res1Data	Width	Color	Xpos
0	$1A00+ypos	$1C00+ypos	$D008	$D012	$D000
1	$1A80+ypos	$1D00+ypos	$D009	$D013	$D001
2	$1B00+ypos	$1E00+ypos	$D00A	$D014	$D002
3	$1B80+ypos	$1F00+ypos	$D00B	$D015	$D003
4 (Missiles)	$1980	$1B00	$D00C	$D019* / $D012-$D015	$D004-$D007

*Missiles can be configured to use all 4 player colors for each 2 bit strip - or $D019 for all 4 2 bit strips ... this is set by PRIOR ($D01B)

The Sprites can be in front of, or behind the background... register **$D01B** (PRIOR) controls the order... and allows all 4 missiles to use color defined at $D019 as the sprite color - instead of the 4 player colors!
Note PRIOR is at **$D01B**... it seems to be incorrectly reported as $D10B or $D21B in some documentation!!!

To make use of sprites, we need to set the addresses shown above for the player sprite attributes, we also need to turn sprites on!

The example code to the right should do the job! note you needto set symbol GTIA to $D000 on the Atari 800, or $C000 on the Atari 5200

```
        lda #%00111110
        sta $D400           ;DMA control (SDMCTL)

        lda #$18 ;Sprites will be at $1800+$300 (or +$180 in low res mode)
        sta $D407    ;Store player sprite base

        lda #%00000011
        sta GTIA+$001D    ;Graphics Control (GRACTL)

        lda #%00010001   ;Priority: sprite 5 to use color 3
        sta GTIA+$1B       ;and put sprites in front of background
```

Atari 800 / 5200 Sprite Registers

MSX & MSX2
Sam Coupe
TI-83
ZX Spectrum
Spectrum NEXT
Camputers Lynx

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6502 Tutorial List
Learn 6502 Assembly
Advanced Series
Platform Specific Series
Hello World Series
Grime 6502
6502 Downloads
6502 Cheatsheet
Sources.7z
DevTools kit
6502 Platforms
Apple IIe
Atari 800 and 5200
Atari Lynx
BBC Micro
Commodore 64
Commander x16
Super Nintendo (SNES)
Nintendo NES / Famicom
PC Engine (Turbografx-16)
Vic 20

68000 Content
68000 Tutorial List
Learn 68000 Assembly
Hello World Series
Platform Specific Series
Grime 68000
68000 Downloads
68000 Cheatsheet
Sources.7z
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68000 Platforms
Amiga 500
Atari ST

Group	Name	Description	Address A80	Address A52	Bits	Notes
GTIA	HPOSP0	horizontal position of player 0	$D000	$C000		
GTIA	HPOSP1	horizontal position of player 1	$D001	$C001		
GTIA	HPOSP2	horizontal position of player 2	$D002	$C002		
GTIA	HPOSP3	horizontal position of player 3	$D003	$C003		
GTIA	HPOSM0	horizontal position of missile 0 (Player 4)	$D004	$C004		
GTIA	HPOSM1	horizontal position of missile 1 (Player 4)	$D005	$C005		
GTIA	HPOSM2	horizontal position of missile 2 (Player 4)	$D006	$C006		
GTIA	HOPSM3	horizontal position of missile 3 (Player 4)	$D007	$C007		
GTIA	SIZEP0	player 0 size	$D008	$C008	------WW	Width of sprite (0-3)
GTIA	SIZEP1	player 1 size	$D009	$C009	------WW	Width of sprite (0-3)
GTIA	SIZEP2	player 2 size	$D00A	$C00A	------WW	Width of sprite (0-3)
GTIA	SIZEP3	player 3 size	$D00B	$C00B	------WW	Width of sprite (0-3)
GTIA	SIZEM	missile size	$D00C	$C00C	wwWWwwWW	Width of sprite (Need to set all 4 parts)
GTIA	GRAFP0	player 0 graphics	$D00D	$C00D		(Used by DMA)
GTIA	GRAFP1	player 1 graphics	$D00E	$C00E		(Used by DMA)
GTIA	GRAFP2	player 2 graphics	$D00F	$C00F		(Used by DMA)
GTIA	GRAFP3	player 3 graphics	$D010	$C010		(Used by DMA)
GTIA	GRAFM	missile graphics	$D011	$C011		(Used by DMA)
GTIA	COLPM0	color/brightness, player/missile 0	$D012	$C012		
GTIA	COLPM1	color/brightness, player/missile 1	$D013	$C013		
GTIA	COLPM2	color/brightness, player/missile 2	$D014	$C014		
GTIA	COLPM3	color/brightness, player/missile 3	$D015	$C015		
GTIA	COLPF3	color/brightness of setcolor 3 / Player 5 (missile)	$D019	$C019		
GTIA	PRIOR	p/m priority and GTIA mode	$D01B	$C01B	GGmMpppp	G=gtia mode (0=normal) C=multiColor M=Missile (player 5) pppp=priority setting (1=sprites in front 4=behind)
GTIA	GRACTL	graphics control	$D01D	$C01D	------L45	Latch Trigger / Enable 4 player / enable 5 (missiles)
ANTIC	DMACTL	Direct Memory access control (DMA)	$D400	$C400		
ANTIC	PMBASE	player/missile address / 256	$D407	$C407		

Coding a Player sprite (sprite 0-3)

The procedure for setting Player sprites 0-4 are all basically the same, we need a 1

byte wide sprite (1 bit per pixel) file, and to set our 'Y position' we'll need to load it into the correct memory address.

First of all we need to set up the sprite settings, we need to turn on sprites, set them to appear in front of the background, and set the memory address of our sprites - we're using 'High Resolution mode, and our sprite base is at $1800... so Player 0's sprite data starts at $1C00

We need to enable the DMA - this is what copies the sprite data to the screen register each screen line to change the sprite vertically.

We're also enabling 'Player 4' - this combines the missile sprites into one 'fifth' sprite - we'll learn how to use it in a moment!

```
;     ---R45bb      ;R=vertical Resolution 4=4players 5=Missiles
lda #%00111110
sta $D400           ;DMA control (SDMCTL)

lda #$18            ;Sprites will be at $1800+$400
sta $D407           ;Store player sprite base

;    ------L45      Latch Trigger / Enable 4 player / enable 5
lda #%00000011
sta GTIA+$1D        ;Graphics Control (GRACTL)
    ; ggmMpppp     C=multiColor M=Missile (player 5)
lda #%00010001      ;Priority: sprite 5 to use color 3
sta GTIA+$1B        ;and put sprites in front of background
```

OK, we're ready to define our sprite!

First we set the Xscale with $D008 - but because the GTIA is in a different place on the Atari 5200 - we'll refer to it with GTIA+$08 ... the setting can be 0-3... there is no Yscale - we need to alter our bitmap data to make the sprite taller!

Next We'll set the Xpos with $D000... There is no Ypos - the sprite covers the entire height of the screen - we need to alter the bitmap data according to where we want it to be.

Finally We set a color with $D012

```
;     ------WW
lda #%00000011      ;Width of sprite (0-3)
sta GTIA+$08        ;Player Sprite 0

lda #$40
sta GTIA+$00        ;Xpos Player 0

lda #$1F
sta GTIA+$12        ;Color Player 0
```

We need to set the sprite data, we do a memory copy from the 'Sprite' label in our code, and write to the $1C00 - adding an offset to change the Ypos ($80 in this case)

The same procedure can be used for sprite 1-3 - just change the memory addresses used.

```
        lda #<Sprite        ;Sprite Source
        sta z_L
        lda #>Sprite
        sta z_H
        ldy #(SpriteEnd-Sprite)+1   ;Length
NextByteP1:
        dey
        lda (z_hl),y        ;Copy Data
        sta (z_de),y
        tya
        bne NextByteP1
```

Coding the Missile sprite (sprite 4)

The 4th 'Player' sprite is made up of the 4x two pixel missiles...
Because of this, we need to set the width in 4 different bit pairs...

We also need to align the Xpos of all 4 parts to make the single sprite.

Depending on our color settings, we can set each part separately, but it's more simple to set them with a shared color, and set them together - we do this with bit 4 of GTIA+$1B

```
;      ฟฟฟฟฟฟฟฟ
lda #%01010101      ;Width of sprite (Need to set all 4 parts)
sta GTIA+$000C

lda #120
sta GTIA+4          ;player Missile Part 1 Xpos
sec
sbc #4
sta GTIA+5          ;player Missile Part 2 Xpos
sbc #4
sta GTIA+6          ;player Missile Part 3 Xpos
sbc #4
sta GTIA+7          ;player Missile Part 4 Xpos


lda #88             ;Missile Color
sta GTIA+$19
;sta  GTIA+$12      ;Missile Parts colors
;sta  GTIA+$13          (When split - bit4 of GTIA+$1B)
;sta  GTIA+$14
;sta  GTIA+$15
```

We need to load the sprite data into the the ram for Sprite 4 (Missile) At $1B00 - again we need to add the Ypos offset. ($40 in this case)

```
        lda #<($1B00+$40)   ;Define Missile sprite
        sta z_E
        lda #>($1B00+$40)   ;Player 0 Ypos=$40
        sta z_D

        lda #<Sprite        ;Sprite Source
        sta z_L
        lda #>Sprite
        sta z_H

        ldy #(SpriteEnd-Sprite)+1   ;Length
NextByteMissile:
        dey
        lda (z_hl),y        ;Copy Data
        sta (z_de),y
        tya
        bne NextByteMissile
    endif
```

In this example we've used the two sprites to draw 'targets' onscreen...

The Player 0 sprite (Yellow) has been scaled super wide!

The weird hardware of the Atari probably goes back to the early days of pong!... the 4 player sprites would be the characters - and the 4 two pixel missiles would be the balls or bullets for those players.

Unfortunately it's not really very impressive by even the standards of the 80s!

Lesson P32 - Hardware sprites on the Atari Lynx

Sprites on the Lynx are not hardware sprites in the same sense as other systems, rather than a layer, the 'Suzy' Chip will quickly scale and render the sprite into our bitmap memory.

Lets Learn how!

SpriteTest.asm

Hardware Sprites

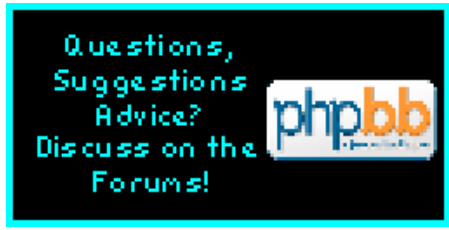
Unlike other systems, Lynx hardware sprites are not an extra layer! the 'Suzy' graphics chip draws the sprite into the Vram area of the 6502's addressable range

This may leave you wondering why not just do our sprites in software with the 6502... but the Suzy chip is VERY fast... it's a 16mhz 16 bit chip... and can even do dynamic scaling of sprites!

Sprites for the Suzy chip have to be held in RAM, and need a 'Sprite control block' to define the drawing of a sprite... this pointer is passed to the Suzy chip to get it to draw a sprite

My Akusprite Editor can Export Literal and RLE bitmaps... but lets take a look at the theory

Sprites can be 'Literal' (plain bmp) or 'RLE compressed' (defined by bit 7 of byte two of the SCB - SCBCTL1).... the colordepth is defined in SPRCTL0 (See later) Each line of a sprite starts with a byte - this an offset to the next line... effectively the number of bytes in the line +1 .... effectively the pointer to the next line. 1 or 0 in this position have special meanings!... 0 means the end of the sprite... 1 means the end of the 'quardrent'... note this is optional! Akusprite does not use it! Quadrent rendering is where the sprite is drawn in 4 sections from the middle... with a 1 byte marking each 1/4 of the sprite... (followed by another 'offset to next line' byte) the first quadrent is DownRight (default)... the second quadrent is UpRight the third quadrent is UpLeft)... the fourth quadrent is DownLeft Apparently there is a bug in the hardware - the last bit of each line must be 0! - we should always have a 0 at the end of our sprites to counter it - color 0 is transparent anyway! You can see a **Literal Sprite** to the right... the Literal bitmap data is in green, and the header bytes are in cyan	**Literal Sprite Example (BMP)** LynxSprite: db $8, $11, $11, $11, $11, $11, $10,0 db $8, $10, $0, $0, $0, $0, $10,0 db $8, $10, $04, $44, $44, $0, $10,0 db $8, $10, $04, $3, $04, $0, $10,0 db $8, $10, $04, $3, $04, $0, $10,0 db $8, $10, $04, $44, $44, $0, $10,0 db $8, $10, $0, $0, $0, $0, $10,0 db $8, $11, $11, $11, $11, $11, $10,0 db 0
RLE Sprite Data is a bit more tricky.... The first byte in a line is again an offset to the next line as before The next BIT will be a 'block definition'... defining what the following data is... 1 marks that the next data will be **LITERAL**	**4bpp RLE Sprite Example** db $8 (offset to next line)



0 marks that the next data will be **RLE** The next 4 bits will be the number of pixels to draw-1... so 0 means 1 pixel, and 15 means 16 pixels... we will call this **N** If the block is **RLE** the next 1/2/3/4 bits (depending on bitdepth) will be used for the color to fill the next **N** pixels If the block **LITERAL** the next **N** *(1/2/3/4) bits (depending on bitdepth) will be used for the color of the next N pixels the next bit will be the next 'block definition'... this pattern repeats until the line is done.	db %01111000,%00000000 (RLE block...16 pixels... Color 0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0) db %00001001,%10000000 (RLE block...2 pixles... Color 3,3) db %10010000,%10010001,%10000000 (Literal block...3 pixels... Color 1,2,3) (next line starts here)

Don't worry about all the work of creating bitmap data, just use AkuSprite Editor (or similar) to export valid bitmaps for the Lynx...

It's worth knowing the theory, but it's unlikely you'd really want to do things yourself.

The Source code

efore we can use sprites, we need to set up the screen hardware, defining the Ram area the sprites will be drawn to (in this case the same as the visible screen)... We also need to set any offset for sprite clipping - we're setting the first visible pixel at (8,8) We also need to send some bytes to the sprite hardware to initialize it - these are pretty fixed bytes and don't really need changing	```;Set screen ram pointer to $C000 lda #$00 sta $FD94 ;DISPADR Display Address L (Visible) sta $FC08 ;VIDBAS Base address of video build buffer L (Sprites) lda #$C0 sta $FD95 ;DISPADR Display Address H (Visible) sta $FC09 ;VIDBAS Base address of video build buffer H (Sprites) LDA #8 ;Offset STA $FC04 ;HOFF Offset to H edge of screen STA $FC06 ;VOFF Offset to V edge of screen ;Defaults for Sprite sys lda #%01000010 sta $fc92 ;SPRSYS System Cotrlol Bits (RW) ;Set to '$F3' after at least 100ms after power up for sprites lda #$f3 sta $FC83 ;SPRINT Sprite Initialization Bits (W)(U) ;let susy take bus (For sprites) lda #1 sta $FC90 ;SUZYBUSEN Suzy bus enable FF```
Our next stage is going to involve setting up a 'Sprite Control Block' (SCB)... we've got a template we're going to patch our settings into. The first byte defines the sprite type, in this example we're using a 16 color (4bpp) RLE sprite	

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Note: Our example won't use scaling, but you can do if you want, just change the WID and HEI bytes - $200 would make the sprite 2x larger

```
                ;Sprite Control block - we'll reprogram this for each sprite
Lynx_SCB:
                ;BBHV-TTT    SPRCTL0... B=bits per pixel (4/3/2/1)
                    ;H=hflip V=vflip T=type (7=normal)
                db %11000101
                ;LSRRPSU1    SPRCTL1... L=Literal (1=RLE) S=Sizing choice (0 only!)
                    ;RR=Reloadable depth (1=Use Size 3=Use Size,ScaleTilt)
                db %00010000        ;P=Palette reload (0=yes) s=skipsprite u=draw up l=draw left
                db 0            ;- SPRCOL - 0= OFF
                dw 0            ;Next SCB (0=none)
Sprite_Source:  dw $0000        ;Sprite pointer
Sprite_Xpos:    dw 70           ;Xpos
Sprite_Ypos:    dw 30           ;Yos
                dw $100         ;Wid ($100 = 100%)
                dw $100         ;Hei ($100 = 100%)
            ;   dw 0            ;Scale - not needed if B4,B5 of SPRCTL<3
            ;   dw 0            ;Tilt - not needed if B4,B5 of SPRCTL<2

                db $01,$23,$45,$67,$89,$AB,$CD,$EF  ;Palette - maps nibbles to colors
                                                    ;(useful for <4 bpp)

                ;End of SCB - just leave alone
                db 0        ;Collision Depository
                db 0        ;Identification number
                db 0        ;Z Depth
                dw 0        ;Last SCB
```

We're going to define a function called 'SetHardwareSprite'...

This will use zeropage entries z_hl to point to the sprite bitmap data.

z_ixl is the X position and z_iyl is the Y position of the sprite

The function handles the job of setting up the SCB, and calling the Suzy chip to draw the sprite to screen.

```
    lda #>Sprite    ;Sprite Ram Address
    sta z_h
    lda #<Sprite
    sta z_l

    lda #90
    sta z_ixl       ;Xpos
    lda #30
    sta z_iyl       ;Ypos

    jsr SetHardwareSprite
```

We need to load the address of the sprite into the SCB

We also set the X and Y position of the sprite

We also Initialize the start address of the SCB to $FC10/1

We're now ready to get Suzy to draw the sprite.

```
SetHardwareSprite:
    lda z_l
    sta Sprite_Source       ;Update Address of sprite ram in SCB
    lda z_h
    sta Sprite_Source+1

    lda z_ixl
    sta Sprite_Xpos         ;Set Sprite Xpos
    lda z_iyl
    sta Sprite_Ypos         ;Set Sprite Ypos

    lda #<Lynx_SCB
    sta $fc10               ;SCBNEXT.L - Address of next SCB
    ldy #>Lynx_SCB
    sty $fc11               ;SCBNEXT.H - Address of next SCB
```

We're ready to draw the sprite, we need to tell the Suzy chip to draw the sprite, and the allow Suzy to take over the ram bus...

We put the CPU to sleep with $FD91 while the sprite is drawing.

For *SOME REASON* the first byte of the SCB is getting altered in the process - I don't know why!

```
    ;-----E-S
lda #%00000101          ;1 SprStart + 4 Everon detector(?)
sta $FC91               ;SPRGO  Sprite Process start bit

stz $FD90               ;SDONEACK - Suzy Done Acknowledge (Sleep CPU)

stz $FD91               ;CPUSLEEP - Cpu Bus Request Disable (0=disable)

lda #%11000101          ;For some reason Byte 0 of the SCB gets altered!?
sta Lynx_SCB            ;Getting changed to %00101101 - I don't know why
```

In this example we've drawn the Cross-hair sprite to two positions onscreen.

Making a 6502 ASM Tron game... Photon1 - Introduction and Data Structures

---

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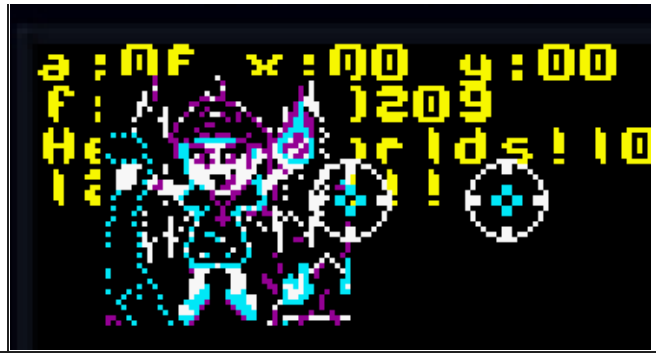


Usually hardware sprites are always onscreen even if the screen/tilemap is cleared··· but the Lynx is different.

We'll need to draw all the sprites again for the next frame - which is a pain, but unlike other systems, there is no limit to the number of sprites we have onscreen!

Lesson P33 - Hardware Sprites on the PC Engine (TurboGrafx-16)

The PC Engine is capable of 64 hardware sprites, each of which is 16 color, and is 16x16 in size.

This gives the PCE some pretty impressive graphical capabilities - lets learn how to make some sprites!

SpriteTest.asm

SATB sprite table

The Sprite table allows for up to 64 sprites... each one has 4 words of data - making 256 words in total... it's held in VRAM between $7F00 and $7FFF

Vram From	Vram To	Purpose
$0000	$03FF	Min Tilemap (Tiles 0-63)
$0400	$0FFF	Possible Tilemap (Tiles 64-255)
$1000	$7FFF	Tiles 256-2048
$7F00	$7FFF	SATB sprite table
$8000	$FFFF	PC-Engine only has 64k, so this is unused

The Sprite table allows for up to 64 sprites... each one has 4 words of data - making 256 words in total... the format is as follows

Word	F	E	D	C	B	A	9	8	7	6	5	4	3	2	1	0	Notes
1	-	-	-	-	-	-	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y=Ypos (64 is first visible line)
2	-	-	-	-	-	-	X	X	X	X	X	X	X	X	X	X	X=Xpos (32 is first visible line)
3	-	-	-	-	-	A	A	A	A	A	A	A	A	A	A	A	A=Address (Top 10 bits $trueaddress>>5)

4	YF	-	YS	YS	XF	-	-	XS	F	-	-	-	P	P	P	P	YF=Yflip XF=Xflip YS=Ysize XS=Xsize F=Foreground (infront of tilemap) P=Palette

Sprite Definitions

The basic sprite size is 16x16, though larger sprites can be created by tilling them, for up to 32x64.... only neighboring sprites can be tilled.

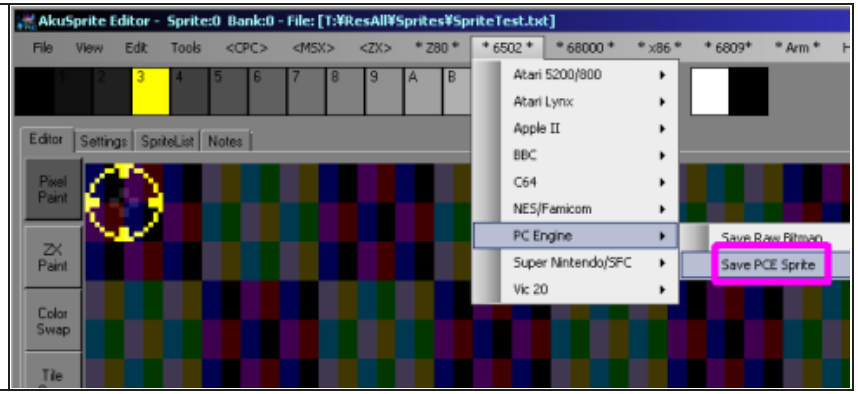
Sprites are NOT in the same format as the tilemap, they are 16x16 with 4 bitplanes, but each plane is sent separately

eg - lets look at a sprite, where all pixels are color 0 or color 15

First 16 bytes (Bitplane 1)	Second 16 bytes (Bitplane 2)	Third 16 bytes (Bitplane 3)	Fourth 16 bytes (Bitplane 4)
1110000000000111 1000000100000001 1000000100000001 0000000100000000 0000000100000000 0000000100000000 0000000100000000 0000000111111100 0011111110000000 0000000010000000 0000000010000000 0000000010000000 0000000010000000 1000000010000001 1000000010000001 1110000000000111	2220000000000222 2000000200000002 2000000200000002 0000000200000000 0000000200000000 0000000200000000 0000000200000000 0000000222222200 0022222220000000 0000000020000000 0000000020000000 0000000020000000 0000000020000000 2000000020000002 2000000020000002 2220000000000222	3330000000000333 3000000300000003 3000000300000003 0000000300000000 0000000300000000 0000000300000000 0000000300000000 0000000333333300 0033333330000000 0000000030000000 0000000030000000 0000000030000000 0000000030000000 3000000030000003 3000000030000003 3330000000000333	4440000000000444 4000000400000004 4000000400000004 0000000400000000 0000000400000000 0000000400000000 0000000400000000 0000000444444400 0044444440000000 0000000040000000 0000000040000000 0000000040000000 0000000040000000 4000000040000004 4000000040000004 4440000000000444

You don't need to worry about working out the sprite data for the PC-Engine format, you can export valid 16x16 sprites using my free Open Source
AkuSprite Editor!

It's included in the sources.7z file!



Sprites are stored in regular VRAM ($0000-$7EFF)... the sprite definitions are stored in special ram which we CANNOT ACCESS...however we can allocate a bank of 256 addresses (each containing one word) called STAB, and then get the hardware to copy that ram to the special ram... it's suggested you use $7F00 for that purpose.

To start the copy we just write the address to **Control Register $13**

Graphics Registers

Reg	Name	Meaning
$00	MAWR	Memory Address Write
$01	MARR	Memory Address Read
$02	VRR/VWR	Vram Data Write / Vram Data Read
$13	SATB	VRAM-SATB Block Transfer Source

Coding for sprites

Transfering Sprite Data

Transfering Data to VRAM is the same as with tiles, we specify a source in ram, destination in VRAM, and use DefineTiles to transfer the data to the VRAM

See **this tutorial** for details of how DefineTiles works

```
lda #<Sprite                    ;Source Bitmap data
sta z_L
lda #>Sprite
sta z_H

lda #<(SpriteEnd-Sprite)        ;Length of bitmap data
sta z_C
lda #>(SpriteEnd-Sprite)
sta z_B

lda #<$2000                     ;Destination in VRAM
sta z_E
lda #>$2000
sta z_D

jsr DefineTiles                 ;Send data to Vram
```

We're going to create a function called 'SetHardwareSprite' to do the heavy lifting for us...

We'll use zero page entries to define the settings for our sprite

A is the hardware sprite number

z_IXH/L will define the X position
z_IYH/L will define the Y position

z_H will set the size & flipping options

z_L will select the layer and palette

z_DE is the top 11 bits of the address of the sprite data in VRAM (Bits XXXXXXXX XXX-----) - we get them by bitshifting the address with >>5

```
lda #0          ;X - Pos
sta z_ixh
lda #96
sta z_ixl

lda #0
sta z_iyh       ;Y - Ypos
lda #128
sta z_iyl

;;Palette and options

    ; Y-yyX--x  ;Y= Yflip y=ysize / X=xflip x=xsize
lda #%00000000  ;size allows tilling for up to 32x64
sta z_h
    ; F---PPPP - F=Foreground / P=Palette
lda #%10000000
sta z_l

lda #>$2000>>5  ;Sprite address (Top 11 bits - High Byte)
sta z_d
lda #<$2000>>5  ;Sprite address (Top 11 bits - Low Byte)
sta z_e
lda #0
jsr SetHardwareSprite
```

Setting a hardware sprite

We're going to need to use the memory mapped hardware graphics ports at $0100/2/3 - and the equivalent ST0/1/2 commands when we're writing fixed values

First the function needs to select the VRAM address of the sprite settings - to do this we multiply the sprite number by 4, and select the address (Starting at $7Fxx) by writing to Register $00 (with ST0)

```
SetHardwareSprite:      ;A=Hardware Sprite No. IX = X , IY=Y ,
    pha                     ;D,E = Source Data, HL=Palette etc

        asl                 ;4 bytes per sprite
        asl

        ;$7Fxx Sprite Table (copy in ram) 4 bytes per sprite x 64 sprites

        st0 #0      ;sta $0100      ;Select Write Address ($00)

        sta $0102   ;st1            ;Low Byte of address  (Sprite x 4)
        st2 #$7F    ;sta $0103      ;High Byte of address ($7Fxx)
```

We need to select Register $02 (with ST0) as we now want to write bytes to the $7Fxx range we selected before...

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We write our Ypos, Xpos, Sprite address and Attributes to vram - as the address autoincs, we don't need to do anything else!

```
st0 #2    ;sta $0100    ;Data Write ($02)

lda z_iyl               ;Ypos (64 is visible top left corner)
sta $0102 ;st1
lda z_iyh
sta $0103 ;st2

lda z_ixl               ;Xpos  (32 is visible top left corner)
sta $0102 ;st1
lda z_ixh
sta $0103 ;st2

lda z_e                 ;Sprite Address >>5
sta $0102 ;st1
lda z_d
sta $0103 ;st2

lda z_l                 ;Sprite Attributes
sta $0102 ;st1
lda z_h
sta $0103 ;st2
```

OK, the data is in VRAM, but that's not enough to change the visible sprites, we need to initiate a copy of the VRAM to the STAB sprite table...

We do this by writing the VRAM address of our sprites ($7F00) to reg $13

```
;Update the STAB address to force a copy to the graphics hardware

st0 #$13  ;sta $0100          ;VRAM-SATB Block Transfer Source
st1 #$00  ;sta $0102
st2 #$7F  ;sta $0103
```

The sprites will now be visible on screen!

In this example we've only looked at a 16x16 sprite, but the PC engine can combine tiles to make sprites up to 32x64, we just need to set more patterns and set the bits to make the sprite bigger.

Lesson P34 - Hardware Sprites on the NES / Famicom

The NES and Famicom use a graphics system called the PPU - they are also Tile / Sprite based systems, with a grid of 8x8 tiles in the background.

Lets learn to use the sprites to draw a 16x16 graphic!

BmpTest.asm

Sprites

for Pixel Plotting

Learn 65816 Assembly: 8 and 16 bit modes on the 65816

SNES - ASM PSET and POINT for Pixel Plotting

ARM Assembly Lesson H3

Lesson P65 - Mouse reading on the Sam Coupe

Mouse Reading in MS-DOS

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Atari 800 / 5200 - ASM PSET and POINT for Pixel Plotting

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Making a 6502 ASM Tron game...
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Sprites on the nes are defined by 256 bytes of OAM memory- 4 bytes per sprite
The byte is selected by setting the OAM-address with memory location $2003 - effectively with 4x the sprite number... then by writing the 4 bytes to $2004 (the OAM address autoincs)

Byte	Purpose	Bits	Meaning
1	Ypos	YYYYYYYY	
2	Tilenum	TTTTTTTT	
3	Attribs	VHB---PP	Vflip Hflip Background priority Palette
4	Xpos	XXXXXXXX	

PPU Graphics ports

To directly alter the sprites, we'll use use ports $2003 and $2004... $2003 selects the OAM address... then we write the 4 bytes to $2004... this can only be done during VBLANK - so it's better to use a buffer, and transfer it to VRAM during Vblank.

Port	Name	Bits	Details	Notes
$2003	OAMADDR		Sprite address	(0-255)
$2004	OAMDATA		Sprite data (to write to addr, autoincs)	

Pattern Definitions for sprites and tiles

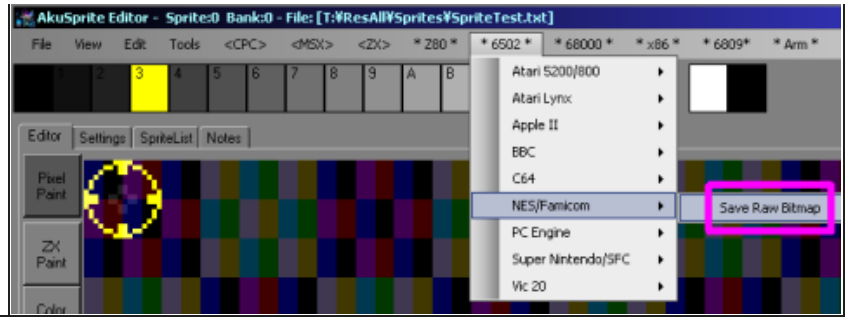
The NES has 2 pattern tables, they are selected with PPU Register $2000 Bit 4 & 3
Basic NES roms have pattern definitions in ROM (CHR-ROM), but we can use a mapper with extra video ram to make things easier - in these tutorials we'll use Mapper 2 - so we don't have to worry about CHR-ROM and can change the patterns whenever we like!

The Famicom uses bitplanes for it's data - 2 bitplanes for 4 colors... this means a tile uses 16 bytes
First we send all 8 lines of the first bitplane, Next we send all 8 lines of the second bitplane.

	Byte Data		Byte Data
First 8 bytes	00111100	Second 8 bytes	00222200
	01111111		02222222
	01100011		02200022
	01100011		02200022
	01111111		02222222
	01100011		02200022
	01100011		02200022
	00000000		00000000

If you want to create NES sprites, my AkuSprite editor can export valid format data.

It's included in the Sources.7z - and is free and open source.



We can set up sprites in two ways, directly by writing to the OAM, or by making a buffer, and using the DMA to copy it...

The DMA way is better... but first we'll look at the 'simpler' direct way.

Simple Sprite Example

Sprite data in VRAM is the same as tile data, so we can just use our **DefineTiles** function to transfer it.

We covered **DefineTiles** in a previous lesson...

```
lda #<Sprite                    ;Source Bitmap data
sta z_L
lda #>Sprite
sta z_H

lda #<(SpriteEnd-Sprite)        ;Length of bitmap data
sta z_C
lda #>(SpriteEnd-Sprite)
sta z_B

lda #<$0C00                     ;Pattern 192 in Vram
sta z_E
lda #>$0C00
sta z_D

jsr DefineTiles                 ;Send data to Vram
```


We're going to create a function called 'SetHardwareSprite' to do the job of talking to the hardware.

A is the hardware sprite number

z_IXL will define the X position
z_IYL will define the Y position

z_L will select the flipping option and palette

z_E is the tile number

First we need to wait for VBLANK - we use the **WaitFrame** function we wrote

before for this...

Then we multiply A by 4 - as there are 4 bytes per sprite... we write A into $2003 - selecting the address in the OAM for the sprite we'll change...

We write all 4 bytes to $2004 - it automatically increments the destination address in the OAM, so these 4 writes set the sprite data...

Writing to the OAM messes up the scroll position, so we have to reset it with our **ResetScroll** function

```
;A=Hardware Sprite No. B,C = X,Y , D,E = Source Data, H=Palette etc
SetHardwareSprite:

    jsr waitframe       ;Can only change OAM during VBLANK

    pha
        asl         ;4 bytes per sprite - 64 sprites total
        asl
        sta $2003       ;Select OAM address of sprite

        lda z_iyl       ;Ypos
        sta $2004

        lda z_E         ;Tilenum
        sta $2004

        lda z_l         ;Attribs VHB---PP Vflip  Hflip
        sta $2004           ;Background priority  Palette

        lda z_ixl       ;Xpos
        sta $2004

    jsr ResetScroll     ;Writing to OAM messes up scroll
```

We're going to show a 16x16 sprite... but sprites on the NES are 8x8 - so we're going to need 4 of them to show our image

The top corner of the sprite will be at position ($40,$40) - and we're using Palette 0 for the sprite...

We're going to use zero page entries z_IXL,z_IYL and z_L to define settings for our 'SetHardwareSprite' function - but we'll use X and Y as temporary registers too - as we build up the 4 sprites.

```
;Common settings for our 16x16 Crosshair (4 sprites)

lda #$40
tax
sta z_ixl       ;Xpos $40

lda #$40
tay
sta z_iyl       ;Ypos $40

lda #0
sta z_l         ;Palette 0
```

We're going to use Hardware sprite 0 for the first part - so we set A to 0... and we loaded our tile patterns into Tile 192... so we set z_e to 192

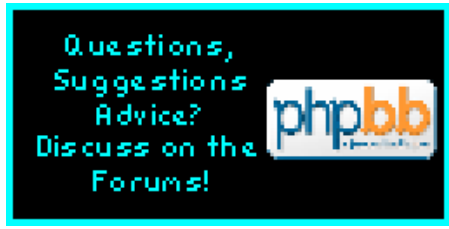
We now call our function to set the sprite.

```
;Define the 4 parts of the sprite

lda #192
sta z_e                     ;Tile 192

lda #0                      ;Sprite 0

jsr SetHardwareSprite       ;Top Left
```

We need to do the same for the other 3 hardware sprites...

We use the X,Y registers we set up before, and add 8 to offset them for the new locations, we also INC z_E to alter the tile number, we set A each time for the hardware sprite numbers

	A	z_E	z_IXL	z_IYL
Pos	Hardware Sprite	Pattern	Xpos	Ypos
Top Left	0	192	$40	$40
Top Right	1	193	$40+8	$40
Bottom Left	2	194	$40	$40+8
Bototm Right	3	195	$40+8	$40+8



```
txa
clc
adc #8                          ;Move X+8
sta z_ix1

inc z_e                         ;Tile 192
lda #1                          ;Sprite 1

jsr SetHardwareSprite           ;Top Right

txa
sta z_ix1                       ;Reset X

tya
clc
adc #8                          ;Move Y+8
sta z_iy1

inc z_e                         ;Tile 193
lda #2                          ;Sprite 2

jsr SetHardwareSprite           ;Bottom Left

txa
clc
adc #8                          ;Move X+8
sta z_ix1

inc z_e                         ;Tile 194
lda #3                          ;Sprite 3

jsr SetHardwareSprite           ;Bottom Right
```


The Code above works... but waiting for the VBLANK all the time is not a realistic way of doing things... instead we can allocate 256 bytes of ram, write changes to the OAM there, then send them all in one go using a DMA!

Lets learn how!

Using a buffer, and copying during Vblank

Address	Purpose	Bits	Detail
4014h	SPR-RAM DMA Register (W)	HHHHHHHH	High byte of ram address to copy to OAM, EG: $02 copies $0200-$02FF

Our 'SetHardwareSprite' code is almost the same, just this time we're storing into the buffer,

We'll transfer the data into the actual OAM during our interrupt handler

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```
;A=Hardware Sprite No. B,C = X,Y , E = Source Tile, H=Palette etc
SetHardwareSprite:
    pha
        asl
        asl
        sta z_c             ;Multiply sprite number by 4

        tya
        pha
            lda #SpriteBuffer/256   ;Spritebuffer at $0300-03FF
            sta z_b

            ldy #0

            lda z_iyl       ;Ypos
            sta (z_bc),y
            iny

            lda z_E         ;Tilenum
            sta (z_bc),y
            iny

            lda z_l         ;Attribs VHB---PP Vflip  Hflip
            sta (z_bc),y        ;Background priority  Palette
            iny

            lda z_ixl       ;Xpos
            sta (z_bc),y
        pla
        tya
    pla
    rts
```

Address $FFFA of our rom is the interrupt handler
We can create an interrupt handler of our own, and put it's address at $FFFA

```
org $FFFA
ifdef CustomNmihandler
    dw CustomNmihandler     ;FFFA - Custom VBLANK handler
else
    dw nmihandler           ;FFFA - Interrupt handler
endif
```

To copy our buffer of the sprites into the OAM, we just write the top byte of the buffer address to $4014...

So if our buffer is at $0300, we write $03

```
CustomNmihandler:
    pushall
        lda #SpriteBuffer/256   ;Data to copy to sprites
        sta $4014               ;Start Spirte DMA transfer to OAM
```

Lesson P35 - Hardware Sprites on the SNES / Super Famicom

Of course the SNES has some pretty powerful hardware sprites - but unfortunately they're not the most simple!

Lets learn how we can easily create some 8x8 sprites and get them to the screen!

BmpTest.asm

Sprite Definitions - Overview

[Making a 6502 ASM Tron game... Photon1 - Introduction and Data Structures]

Gaming + more:

[Emily The Strange (DS) - Live full playthrough]

[$150 calculator: Unboxing the Ti-84 Plus CE (eZ80 cpu)]

Sprites use as special bank of 512 bytes of 'OAM' memory for their definitions... they also use standard VRAM for the pattern data.
In theory the Pattern data can be relocated... but in practice it's best to just assume it's at $4000 (address in 16 bit words)
Sprites can be various sizes - a 'default size' is set for all sprites... and certain selected sprites can be double size...
this is, however a bit tricky... lets say you have the default size as 8x8... and one double size 16,16 sprite
If we point this sprite 'double size' 16x16 sprite to pattern 'Tile 0', the 4 8x8 chunks will be made up of tile numbers:

1	2
16	17

Lets look at this example of a 16x16 sprite in AkuSprite Editor... Akusprite editor is designed for 8x8 sprites, but we can export a 16x16 one in the following way

If we want to export this quickly, so we can use it as a single doublesize sprite, one option is to tick the 'FixedSize' tickbox, and set the size to 128,16

This will export the sprite correctly - of course there will be a lot of unused space in the exported file... so we would want to combine all our 16x16 together into a single image

16x16 tiles are rather a pain··· so even though our sprite today is 16x16 - we'll actually make it up out of 8x8 tiles anyway!

Sprite Definitions - Ports Used

Address	Name	Purpose	Bits	Details
$2101	OBSEL	OAM size (Sprite)	SSSNNBBB	S=size N=Bame addr B=Base addr
$2102	OAMADDL/L	OAM address	LLLLLLLL	a=oam address L
$2102	OAMADDL/H	OAM address	R000000H	R= priority Rotation / H=oam address MSB
$2104	OAMDATA	OAM data	????????	???????? Data to write to OAM ram
$212C	TM	Main screen designation	---S4321	S=sprites 4-1=enable Bgx
$2138	OAMDATAREAD	Read data from OAM	????????	???????? Data read from OAM ram

Sprite Definitions - OAM Data

Selecting a HL address is done by setting registers $2102 (L) and $2103 (H)
Each address below $0100 holds Two Bytes (The first table)...each address $0100 or above holds just one!... All data is written via the $2104
Note, Sprites use Palettes from 128... so the color palette used is the value in CCC +128
Sprite data should only be written to Vram during Vsync.

Address	Byte 1	Byte 2	Meaning	SprNum
$0000	XXXXXXXX	YYYYYYYY	X=Xpos (bits 0-7) Y=Ypos	0
$0001	YXPPPCCCT	TTTTTTTT	Y=yflip X=xflip P=priority compared to BG (C=palette +128)	0
$0002	XXXXXXXX	YYYYYYYY	X=Xpos (bits 0-7) Y=Ypos	1
$0003	YXPPPCCCT	TTTTTTTT	Y=yflip X=xflip P=priority compared to BG (C=palette +128)	1
$00FE	XXXXXXXX	YYYYYYYY	X=Xpos (bits 0-7) Y=Ypos	127
$00FF	YXPPPCCCT	TTTTTTTT	Y=yflip X=xflip P=priority compared to BG (C=palette +128) T= Tile Pattern number	127
$0100	SXSXSXSX	(no 2nd byte)	S=doubleSize sprite X=Xpos (bit 8)	0-3
$0101	SXSXSXSX	(no 2nd byte)	S=doubleSize sprite X=Xpos (bit 8)	4-6
$011F	SXSXSXSX	(no 2nd byte)	S=doubleSize sprite X=Xpos (bit 8)	124-127

Programming a Sprite Example!

We're going to define a 16x16 sprite... but we'll do it with 4 smaller 8x8 sprites...

First we need to define some bitmap data... we used AkuSprite editor to export the sprites, then we need to send the data to VRAM

```
lda #<Sprite            ;Source Bitmap data
sta z_L
lda #>Sprite
sta z_H

lda #<(SpriteEnd-Sprite);Length of bitmap data
sta z_C
lda #>(SpriteEnd-Sprite)
sta z_B

lda #<($4000+16)        ;Skip tile 0
sta z_E                     ;(for unused sprites to be hidden)
lda #>($4000+16)
sta z_D

jsr DefineTiles         ;Send data to Vram
```

We'll use a 'SetHardwareSprite' function to do the work... we'll look at it in a moment!

We need to set the X position in zero page entries z_IXH&L (a 16 bit pair)

We need to set the X position in zero page entries z_IYH&L (a 16 bit pair)

The Pattern number for the first part one of the sprite is 1... we store it in z_h

We need to define the priority of the sprite... we store it in z_l
We can also set the palette... NOTE Sprites use palette 128+

Finally we set A to the hardware sprite number... our first part will be sprite 0 (Top Left)

```
lda #<32    ;Xpos = 32
sta z_ixl   ;(Add 512 for doublesize sprite)
lda #>32
sta z_ixh

lda #<100   ;Ypos = 100
sta z_iyl
lda #>100
sta z_iyh

lda #1
sta z_h     ;Tile Pattern Num

    ;YXPPPCCCT - Y=yflip X=xflip P=priority compared to BG...
lda #%00110000      ; C=palette +128 T= Tile Pattern number
sta z_l

lda #0      ;Spritenum 0

jsr SetHardwareSprite   ;Draw One!  ;;;;;;;;;;;;;;;;;;;;;;;;
```

Now we need to do the 2nd part... We add 8 to the X position, increase our tile

number, and set our hardware sprite to 1.

We draw the second part (Top Right)

```
lda #8      ;Xpos + 8
clc
adc z_ix1
sta z_ix1

inc z_h     ;tile +1
lda #1      ;Spritenum

jsr SetHardwareSprite   ;Draw One!  ;;;
```

We're going to do the 3rd part... we move the Xpos left 8, and the Ypos down 8

We increase our tile number again, set our hardware sprite to 2

We draw the third part (Bottom Left)

```
lda #-8     ;Xpos - 8
clc
adc z_ix1
sta z_ix1

lda #8      ;Ypos + 8
clc
adc z_iy1
sta z_iy1

inc z_h     ;tile +1
lda #2      ;Spritenum

jsr SetHardwareSprite   ;Draw One!  ;;;
```

Last part! We increas the Xpos by 8, Increase the Tilenum again... and set the hardware sprite to 3

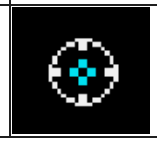
We now draw the last part (Bottom Right)

```
lda #8      ;Xpos + 8
clc
adc z_ix1
sta z_ix1

inc z_h     ;tile +1
lda #3      ;Spritenum

jsr SetHardwareSprite   ;Draw One!  ;;;;
```

The result can be seen here.



Setting a hardware sprite

Ok, Lets look at that SetHardwareSprite function... but first we need to set up sprites to work!

We need to turn on the sprite layer, and also define the default memory... in these tutorials we have our sprite ram defined as memory address $4000

```
;Set Sprite defaults

    ; ---S4321 - S=sprites 4-1=enable Bgx
lda #%00010001      ;Turn on BG1+Sprites
sta $212C           ;Main screen designation [TM]

    ; SSSNNBBB - S=size N=Name addr B=Base addr
lda #%00000010      ;Set Sprite pos to $4000
sta $2101           ;OAM settings
```

OK, we're ready to start setting up our sprite...

We need to write 4 bytes into the first part of the OAM... the VRAM addresses are 16 bit, so each is 2 bytes... This means we need to double the sprite number to calculate the OAM address for the hardware sprite.

We then write the 4 main parameters to the OAM

```
SetHardwareSprite:
    tay             ;Lets do the main 4 definitions

      asl           ; Double Sprite number
                    ;(2 bytes per address - 2 addresses)
      sta $2102     ;Address L
      lda #0
      sta $2103     ;Address H

      lda z_ix1
      sta $2104     ;X-pos
      lda z_iy1
      sta $2104     ;Y-pos
      lda z_h
      sta $2104     ;Tile pattern
      lda z_1
      sta $2104     ;Attribs
    tya
```

OK, the next bit is a real pain...
The last bit of the Xpos, and the 'Doublesize' parameter for each sprite is combined into a single byte with 4 other sprites!... GRR!

We need to work out which address to work with, so we divide the sprite number by 4, and read in from the $01xx range to get the current state of the address (as it holds 3 other sprites info!)

```
  ;4 sprites Attr2 are combined into one Attr2

  and %11111100         ;Work out which one to change by sprite num
  lsr
  lsr
  pha
      sta $2102         ;Address L
      lda #1
      sta $2103         ;Address H ($01xx)

      lda $2138         ;Get current attr2
      sta z_as
  pla
  sta $2102             ;Address L
  lda #1
  sta $2103             ;Address H
```

OK, We need to work out the position of the bits we need to change, and move the two bits of our passed z_ixh into that position...

To do this we define a 'Mask' - we then shift both the Mask and our data into the correct position depending on the 2 low bits of our sprite number (0-3)... this is because 4 sprites are combined into the same byte

```
  lda #%11111100      ;Prep the mask
  sta z_b

  tya
  and #%00000011      ;Get low 2 bits of sprite num
  tax

  lda z_ixh
  and #%00000011      ;Two bits we want to store in attr2

  cpx #0              ;Shift bits ------sx into correct position
  beq SpriteSkipShift
SpriteShiftAgain:
  asl
  asl           ;Shift new val
  asl z_b
  asl z_b       ;Shift mask
  dex
  bne SpriteShiftAgain
SpriteSkipShift:
```

Now we've got our mask, we use it to clear the 2 bits of the old value...

Now we OR in the new value, and write the result to VRAM...

We've finished the sprite!

```
pha
    lda z_as        ;Get back current value
    and z_b         ;Apply mask
    sta z_as        ;Get back current value
pla
ora z_as            ;Or in Old value to new one
sta $2104           ;Store it!
rts
```

The SNES is capable of a large number of 16 color sprites, but it's a little difficult in some ways, the 16x16 tiles are harder to use than it feels they should be, and the layout of the OAM makes setting the sprites a little tricky.

for Pixel Plotting

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Still, the fact we can use 128 hardware sprites onscreen easily is certainly a bonus!

Lesson P36 - Hardware Sprites on the C64

The Commodore 64 is capable of 8 hardware sprites on screen at the same time - and they can be 2 or 4 color just like the bitmap screen, but they don't need to be the same color depth as the screen, or even as each other... lets learn more!

SpriteTest.asm

Technical Details of Hardware Sprites

The Sprite pointers for the bitmap data, are a single byte... multiplying the sprite pointer by 64 will give the address of the sprite *within the 16k bank of Vram* (so must be in the range $0000-$3FFF)
$1000-$2000 and $9000-$A000 are seen by the VIC as character ROM, so sprites cannot be in this area!

Sprites are 21 vertical lines and 63 bytes each...
In 1bpp (2 color) mode this makes sprites 24x21...
In 2bpp (4 color) mode they are 12x21...

In both modes, Color 0 is Transparent

In 2bpp mode color 1,2 are read from $D025/6... and color 3 is the sprite color.

We're going to map the screen to the $4000-$8000 range - out the way of our program (which starts at $0800) and the rottern character rom (which appears at $1000-$2000 and $9000-$A000)

This means we've changed our Font routines, and GetScrPos routine for any bitmap sprite functions as well!

Address	Purpose	Bits	Meaning
$07F8-$07FF	Sprite pointers (default - will change if screen moved)	SSSSSSSS	s*64=memory address
$D000	Sprite #0 X-coordinate	XXXXXXXX	(only bits #0-#7).
$D001	Sprite #0 Y-coordinate	YYYYYYYY	
$D002	Sprite #1 X-coordinate	XXXXXXXX	(only bits #0-#7).
$D003	Sprite #1 Y-coordinate	YYYYYYYY	
$D004	Sprite #2 X-coordinate	XXXXXXXX	(only bits #0-#7).
$D005	Sprite #2 Y-coordinate	YYYYYYYY	

$D006	Sprite #3 X-coordinate	XXXXXXXX	(only bits #0-#7).
$D007	Sprite #3 Y-coordinate	YYYYYYYY	
$D008	Sprite #4 X-coordinate	XXXXXXXX	(only bits #0-#7).
$D009	Sprite #4 Y-coordinate	YYYYYYYY	
$D00A	Sprite #5 X-coordinate	XXXXXXXX	(only bits #0-#7).
$D00B	Sprite #5 Y-coordinate	YYYYYYYY	
$D00C	Sprite #6 X-coordinate	XXXXXXXX	(only bits #0-#7).
$D00D	Sprite #6 Y-coordinate	YYYYYYYY	
$D00E	Sprite #7 X-coordinate	XXXXXXXX	(only bits #0-#7).
$D00F	Sprite #7 Y-coordinate	YYYYYYYY	
$D010	Sprite #0-#7 X-coordinates	76543210	(bit #8)
$D015	Sprite enable register	76543210	1=on
$D017	Sprite double height register	76543210	
$D01B	Sprite priority register	76543210	
$D01C	Sprite multicolor mode register	76543210	0=2 color 1=4color
$D01D	Sprite double width register	76543210	
$D01E	Sprite-sprite collision register	76543210	
$D01F	Sprite-background collision reg	76543210	
$D025	Sprite extra color #1	----CCCC	
$D026	Sprite extra color #2	----CCCC	
$D027	Sprite #0 color	----CCCC	
$D028	Sprite #1 color	----CCCC	
$D029	Sprite #2 color	----CCCC	
$D02A	Sprite #3 color	----CCCC	
$D02B	Sprite #4 color	----CCCC	
$D02C	Sprite #5 color	----CCCC	
$D02D	Sprite #6 color	----CCCC	
$D02E	Sprite #7 color	----CCCC	

Palette

0	1	2	3	4	5	6	7
8	9	A	B	C	D	E	F

Coding to support Hardware Sprites

We need to store our sprites in the 16k bank with our Screen Ram... but this will cause us a problem
The Stack and Zeropage are $0000-$0200, the screen is at $0400-$0800, our program is at $800+, the Screen Bitmap is at $2000-$4000 - We've not got much memory left!

This wouldn't be too bad if $1000-$2000 was free, but it isn't! In the VIC-20 terms this area is used by the Character Rom!...

```
ifdef C64_ScrBase4000
    lda $DD00
    and #%11111100
    ora #%00000010  ;Screen base at %4000 range
    sta $DD00
endif
```

We're going to move the screen to the $4000-$8000 range - out of the way of the program, and the Character rom (it uses $1000-$2000 AND $9000-$A000)

We move the screen to $4000-$7FFF by changing bits 0 and 1 of $DD00 to %0000010

We'll need to change our font code to write to the same area, or we won't see our text.

We're going to need to alter particular bits of the registers depending on the sprite number,

To facilitate this, we're going to use a lookup table of bits and bitmasks to clear and set the values by sprite number.

```
LookupBits:     db %00000001,%00000010,%00000100,%00001000,%00010000,%00100000,%01000000,%10000000
LookupMaskBits: db %11111110,%11111101,%11111011,%11110111,%11101111,%11011111,%10111111,%01111111
```

Ok, we're going to define our SetHardwareSprite function to do the job of drawing a sprite...

First we need to set the correct bit in $D015 - we do this by moving the sprite number to Y, and ORing in the bit from

```
;  A=Hardware Sprite Number
;z_IX=Xpos
;z_IY=Ypos
; z_H=Pointer to sprites /64
; z_L=%-XY4CCCC 4=4color mode C= sprite color X=doubleX Y=doubleY
SetHardwareSprite:
        tay                 ;Sprite Number
        and $D015
        ora LookupBits,y    ;Turn on Sprite Y
        sta $D015           ;Sprite on
```

We're going to use bit 4 from z_L - and set the 4 color mode accordingly in $D01C

To do this we'll use 'C64SpriteConvertToMask'... it will return a mask for the sprite bit in A... and 1 or 0 depending on the bit of z_L anded with A

```
lda #%00010000      ;Want bit 4 form z_L
jsr C64SpriteConvertToMask
and $D01C
ora z_as
sta $D01C           ;4 color
```

C64SpriteConvertToMask ANDS in z_L

If the result is zero, we set z_as to zero, and load in the mask to keep the bits other than bit Y
if the result is one, we set z_as so bit Y is 1, and load in the mask to keep the bits other than bit Y

This gives us the function we need!

```
C64SpriteConvertToMask:
        and z_l             ;Mask one of the bits in z_L
C64SpriteConvertToMaskB:
        beq C64SpriteConvertToMaskZero
        lda LookupBits,y    ;Bit Y=1
C64SpriteConvertToMaskZero:
        sta z_as
        lda LookupMaskBits,y ;Mask to clear bit
        rts
```

We now want to do the same for $D017 (DoubleHeight) and $D016 (DoubleWidth) using different bits of z_L

```
lda #%00100000      ;Want bit 5 form z_L
jsr C64SpriteConvertToMask
and $D017
ora z_as
sta $D017           ;DoubleHeight

lda #%01000000      ;Want bit 6 form z_L
jsr C64SpriteConvertToMask
and $D01D
ora z_as
sta $D01D           ;DoubleWidth
```

We're now going to load the 1 byte pointer (Address in VRAM /64) and save it to $07F8+SpriteNum

Next we store the color (in the bottom nibble of z_L) and store it into $D027+SpriteNum	`lda z_h`
	`sta ScrBase+$07F8,y ;Pointer`
	
	`lda z_l`
	`and #%00001111`
	`sta $D027,y ;Color`

We need to store 9 bits of the X position, and we treat the 9th bit in the same way as the other functions , where all these 9th xbits are held in $D010... We use our C64SpriteConvertToMask to do the job, but this time we AND with z_xh	`lda #%00000001`
	`and z_ixh`
	`jsr C64SpriteConvertToMaskB`
	`and $D010`
	`ora z_as`
	`sta $D010 ;8th bit of X`

Ok, we need to write the X and Y position - but these are next to each other in memory...
 	
To write them to the correct addresses, we double the sprite number in Y, and write the Low X byte to $D000+Y and the high byte to $D001+Y
 	
Phew! We're finally done!
	`tya`
	`asl ;Double Y`
	`tay`
	
	`lda z_ixl`
	`sta $D000,y ;X-pos`
	
	`lda z_iyl`
	`sta $D001,y ;Y-pos`
	
	`rts`

Using our function for a test

First we need to copy our sprite data into the correct location in vram...
 	
In our test our Screen base is $4000 - so we'll load the sprites to $5000
 	
we use the LDIR command to copy z_BC bytes from z_HL to z_DE
	`lda #<Sprite ;Source Bitmap data`
	`sta z_L`
	`lda #>Sprite`
	`sta z_H`
	
	`lda #<(SpriteEnd-Sprite) ;Length of bitmap data`
	`sta z_C`
	`lda #>(SpriteEnd-Sprite)`
	`sta z_B`
	
	`lda #<(ScrBase+$1000) ;Will only work when scrBase @ $4000`
	`sta z_E ;Due to CHAR ROM`
	`lda #>(ScrBase+$1000)`
	`sta z_D`
	
	`jsr LDIR ;Copy sprite to correct address in VRAM`

Ok lets set one of the sprites! We set z_IXH/L to the Xpos... We set z_IYH/L to the Ypos we need to calculate the Position in z_h... we take the OFFSET of our sprite (Sprite-Vase= $5000 -$4000=$1000) - and divide this value by 64... Remember, each sprite is 64 bytes in size! All the other settings are in z_L... Sprite Color, XY scaling, and 4 color mode bit. We set A to a number 0-7 to select the hardware sprite we want to change.	

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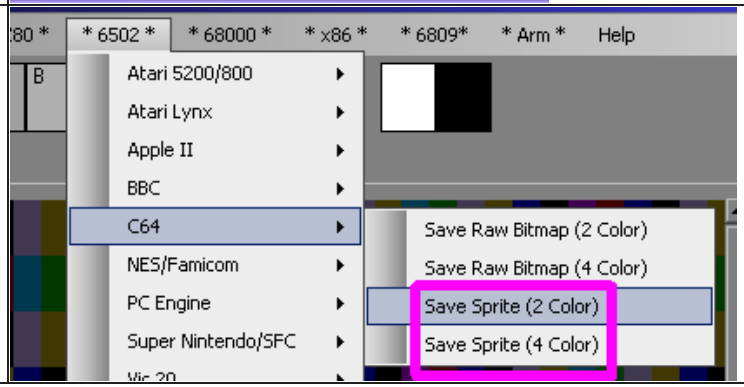
```
lda #<200           ;Xpos
sta z_ix1
lda #>200
sta z_ixh

lda #<150           ;Ypos
sta z_iy1
lda #>150
sta z_iyh

lda #($1000/64)     ;Sprite Ram base
sta z_h                 ;relative to Screen Base

    ; -XY4CCCC  4=4color mode C= sprite color X=doubleX Y=doubleY
lda #%01111111
sta z_1

lda #0              ;Hardware Sprite Number
jsr SetHardwareSprite
```

Here we've drawn two hardware sprites, a streched 4 color one, and 2 color one

If you want to create valid bitmap data for sprites, you can use my AkuSprite Editor... it's what I used to create the test sprites for this tutorial!



The C64 is capable of 8 sprites at one time, but if we're very clever, and switch the sprite data while the screen is drawing, we can up this to 8 sprites per line?
Lets say there's 8 sprites on the top line of the screen... if we move those sprites to the bottom of the screen when the middle is being drawn - we'll double our sprites - we'd have to move them back before the start of the screen is drawn again!

It's complex - and beyond the scope of this tutorial, but it's what the best C64 games do to make the most of the hardware!

Lesson P37 - Screen settings with the CRTC on the BBC Micro!

The BBC Screen uses the same CRTC chip as the Amstrad CPC - and

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allows for reshaping and reconfiguration of the screen - lets take a look, and see what the settings do to the visible screen

BBC_CRTC_Test.asm

The CRTC Registers

The CRTC 6845 handles the display, it will size and position, and define the memory used by the screen...

In theory there are 17 registers, but in practice ones such as the Lightpen and Cursor registers may not be any use to us... the most interesting registers are marked in **Yellow**

Reg	Abbrev	Name	Range	Bits	Mode 0	Mode 1	Mode 2	Mode 3	Mode 4	Mode 5	Mode 6	Mode 7	Details
0	**HTOT**	**Horizontal Total**	0-255	DDDDDDDD	127 ($7F)	127 ($7F)	127 ($7F)	127 ($7F)	63 ($3F)	63 ($3F)	63 ($3F)	63 ($3F)	Physical width of screen
1	**HDISP**	**Horizontal Displayed**	0-255	DDDDDDDD	80 ($50)	80 ($50)	80 ($50)	80 ($50)	80 ($50)	40 ($28)	40 ($28)	40 ($28)	Logical width in Chars
2	**HSYNC**	**Horizontal Sync Position**	0-255	DDDDDDDD	98 ($62)	98 ($62)	98 ($62)	98 ($62)	49 ($31)	49 ($31)	49 ($31)	51 ($33)	Logical Xpos
3	**V/HWID**	**Horiz. and Vert. Sync Widths**	0-15,0-15	VVVVHHHH	40 ($28)	40 ($28)	40 ($28)	40 ($28)	36 ($24)	36 ($24)	36 ($24)	36 ($24)	Hsync / Vsync area size
4	**VTOT**	**Vertical Total**	0-127	-DDDDDDD	38 ($26)	38 ($26)	38 ($26)	30 ($1E)	38 ($26)	38 ($26)	30 ($1E)	30 ($1E)	Physical height of screen
5	**VADJ**	**Vertical Total Adjust**	0-31	---DDDDD	0 ($0)	0 ($0)	0 ($0)	0 ($0)	0 ($0)	0 ($0)	0 ($0)	0 ($0)	Scanline Offset
6	**VDISP**	**Vertical Displayed**	0-127	-DDDDDDD	32 ($20)	32 ($20)	32 ($20)	25 ($19)	32 ($20)	32 ($20)	25 ($19)	25 ($19)	Logical Height in Chars
7	**VSYNC**	**Vertical Sync position**	0-127	-DDDDDDD	34 ($22)	34 ($22)	34 ($22)	27 ($1B)	34 ($22)	34 ($22)	27 ($1B)	27 ($1B)	Logical Ypos of screen
8		**Interlace and Skew**	0-3	------DD	1 ($1)	1 ($1)	1 ($1)	1 ($1)	1 ($1)	1 ($1)	1 ($1)	2 ($2)	0/2=off 1/3=on
9	**MR**	**Maximum Raster Address**	0-31	---DDDDD	7 ($7)	7 ($7)	7 ($7)	9 ($9)	7 ($7)	7 ($7)	9 ($9)	18 ($12)	Scanlines per Char row
10		**Cursor Start Raster**	0-127	-DDDDDDD	0	0	0	0	0	0	0	0	Unneeded
11		**Cursor End Raster**	0-31	---DDDDD	8 ($8)	8 ($8)	8 ($8)	9 ($9)	8 ($8)	8 ($8)	9 ($9)	19 ($13)	Unneeded
12	**DISPH**	**Display Start Address**	0-63	--HHHHHH	8 ($8)	8 ($8)	8 ($8)	8 ($8)	8 ($8)	8 ($8)	8 ($8)	8 ($8)	Screen Address H
13	**DISPL**	**Display Start Address**	0-255	LLLLLLLL	48 ($30)	48 ($30)	48 ($30)	48 ($30)	48 ($30)	48 ($30)	48 ($30)	48 ($30)	Screen Address L
14	**CURH**	**Cursor Address H**	0-63	--HHHHHH	0	0	0	0	0	0	0	0	unused
15	**CURL**	**Cursor Address L**	0-255	LLLLLLLL	0	0	0	0	0	0	0	0	unused
16	**LPH**	**Light Pen Address**	0-63	--HHHHHH	0	0	0	0	0	0	0	0	Read Only

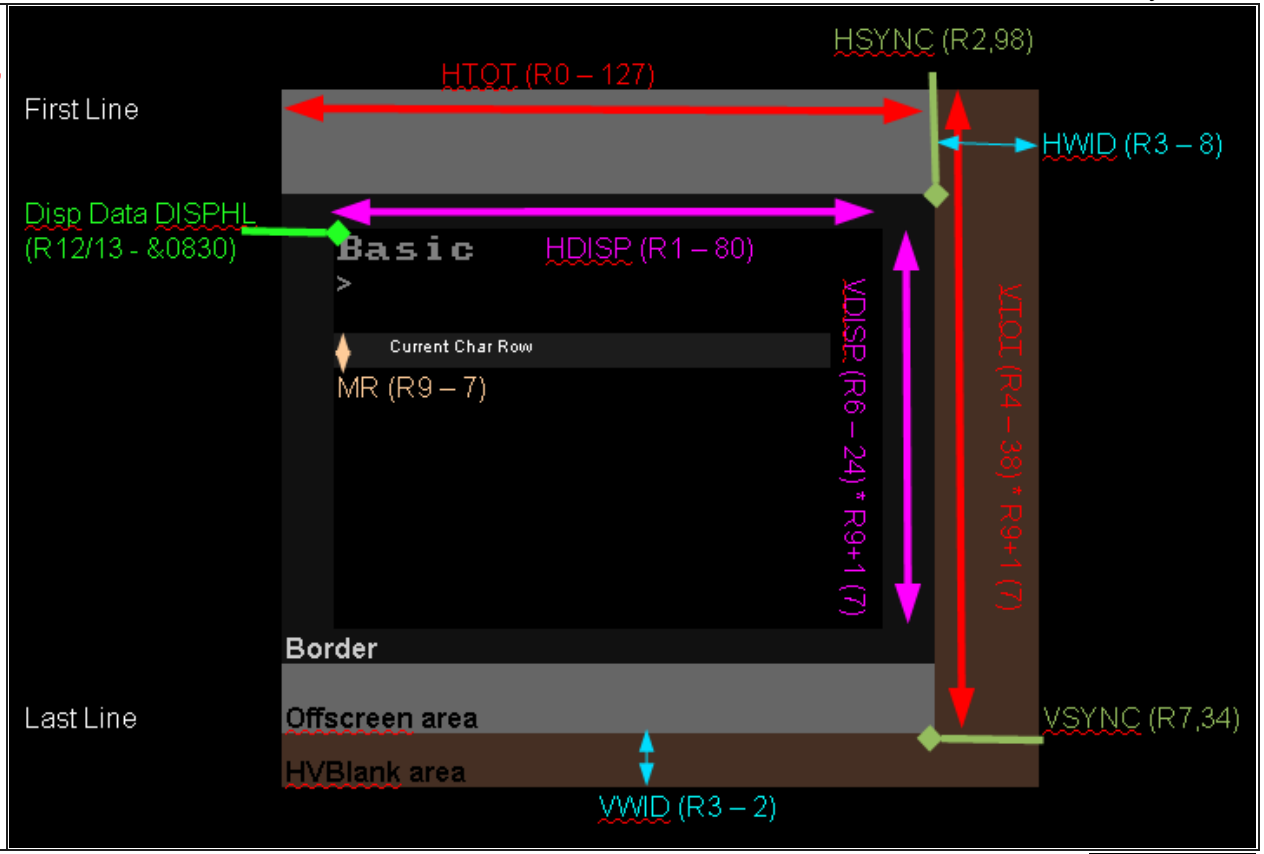
17	LPL	Light Pen Address	0-255	LLLLLLLL	0	0	0	0	0	0	0	0	Read Only

The Various registers will define the width, height and starting position of the screen.

Each screen mode will have a set of recommended registers settings (shown in the chart above), but we can resize the screen in some cases to make a smaller screen - and we may wish to do this to save memory if we don't need a 'full size' screen.

By altering Reg12 we can effect hardware page flipping with **Double Buffering** - by allocating one memory area for a visible buffer, and a second for the drawing area, we can make sure the viewer won't see the screen redraw.

In addition, we can alter Reg12+13 to effect a Horizontal or Vertical **Hardware scroll** - but this will expose other areas of Ram, which weren't used by the screen before.



Beware! While BeebEM recrates some of the registers - it seems it does not 'accurately' emulate a real monitor... some of the settings which may work fine on the emulator, may not work correctly on a real BBC (or may risk damage to the display in the worst situations.)

Using and Testing the registers!

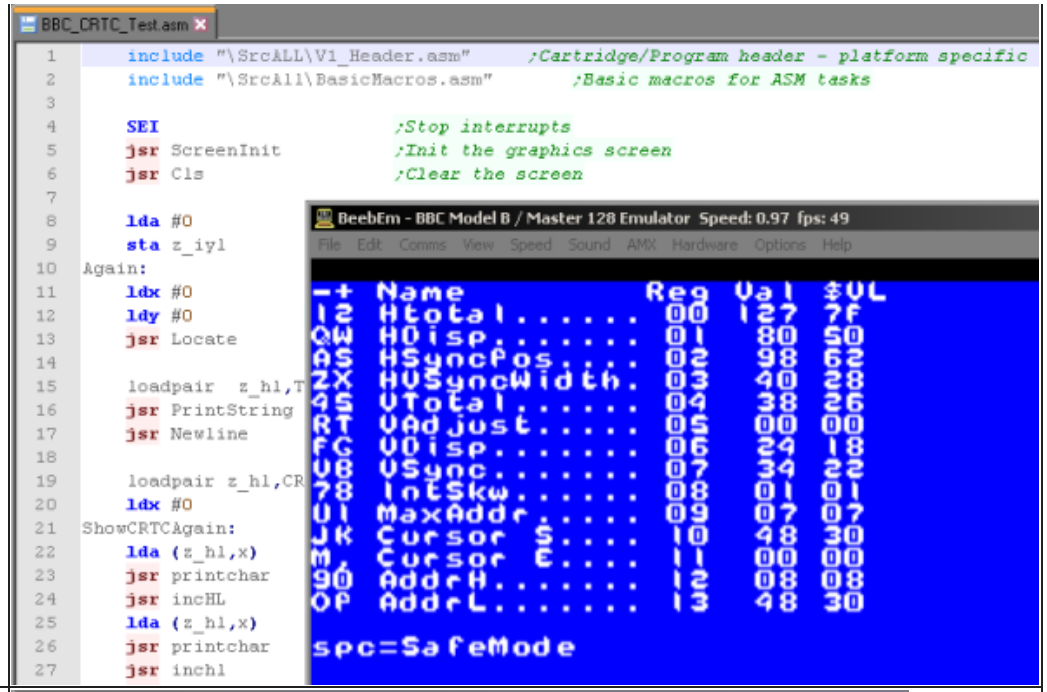
We're going to define a function called SetCRTC - it will use A as the new value for CRTC register z_C

We select a register using $FE00 - then set the new value for that register with $FE01

```
SetCRTC:
    pha
        lda z_c      ;$FE00=CRTC Reg select
        sta $FE00
    pla
    sta $FE01        ;$FE01=CRTC Val select
    rts
```

We're not going to look at the program code - it's long and not particularly related to the CRTC - what it does is let us see the changes to each register onscreen!

To use it, compile 'BBC_CRTC_Test.asm'



On the left are **two letters** - these are keys you can press to change the register - for example J and K will change the address of the start of the screen!

Try the keys - you'll see the settings in VAL (decimal) and &VL (hex) and the effect onscreen!

Because our text drawing code hasn't changed, Altering AddrH will make the screen look weird - we'd need to reprogram our drawing code to accommodate our new settings to make it all work seamlessly..

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It's very easy to use some setting that are impossible to view, and now we can't see the settings any more!

The tool has a Safe Mode to get around this...
Press Space... this will turn on safe mode!

In Safe Mode, the settings you choose will be applied for an instant, and then it will flip back to the defaults - so you can see the effect of the settings you chose, and still see all the options on a normal screen

This program just allows you to test what each register does - and find suitable settings for the screen size and position you need...

Once you've done that, you'll need to reprogram your sprite, font and other drawing routines to work with the new screen position and orientation.

Lesson P38 - Character Block Graphics on the PET

The PET does not have bitmap graphics, what it does have is the full combination of possibilities of a 2x2 'block' pixels defined as characters.

We can use these for simple graphics.

PET_Bitmap.asm
PET_Bitmap2.asm

Character Map

The PET has a character map of 128 characters... when the top bit (bit 7) is 1, these characters will be inverted - we'll need to use a combination of both for the block graphics.

The early PET had a single upper case character map... later systems had a second character map with lower case... The block characters used in this lesson exist in both.

We can switch between the two by writing to register $E84C...

Write #12 to $E84C	Write #14 to $E84C

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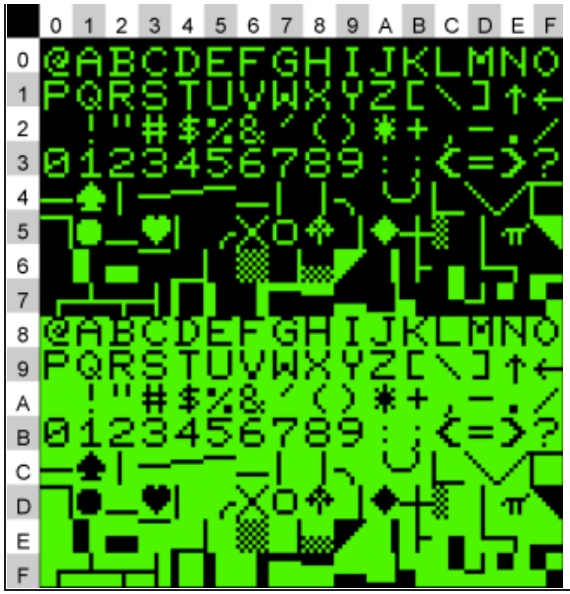
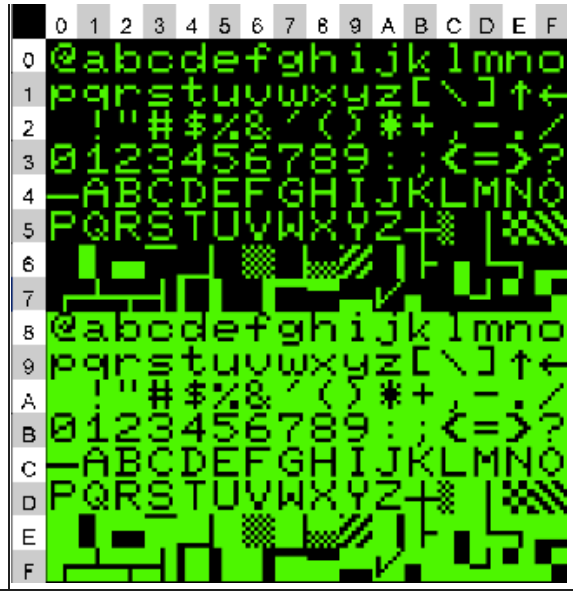




VRAM Addresses

The screen is 40x25 characters... or 80x25 on later models.

Putting a character onscreen is easy!... we just write a character to memory address $8000 onwards.

Our formula for an address on the 40 char wide screen is Vram Address = $8000+ (Ypos*40)+Xpos
Our formula for an address on the 80 char wide screen is Vram Address = $8000+ (Ypos*80)+Xpos

```
GetVDPScreenPos:    ; Get Screen address BC=XYpos in z_DE
    lda #$80            ;Screen base is $8000
    sta z_d

    txa                 ;Xpos
    ifdef ScreenWidth32
        clc
        adc #4
    endif
    sta z_e

    tya                 ;Ypos
    beq GetVDPScreenPos_YZero
GetVDPScreenPos_Addagain:   ;Repeatedly add screen width
    clc                         ;Y times
    lda z_e
    ifdef DoubleWidth
        adc #80         ;80 bytes per line
    else
        adc #40         ;40 bytes per line
    endif
    sta z_e
    lda z_d
    adc #0          ;Add Carry
    sta z_d

    dey
    bne GetVDPScreenPos_Addagain
GetVDPScreenPos_YZero:
    rts
```

When we want to move down a line, we just add 40 or 80 to our memory address.

```
GetNextLine:                ;Move z_DE down a line
    clc
    ifdef DoubleWidth
        lda #80             ;Move Dest down 1 line
    else
        lda #40             ;Move Dest down 1 line
    endif
    adc z_e
    sta z_e                 ;Update Low byte
    lda z_d
    adc #0                  ;Update High byte with carry
    sta z_d
    rts
```


The character blocks

if we imagine the character block as 4 pixels in a 2x2 grid, there are 16 possible combinations.
Here are the 16 - Shown separated by 'Club' symbols.

Here is the bytes that produce this pattern.

The character numbers for these are a bit erratic... the ones >$80 are inverted - we have to invert half the characters to make the patterns we need.

Note, the 'club' character here is ASCII 'X'

```
BitPatterns:
    db 'X',$60,'X',$7E,'X',$7C,'X',$E2
    db 'X',$7B,'X',$61,'X',$FF,'X',$EC
    db 'X',$6C,'X',$7F,'X',$E1,'X',$FB
    db 'X',$62,'X',$FC,'X',$FE,'X',$E0
    db 0
```

Showing our 'bitmap'

Here is the routine we'll use to show a bitmap.

It's pretty simple, it copies lines of bytes from the source to screen ram, moving down a line after each line.

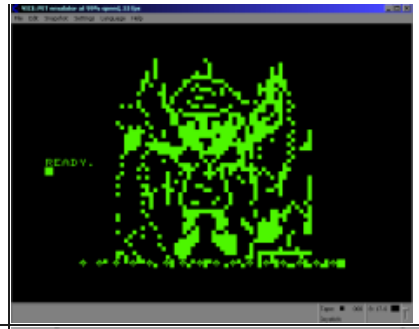
```
ShowBitmap: ;Show Zero terminated 'bitmap' from z_HL to z_DE
            ;Size (W,H) z_B,z_C

    ldy z_b             ;Width
ShowBitmapH:
    dey
    lda (z_hl),y        ;Transfer one char
    sta (z_de),y
    cpy #0              ;Transfer bytes until char 0
    bne ShowBitmapH     ;next Char

    jsr GetNextLine     ;Next Dest line

    clc
    lda z_b             ;next line of source data.
    adc z_l
    sta z_l
    lda z_h
    adc #0
    sta z_h

    dec z_c
    bne ShowBitmap      ;Next line
    rts
```

When we want to show a bitmap, we first calculate the destination address in Vram with GetVDPScreenPos,

We then specify the source data into zero page pair z_hl, and specify our bitmap size before using ShowBitmap.

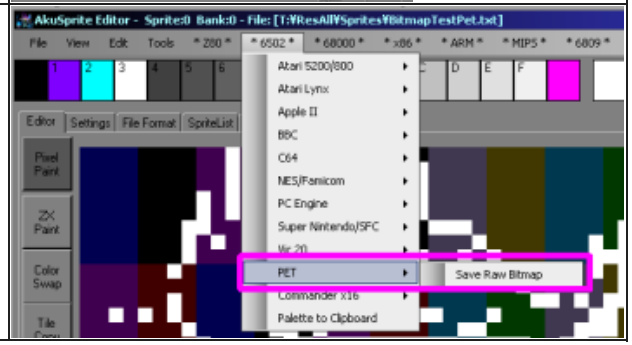
```
ldx #8
ldy #0
jsr GetVDPScreenPos     ;Get Vram Address in z_DE

loadpair z_hl,Bitmap    ;Source bitmap
lda #24
sta z_b     ;Wid
lda #24
sta z_c     ;Hei
jsr ShowBitmap
```

Here is the result!



If you want to create a 'bitmap' for the PET, you can do it with my **Akusprite editor**.

It will take a bitmap, and covert it to bytes that represent the correct characters - it's what was used for this tutorial!.



The PET doesn't have any graphics modes that can do bitmaps, and unlike its successor the VIC-20, it also cannot have 'redefined' character codes.

We'll have to make do with these characters in the charset for any 'game graphics'... but that's kind of the charm of these old systems!

Lesson P39 - Key reading on the PET

In this episode we'll learn how to read in from the keyboard,
We'll read in keys, and use them to simulate the Up,Down,Left,Right and Fire of a controller - we'll use this for games later!

PET_V1_ReadJoystick.asm

The PET Keyboard

The Keyboard of the pet is split into 10 'Blocks' (0-9)... we select one of these by writing to memory mapped port $E810,

We then read from $E812 - this will return the state of each of the keys in that block ('Row' of the key matrix) - each key will be represented by one bit... a value of 1 means that key is not pressed... a value of 0 means the key is pressed!

```
lda #6          ;Row Number 6
sta $E810       ;Select a 'Row'

lda $E812       ;Get the keys of that row (0=pressed)

jsr ShowHex ;(Z,C,B,M,Full stop,Return,Num1,Num3)
```

For example... Suppose we want test the Return key... this is in group 6, so we write #6 to port $E810... we then read back from $E812 - among the other keys, Bit 5 (PB5) will represent the state of Return... this row also includes Z,C,B,M,Full stop, Num1 and Num3 !

The keys matrix layout is shown below:

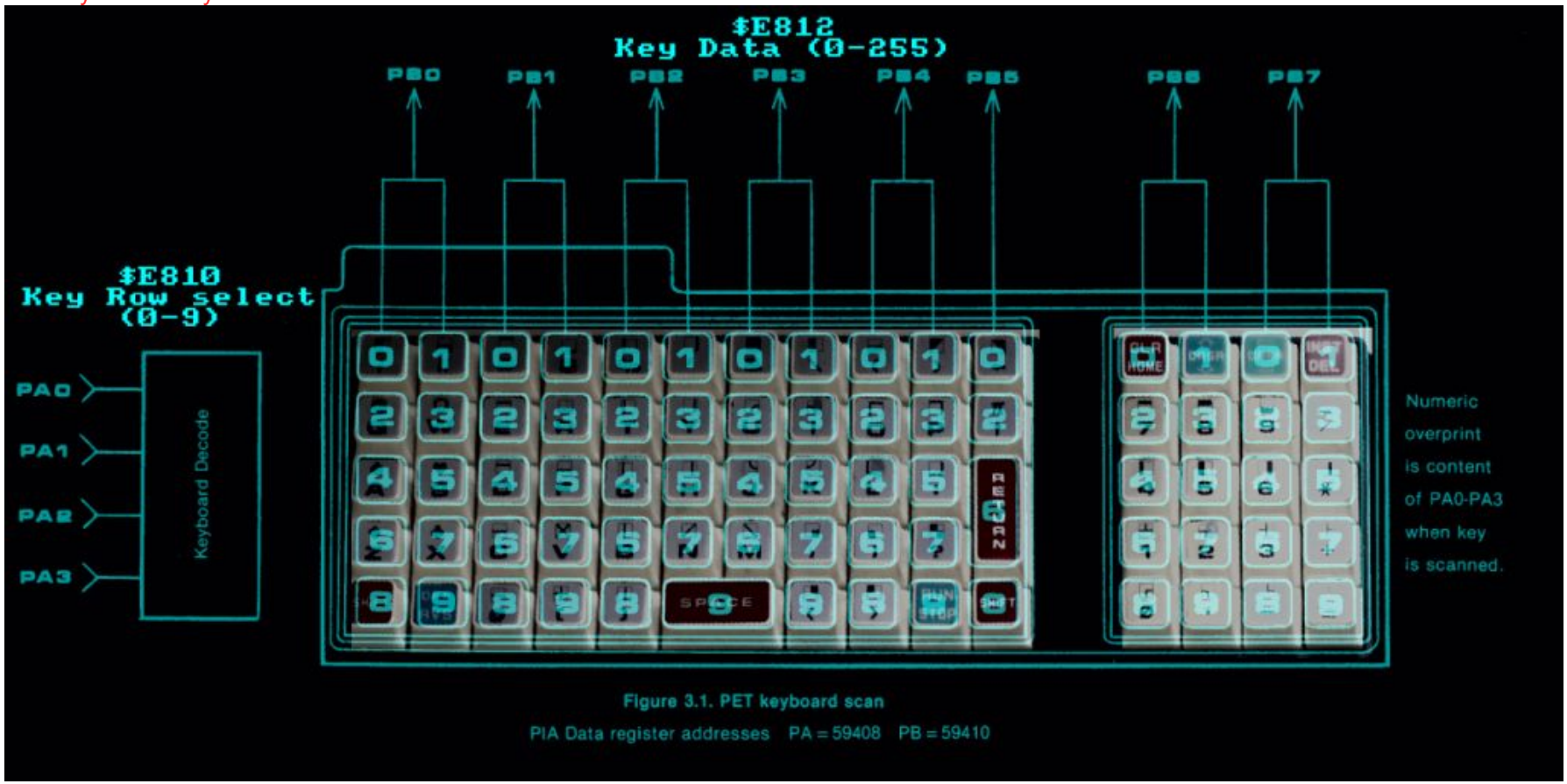


Figure 3.1. PET keyboard scan

PIA Data register addresses PA = 59408 PB = 59410

Simulating a joystick

We're going to read in the numpad, and use 8,2,4 and 6 as directions so we can port Y-quest and Grime to the PET

We're going to create a function called "TestCursorBit" - this will test a bitmask in X of row A , and shift a bit into zero page entry z_H

```
TestCursorBit:
    pha
        sta $E810           ;Select line
        txa
        and $E812           ;test key
        clc                 ;Clear carry (Pressed)
        beq TestCursorBitB
        sec                 ;Set carry (not pressed)
TestCursorBitB:
        rol z_h             ;shift the key into the buildup
    pla
    rts
```

We'll use this function to read in the 4 directions, and space and enter as fire buttons!

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```
Player_ReadControlsDual:    ;--21RLDU
    lda #255
    sta z_h                 ;Cursor buildup
    sta z_1                 ;Unused

    lda #6
    ldx #%00100000          ;Fire 2 (Enter)
    jsr TestCursorBit

    lda #9
    ldx #%00000100          ;Fire 1 (Space)
    jsr TestCursorBit

    lda #4
    ldx #%10000000          ;Right (Numpad 6,
    jsr TestCursorBit

    ;lda #4
    ldx #%01000000          ;Left (Numpad 4)
    jsr TestCursorBit

    lda #7
    ;ldx #%01000000         ;Down (Numpad 2)
    jsr TestCursorBit

    lda #3
    ;ldx #%01000000         ;Up (Numpad 8)
    jsr TestCursorBit
    rts
```

The PET didn't come with a joystick port, however it is possible make a converter and connect one via the parallel port.

However, for simplicity, we'll stick to the built in keyboard for our game-controller needs!

Lesson P40 - Sound on the PET

While the PET didn't come with a speaker, it's possible to add one to the external IO port.

We can then use it to make simple beeps... Lets learn how!

PET_V1_ChibiSound.asm

PET Sound!

The PET is capable of up to 4 octaves... one of 3 possible pairs can be selected with $E84A.

Address **$E84B** will turn the sound on or off... we write #16 to turn it on, #0 to turn it off.
Address **$E84A** can be used to select the Octave with value 15/51/85
Address **$E848** can be used to select the note, a value of 64-255 should be passed.

It is not possible to set the volume, or play multiple tones at the same time.

Note Freq	octave=15		octave=51		octave=85	
	Octive 0	Octive 1	Octive 1	Octive 2	Octive 2	Octive 3

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B	251	125	251	125	251	125
C	238	118	238	118	238	118
C#	224	110	224	110	224	110
D	210	104	210	104	210	104
D#	199	99	199	99	199	99
E	188	93	188	93	188	93
F	177	88	177	88	177	88
F#	168	83	168	83	168	83
G	158	78	158	78	158	78
G#	149	74	149	74	149	74
A	140	69	140	69	140	69
A#	133	65	133	65	133	65

(Sound info taken from the **PetFaq**)

Sfx with Chibisound!

These tutorials use a sound 'driver' called ChibiSound,
Chibisound uses a single byte parameter in the Accumulator, and provides 64 different pitches, in low or high volume with either tones or noise.
Sending a value of 0 mutes sound, all other values make a tone...

Chibisound is intended to make it simple to have SFX in multiplatform games and was used in Grime Z80 and Grime 6502

7 6 5 4 3 2 1 0

T V P P P P P P

T=Tone
V=Volume
P=Pitch

Writing Chibi Sound!

We turn the sound on or off with $E84B.

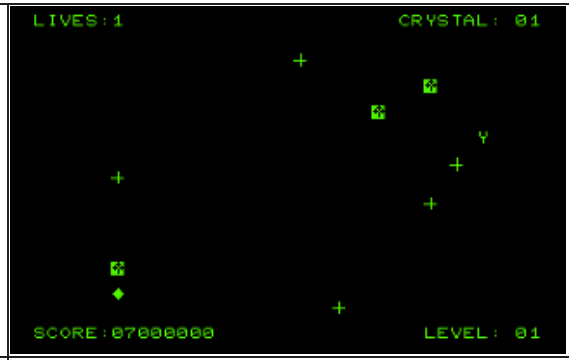
We select our tone with $E848... Chibisound only uses one octive, setting $E848=15

```
ChibiSound: ;NVPPPPPP - N=Noise V=Volume P=Pitch

;Note the PET can't really do Volume or Noise.

    pha
        lda #16     ;16= sound on ... 0=off
        sta $E84B
    pla
    beq silent
    tax
    and #%00111111
    rol
    rol
    ora #%00000011
    sta $E848
    lda #15     ;octive (15/51/85)
    sta $E84A
ChibiSoundFinish:
    rts
silent:
        lda #0      ;16= sound on ... 0=off
        sta $E84B
    rts
```


Now we've got graphics, sound and input routines we can port Yquest and Grime to the PET!

We'll have to use graphics characters for our game graphics!

We have to use Ascii characters for all the graphics of Yquest and Grime.



Rather than sprite bitmap data, these games use a 'list' of graphics characters to use for each object and frame of animation.

```
SpriteImages:
    db $00+$19,$00+$58,$00+$5A,$00+$58,$00+$56,$00+$23,$00+$2B,$00+$2
    db $00+$19,$80+$58,$00+$5A,$80+$58,$00+$5B,$00+$23,$00+$2B,$00+$2
    db $00+$19,$00+$58,$00+$5A,$00+$58,$00+$56,$00+$23,$00+$2B,$00+$2
    db $00+$19,$80+$58,$00+$5A,$80+$58,$00+$5B,$00+$23,$00+$2B,$00+$2
```

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