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| MICROCOM GPU v1.0 MANUAL |
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| A hardware and software guide to using the Microcom GPU  10103  Authored by: J.Nock |



10103

Contents

[Technical Specifications 4](#_Toc48229049)

[Memory Map & Registers 5](#_Toc48229050)

[Memory map for EP4CE10 FPGA: 5](#_Toc48229051)

[Verilog HDL notes: 6](#_Toc48229052)

[MAGGIEs 7](#_Toc48229053)

[MAGGIE Registers 8](#_Toc48229054)

[BP2RAST\_cmd 9](#_Toc48229055)

[Bits 7-6 – Text\_mode\_master / text\_mode\_slave 9](#_Toc48229056)

[Bit 4 – mode\_565 9](#_Toc48229057)

[Bit 3 – BART enable 9](#_Toc48229058)

[Bit 2 – 16\_bit\_mode 9](#_Toc48229059)

[Bits 1-0 – Video Mode / pixels per byte 9](#_Toc48229060)

[Text Mode 10](#_Toc48229061)

[DEFAULT MAGGIE SETTINGS 12](#_Toc48229062)

[PALETTES 13](#_Toc48229063)

[ARGB4444 Palette 13](#_Toc48229064)

[Host IO ports 14](#_Toc48229065)

[PS/2 DATA PORT 14](#_Toc48229066)

[PS/2 STATUS REGISTER 14](#_Toc48229067)

[Hardware-Accelerated Graphics engine 15](#_Toc48229068)

[Hardware Commands 16](#_Toc48229069)

[X & Y registers 16](#_Toc48229070)

[Set destination screen memory pointer (124-127) 16](#_Toc48229071)

[Set source screen memory pointer (120-123) 17](#_Toc48229072)

[Set destination raster bytes-per-horizontal line – X[2] (115) 17](#_Toc48229073)

[Set source raster bytes-per-horizontal line – Y[2] (114) 17](#_Toc48229074)

[Set destination raster bytes-per-horizontal line – X[3] (113) 18](#_Toc48229075)

[Set source raster bytes-per-horizontal line – Y[3] (112) 18](#_Toc48229076)

[Set max width & height of screen – X[0]/Y[0] (95) 18](#_Toc48229077)

[Set max width & height of screen – X[1]/Y[1] (94) 19](#_Toc48229078)

[Set max width & height of screen – X[2]/Y[2] (93) 19](#_Toc48229079)

[Set max width & height of screen – X[3]/Y[3] (92) 19](#_Toc48229080)

[Clear pixel collision counter (91) 20](#_Toc48229081)

[Clear blitter copy pixel collision counter (90) 20](#_Toc48229082)

[Appendix A – Character Codepage 24](#_Toc48229083)

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| Technical Specifications Depending on the FPGA used in the uCOM GPU card, the following features will be available in varying capacities. Listed below are *minimum specifications* based on an Intel EP4CE6 FPGA (used in development of the prototype GPU):   * 22KB FPGA graphics RAM, plus 1 KB for palettes * 7 graphics layers * 640x480 resolution at 60 fps (VGA) * Various palettes from 4,096 colours   An Intel EP4CE10 FPGA (used in the first proper video card) provides the following:   * 40KB FPGA graphics RAM, plus 1 KB for palettes * 10 graphics layers   **NOTE:** *All 16-bit words in the uCOM GPU are big-endian*. |
|  |

|  |
| --- |
| Memory Map & Registers The uCOM GPU uses a vacant 512 KB slot in the host system’s memory space – see the uCOM’s manual for more information on this. This 512 KB window is filled with the GPU’s own RAM – if the GPU has less than 512 KB of RAM, accessing memory above the GPU’s upper memory limit will return FF values and be read-only (writes will be ignored). *Only the last 16 bytes of the last page of the 512KB will return anything other than FF, and this will be the BANK\_ID as per the uCOM’s memory specifications. This is a pseudo-ROM location, with a value returned from a hardwired value in the HDL of the FPGA.* Memory map for EP4CE10 FPGA:  * 0000-01FF – GPU HW registers:   + **00-07** = H&V triggers for 4 yellow test cursors   + **0C-0D** = H&V reset coordinates for all 15 MAGGIE\_Layer#s   + **10-13 + 4\*MAGGIE\_Layer#** = H&V top left edge of each MAGGIE\_Layer# window   + **60 + 10\*MAGGIE\_Layer#** = 16 byte controls for each of the 15 MAGGIE layers * 0200-11FF – Default IBM VGA 8x16 font. * 1200-9FFF – Video RAM (for text buffers / sprite data)   + **1200-1B5F** – Typical memory space for a full screen of text * A000-A3FF – Palettes:   + **A000-A1FF** – primary palette (ARGB4444)   + **A200-A3FF** – secondary palette (RGB565)   Without text you can mix 10 on-screen sprites, or 1 text layer and 8 sprites. Other than a RAM limitation, there are no other output limitations. Any mode and any resolution with any palette may all be mixed simultaneously onscreen. Verilog HDL notes: NUM\_LAYERS = 2 through 15 = 2 layers through 15 layers.  PALETTE\_ADDR = Sets the base address for the 2 palettes.  Palettes occupy the last 1024 bytes of GPU RAM. If the RAM ends on 2^ADDR\_SIZE (i.e. 32768), then (2\*\*ADDR\_SIZE)-1024 can be used to set PALETTE\_ADDR, otherwise PALETTE\_ADDR must be set explicitly to the last 1KB of available GPU RAM. Obviously, this depends on the amount of RAM available in the FPGA used. |
| MAGGIEs The **M**ultiple **A**ddress **G**enerator and **G**raphic **I**nstruction **E**ngines are the workhorses of the GPU. There are 10 MAGGIEs in the smallest system, numbered 0-6.  All MAGGIEs have their HV resets set to HV\_Trigger 0C & 0D.  MAGGIE top-left window X/Y positions:   * MAGGIE0 at HV\_Trigger 0010-11 & 0012-13 * MAGGIE1 at HV\_Trigger 0014-15 & 0016-17 * MAGGIE2 at HV\_Trigger 0018-19 & 001A-1B * MAGGIE3 at HV\_Trigger 001C-1D & 001E-1F * MAGGIE4 at HV\_Trigger 0020-21 & 0022-23 * MAGGIE5 at HV\_Trigger 0024-25 & 0026-27 * MAGGIE6 at HV\_Trigger 0028-29 & 002A-2B * MAGGIE7 at HV\_Trigger 002C-2D & 002E-2F * MAGGIE8 at HV\_Trigger 0030-31 & 0032-33 * MAGGIE9 at HV\_Trigger 0034-35 & 0036-37   MAGGIE register addresses – 16 bytes for each MAGGIE:   * MAGGIE0 – 0060 * MAGGIE1 – 0070 * MAGGIE2 – 0080 * MAGGIE3 – 0090 * MAGGIE4 – 00A0 * MAGGIE5 – 00B0 * MAGGIE6 – 00C0 * MAGGIE7 – 00D0 * MAGGIE8 – 00E0 * MAGGIE9 – 00F0 |

## MAGGIE Registers

|  |  |  |
| --- | --- | --- |
| Address | Name | Function |
| Base + 00 | BP2RAST\_cmd | 8-bit composite. Video Mode setting. |
| Base + 01 | BP2RAST\_bgc | Background colour. |
| Base + 02 | BP2RAST\_fgc | Foreground colour. |
| Base + 03 | RST\_ADDR\_H | MSB bits of 24-bit base read address. |
| Base + 04 | RST\_ADDR\_M | MID bits of 24-bit base read address. |
| Base + 05 | RST\_ADDR\_L | LSB bits of 24-bit base read address. |
| Base + 06 | YINC\_ADDR\_H | MSB of 16-bit Y-line increment for read address. |
| Base + 07 | YINC\_ADDR\_L | LSB of 16-bit Y-line increment for read address. |
| Base + 08 | X\_SIZE\_H | MSB of 16-bit display width screen pixels. |
| Base + 09 | X\_SIZE\_L | LSB of 16-bit display width screen pixels. |
| Base + 0A | Y\_SIZE\_H | MSB of 16-bit display height screen lines. |
| Base + 0B | Y\_SIZE\_L | LSB of 16-bit display height screen lines. |
| Base + 0C | X\_SCALE | Two 4-bit words. Upper 4 controls x-increment every period, lower 4 is pixel period counter to define number of pixels until upper 4 bits are added to the address pointer. |
| Base + 0D | Y\_SCALE | Two 4-bit words. Upper 4 bits reserved for text tile mode y-size; lower 4 bits is line period counter to define number of lines until YINC\_ADDR is added to address pointer. |
| Base + 0E | X\_START\_SUB | 8-bit word. Defines an odd pixel start position within the period counter and x-position within a bit plane’s x-coordinate position. |
| Base + 0F | Y\_START\_SUB | 8-bit word. Defines an odd line start within the period counter and y-coordinates inside a font. |

### BP2RAST\_cmd

The BP2RAST\_cmd register is composed of the following bit settings:

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 |
| text\_mode\_master | text\_mode\_slave | not used | mode\_565 | bart\_enable | 16\_bit\_mode | Video Mode | Video Mode |

### Bits 7-6 – Text\_mode\_master / text\_mode\_slave

When using text/font/tile mode, two adjacent MAGGIEs must be used. The first one must have the '*text\_mode\_master*' bit set in the '*BP2RAST\_cmd*' while the second MAGGIE must have the '*text\_mode\_slave*' bit set in the '*BP2RAST\_cmd*'. These bits must be zero for graphics output.

### Bit 4 – mode\_565

### Bit 3 – BART enable

This bit must be HIGH for the linked BART to output pixel data. If the bit is LOW, the MAGGIE/BART pipeline is effectively turned off, unless the MAGGIE is a text\_mode\_master.

### Bit 2 – 16\_bit\_mode

If HIGH, the BART works in 16-bit mode (so all addresses must be even) to use two-byte words when reading the pixel data.

### Bits 1-0 – Video Mode / pixels per byte

Determines the Video Mode, or pixels per byte. The table below shows how bits 2-0 work together to determine the Video Mode:

|  |  |  |  |
| --- | --- | --- | --- |
| Bit 2 | Bit 1 | Bit 0 | Video Mode |
| 0 | 0 | 0 | 1-bit colour |
| 0 | 0 | 1 | 2-bit colour |
| 0 | 1 | 0 | 4-bit colour |
| 0 | 1 | 1 | 8-bit colour |
| 1 | 0 | 0 | 16-bit, 8 pixels-per-word |
| 1 | 0 | 1 | 16-bit, 4 pixels-per-word |
| 1 | 1 | 0 | 16-bit, 2 pixels-per-word |
| 1 | 1 | 1 | 16-bit, true colour |

## Text Mode

Two MAGGIEs are required for text mode – a master and a slave – and they must be adjacent to each other (i.e. MAGGIE0 & MAGGIE1, MAGGIE3 & MAGGIE4 etc).

The master MAGGIE is responsible for the positioning of the window on the screen and pointing to the source data (*screen buffer*), whereas the slave MAGGIE controls the foreground and background colours.

The screen buffer location is specified in the master MAGGIE in the 24-bit word at register addresses +3 to +5.

The Video Mode in both MAGGIEs must match, except in the master where the BP2RAST\_cmd BART\_enable (bit 3) must be disabled; otherwise you will get junk on the screen.

In 16-bit text mode, each character tile is followed by a palette byte. The upper 4-bits control the foreground colour, the lower 4-bits control the background colour.

All other controls are the same as when using it as a bitmap graphics window.

The '*font\_y\_size*', combined upper bits of '{hw\_regs[Y\_START\_SUB][7:6], hw\_regs[Y\_SCALE][7:4]}' in the *text\_mode\_master* which must also be set to the font/tile height -1 (e.g.: 0=1 line, 7=8 lines, 15=16 lines, 31=32 lines) when in text/font/tile master mode.

For the *'text\_mode\_slave*' MAGGIE, the only functioning 4 controls are:

1. reset\_addr which points to the base memory address for font/tile graphics data,
2. period\_x[4] which defines a font as 16 pixels wide when set, or 8 pixels when low, and period\_x[3:0] which mask out the upper bits for fonts/tile addressing for 256, 512, 1024, 2048, 4096 characters (used in 16 bit addressing mode, otherwise set these bits to 0),
3. period\_y[1:0] which defines the font height (0=8, 1=16, 2=32, 3=64 lines tall), and
4. BP2RAST\_cmd which should match the *text\_mode\_master* MAGGIE settings except for the master and slave bit.

All base memory address settings should be on an even byte when using 16-bit mode. Fonts/tile graphics data should always begin on an even byte address.

## DEFAULT MAGGIE SETTINGS

Example default MAGGIE settings for the ‘chip’ image:

Top image: MAGGIE4 - HW triggers @ 20-21 & 22-23

A0 - 1A 10 00 00 33 00 00 60 00 BF 00 77 00 00 00 00

Middle image: MAGGIE5 - HW triggers @ 24-25 & 26-27

B0 - 1A 70 00 00 33 00 00 60 00 BF 00 77 01 01 00 00

Background image: MAGGIE6 - HW triggers @ 28-29 & 2A-2B

C0 - 0A B0 00 00 33 0A 00 60 00 BF 00 77 03 03 00 00

# PALETTES

The palettes are held in memory at $9C00-$9FFF and are 512 entries wide, with the 4444 colour palette occupying the first 256x16 entries while the 565 palette occupies the second 256x16 entries. Both palettes are 16-bit.

## ARGB4444 Palette

This is the default palette for Text Mode, requiring two bytes per palette entry. As it is commonly used with Text Mode, which can specify a maximum of 16 index values, it is generally divided into separate palettes of 16 entries, with the first 16 being the default palette.

Each entry consists of two bytes, as follows:

|  |  |  |  |
| --- | --- | --- | --- |
| 1st BYTE | | 2nd BYTE | |
| 4-bits | 4-bits | 4-bits | 4-bits |
| Transparency | RED | GREEN | BLUE |

Four pages of Bank 0x42 contains the palette, with the first 32 bytes containing the default palette. If Bank 0x42 is mapped to Area 3, the palette memory starts at 0xE000 and ends at 0xE3FF.

# Host IO ports

The GPU exposes some specific IO addresses to the host to facilitate extra hardware functions, listed below. The IO addresses are separate from the GPU RAM address space and are easily customizable in Quartus via the parameter settings in the Z80\_bridge.

|  |  |  |
| --- | --- | --- |
| **IO Address** | **Read/Write** | **Function** |
| **240 / F0** | Read-only | PS/2 DATA port (*keyboard interface*) |
| **241 / F1** | Read-only | PS/2 STATUS register (*keyboard interface*) |
| **242 / F2** | Write-only | SPEAKER enable (0=off, ~0=on) |
| **243 / F3** | Write-only | VIDEO output enable (0=off, ~0=on) |
| **244 / F4** | Write-only | TONE (frequency) register for speaker (0-255) |
| **245 / F5** | Write-only | DURATION register for speaker (0-255) |

## PS/2 DATA PORT

This 8-bit data port returns the current MAKE or BREAK code (with bit 7 set). ASCII characters are returned as a result of a key being pressed on the PS/2 keyboard attached to the GPU card. Once read, the PS/2 DATA PORT is set to zero – any further reads will return 0x00 unless another MAKE or BREAK code is ready to be transmitted.

## PS/2 STATUS REGISTER

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 |
| N/A | N/A | N/A | N/A | N/A | N/A | BREAK | VALID\_DATA |

The PS/2 STATUS register provides information on the current state of the PS/2 DATA port. If Bit 0 is HIGH, valid data is available on the DATA port. Bit 1 is set HIGH if the ASCII character at the DATA port is a BREAK code (i.e. the result of the key being released on the keyboard). BREAK codes are generally filtered out by the DMI and CP/M BIOS, unless special code is written to make use of them. BREAK codes are filtered out by ignoring characters with bit 7 set, or status bytes with bit 1 set.

# Hardware-Accelerated Graphics engine

The HAG is a powerful hardware module in the GPU that performs basic graphics functions on behalf of the host system – including:

1. Pixel plotting
2. Line drawing (x[0], y[0] to x[1], y[1])
3. Filled/unfilled-rectangle (x[0], y[0] to x[1], y[1])
4. …more to come…

As well as the primary drawing functions, there are a number of support functions:

* Set 24-bit destination screen memory pointer
* Set 24-bit source screen memory pointer
* Set byte-width for destination raster (in x[n], y[n]) (n = 2 to 3)
* Set byte-width for source raster (in x[n], y[n]) (n = 2 to 3)
* Set maximum bitmap width & height to x[n], y[n] (n = 0 to 3)
* Clear pixel collision counter
* Clear blitter copy pixel collision counter

The HAG has a 16-bit interface, driven by multiple IO writes from the Z80 in little-endian format – the LOW byte is always written first to IO port 246, then the HIGH byte which causes the GPU to act on the data/command is written to IO port 247.

## Hardware Commands

### X & Y registers

There are four 12-bit X and Y registers, X[0-3], Y[0-3], their contents set using the 16-bit input register. As with all data sent to the HAG, the low byte must be written first to port 246, followed by the high byte to port 247.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| HIGH BYTE | | | | | | | | LOW BYTE | | | | | | | |
| 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| 1 | R | n | n | ? | ? | ? | ? | ? | ? | ? | ? | ? | ? | ? | ? |

R - high-byte bit 6 (register bit 14)

This bit determines which register – X or Y – is being written to. 0 = X, 1 = Y.

nn – high-byte bits 5 & 4 (register bits 13 & 12)

These bits specify which of the four X/Y registers to write to.

? – data bits to be written to the specified register.

### Set destination screen memory pointer (124-127)

The following command sets the destination screen memory pointer to the data in the indicated 12-bit registers.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| HIGH BYTE | | | | | | | | LOW BYTE | | | | | | | |
| 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| 0 | 1 | 1 | 1 | 1 | 1 | n | n | x | x | x | x | x | x | x | x |

nn – high-byte bits 1 & 0 (register bits 9 & 8)

These bits specify which of the four X/Y registers to use the data from.

x – don’t care – these bits are ignored.

### Set source screen memory pointer (120-123)

The following command sets the source screen memory pointer to the data in the indicated 12-bit registers.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| HIGH BYTE | | | | | | | | LOW BYTE | | | | | | | |
| 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| 0 | 1 | 1 | 1 | 1 | 0 | n | n | x | x | x | x | x | x | x | x |

nn – high-byte bits 1 & 0 (register bits 9 & 8)

These bits specify which of the four X/Y registers to use the data from.

x – don’t care – these bits are ignored.

### Set destination raster bytes-per-horizontal line – X[2] (115)

Sets the destination raster’s bytes-per-horizontal line to the data in the X[2] register. Y register is ignored. Low byte bits 2-0 specify bits-per-pixel.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| HIGH BYTE | | | | | | | | LOW BYTE | | | | | | | |
| 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| 0 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | x | x | x | x | x | x | x | x |

x – don’t care – these bits are ignored.

### Set source raster bytes-per-horizontal line – Y[2] (114)

Sets the source raster’s bytes-per-horizontal line to the data in the Y[2] register. X register is ignored. Low byte bits 2-0 specify bits-per-pixel.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| HIGH BYTE | | | | | | | | LOW BYTE | | | | | | | |
| 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | x | x | x | x | x | x | x | x |

x – don’t care – these bits are ignored.

### Set destination raster bytes-per-horizontal line – X[3] (113)

Sets the source raster’s bytes-per-horizontal line to the data in the X[3] register. Y register is ignored. Low byte bits 2-0 specify bits-per-pixel.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| HIGH BYTE | | | | | | | | LOW BYTE | | | | | | | |
| 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| 0 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | x | x | x | x | x | x | x | x |

x – don’t care – these bits are ignored.

### Set source raster bytes-per-horizontal line – Y[3] (112)

Sets the source raster’s bytes-per-horizontal line to the data in the Y[3] register. X register is ignored. Low byte bits 2-0 specify bits-per-pixel.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| HIGH BYTE | | | | | | | | LOW BYTE | | | | | | | |
| 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | x | x | x | x | x | x | x | x |

x – don’t care – these bits are ignored.

### Set max width & height of screen – X[0]/Y[0] (95)

Sets the bitmap dimensions to the data in the 0-index registers (X[0], Y[0]). Low byte is ignored.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| HIGH BYTE | | | | | | | | LOW BYTE | | | | | | | |
| 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | x | x | x | x | x | x | x | x |

x – don’t care – these bits are ignored.

### Set max width & height of screen – X[1]/Y[1] (94)

Sets the bitmap dimensions to the data in the 1-index registers (X[1], Y[1]). Low byte is ignored.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| HIGH BYTE | | | | | | | | LOW BYTE | | | | | | | |
| 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| 0 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | X | x | x | x | x | x | x | x |

x – don’t care – these bits are ignored.

### Set max width & height of screen – X[2]/Y[2] (93)

Sets the bitmap dimensions to the data in the 0-index registers (X[0], Y[0]). Low byte is ignored.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| HIGH BYTE | | | | | | | | LOW BYTE | | | | | | | |
| 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| 0 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | x | x | x | x | x | x | x | x |

x – don’t care – these bits are ignored.

### Set max width & height of screen – X[3]/Y[3] (92)

Sets the bitmap dimensions to the data in the 3-index registers (X[3], Y[3]). Low byte is ignored.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| HIGH BYTE | | | | | | | | LOW BYTE | | | | | | | |
| 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| 0 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | x | x | x | x | x | x | x | x |

x – don’t care – these bits are ignored.

### Clear pixel collision counter (91)

Clears the pixel collision counter and sets all three transparent mask colours to one 8-bit colour in the source function data.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| HIGH BYTE | | | | | | | | LOW BYTE | | | | | | | |
| 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | ? | ? | ? | ? | ? | ? | ? | ? |

? – sets the mask colour.

### Clear blitter copy pixel collision counter (90)

Clears the blitter copy pixel collision counter and sets all three transparent mask colours to one 8-bit colour in the source function data.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| HIGH BYTE | | | | | | | | LOW BYTE | | | | | | | |
| 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | ? | ? | ? | ? | ? | ? | ? | ? |

? – sets the mask colour.

To get the HAG to perform, she needs a minimum setup:

1. Set X and Y values.
2. Set the destination screen memory pointer based on those values.

Optional:

1. Set byte-width for destination raster
2. Set maximum bitmap width & height

Step 1 is vital as the HAG needs to know where the pixels are being written to. The next two steps are important, but not necessary if you’re careful to keep any drawing operations from wrapping the edge of the screen or going outside of the bitmap space.

e.g:

High-byte values of 128 and 192 set X[0] and Y[0] respectively.

1. Set destination screen memory pointer to 0x6000:  
   OUT 246,0  
   OUT 247,128 ; Sends 0x00 to X[0] (lower 12-bits of address)  
   OUT 246,6  
   OUT 247,192 ; Sends 0x06 to Y[0] (upper 12-bits of address)  
   OUT 246,1 ; Set bpp?  
   OUT 247,124 ; Sends command to set destination memory pointer
2. Set destination raster width:  
   OUT 246,90  
   OUT 247,128 ; Sends width (90 bytes) to X[0]  
   OUT 246,100  
   OUT 247,192 ; Sends height (100 bytes) to Y[0]  
   OUT 246,1 ; Set bpp?  
   OUT 247,95 ; Sends command to set bitmap size
3. Send drawing coordinates and draw the line:  
   OUT 246,5  
   OUT 247,128 ; Sends 0x05 to X[0]  
   OUT 246,5  
   OUT 247,192 ; Sends 0x05 to Y[0]  
   OUT 246,10  
   OUT 247,144 ; Sends 0x10 to X[1]  
   OUT 246,7  
   OUT 247,208 ; Sends 0x07 to Y[1]  
   OUT 246,0  
   OUT 247,1 ; Sends command to draw line

# Appendix A – Character Codepage

