

Colour Graphics Adapter: Notes

This document describes the behaviour of IBM's original CGA, and some clones.

The CGA is a colour card. According to the IBM technical manual, it can display on one of:

- The IBM Color Display (or a compatible CGA monitor)
- A television-frequency composite monitor
- An NTSC television (with an add-on RF modulator)

The composite video output will also work with devices such as modern televisions and TV tuner cards. But if the device doesn't support NTSC, you'll only get monochrome output.

Hardware requirements

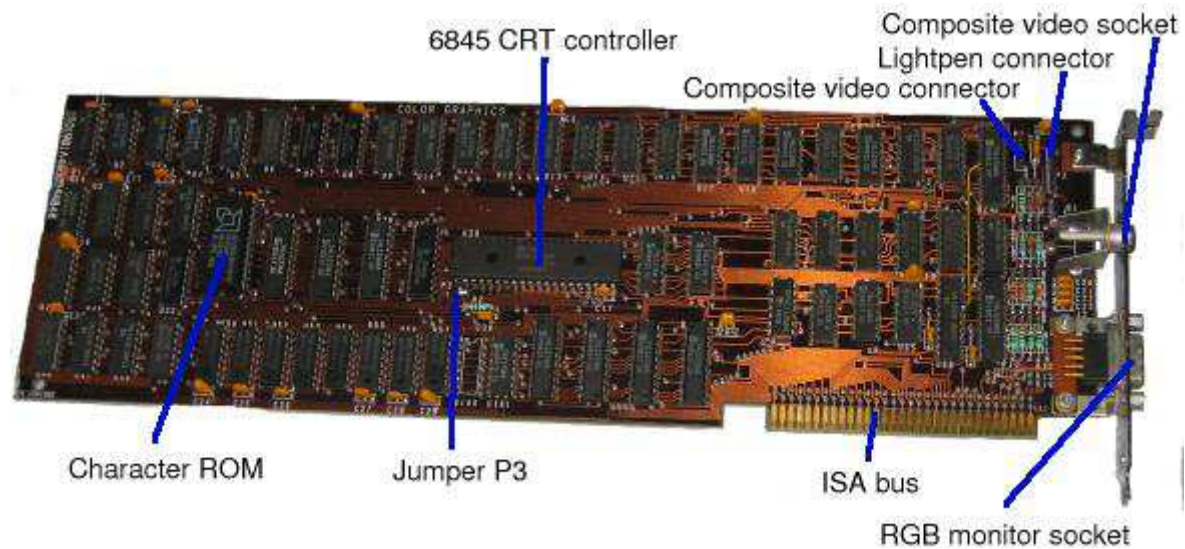
The original CGA is a full-length 8-bit ISA card. The physical shape of the card is such that it won't fit in a 16-bit slot. Cards like this are probably why many motherboards (at least up to the 486 era) had both 8-bit and 16-bit slots.

When present in a computer, the CGA uses the following system resources:

- 16k of RAM at address 0B8000h for its frame buffer. The address is incompletely decoded; the frame buffer is repeated at 0BC000h.
- I/O addresses used are 03D0h-03DFh.

The hardware

Like the MDA, the CGA is built around an MC6845 cathode ray tube controller (CRTC) and discrete logic. The two big chips are the 6845 (soldered on) and the character generator ROM (socketed). Since the character set is in ROM, the only way you'll get a different one is by replacing the ROM.



The same character ROM is used as in the MDA; so it contains the MDA's 14-row font and two 8x8 fonts (one with thick uprights and one with thin uprights). Only one of the 8x8 fonts is used at any one time; by default, it's the thick one, because the thin one doesn't show up well on composite displays.

Note that the character ROM is a 9264, which has a different pinout from the normal 27xx chip range (2764, 27128 etc.). [This USENET posting](#) describes how to get a 2764 ROM to work in a 9264 socket (it refers to the PC motherboard, but the pinout is the same for the MDA and CGA cards).

9264 pinout deduced from the above USENET post:

		+---V---		
A7	-	01	24	- Vcc
A6	-	02	23	- A8
A5	-	03	22	- A9
A4	-	04	21	- A12
A3	-	05	20	- /OE
A2	-	06	19	- A10
A1	-	07	18	- A11
A0	-	08	17	- D7
D0	-	09	16	- D6
D1	-	10	15	- D5
D2	-	11	14	- D4
GND	-	12	13	- D3
		+-----+		

Unlike an MDA, the CGA card does not contain a clock crystal. Instead, the Oscillator signal on the ISA bus is used to generate timing. This is 14.318MHz (4 times the NTSC subcarrier frequency). On the original PC and XT, the same clock signal, divided by 3, gave the 4.77MHz CPU clock.

On a PC with a 5161 expansion unit, the CGA should be fitted in the main PC, not the expansion unit. This is probably because the 14.318MHz clock is not shared between the PC and the expansion unit; each has its own, and they may not be in sync.

There are two external connectors - a standard RCA jack for composite video, and a DE9 socket with this pinout:

1. Ground
2. Ground
3. Red
4. Green
5. Blue
6. Intensity
7. Reserved
8. Horizontal sync
9. Vertical sync

The CGA has two (or possibly three) headers on the card:

- P1 is a 4-pin header for composite video output:
 - Pin 1 is +12V
 - Pin 2 is not present
 - Pin 3 is composite video
 - Pin 4 is ground

According to IBM's technical manual, this connector is for an add-on RF modulator. In the 5155 (portable PC) it is connected to the internal 9-inch monitor.

- P2 is a 6-pin header for a light-pen:
 - Pin 1 is light pen input
 - Pin 2 is not present
 - Pin 3 is the light pen switch input
 - Pin 4 is logic ground
 - Pin 5 is +5V
 - Pin 6 is +12V
- P3 (next to pin 1 of the 6845 CRTC) would have a two-pin header, but is normally left as just a couple of pads. If the two pins or pads are shorted together, the alternative (thin) font is used.

The CGA uses single-ported RAM, which means that if the host PC is reading or writing screen memory, the CRT controller can't. This manifests itself as "snow" - little white rectangles (like extra cursors) briefly appear at what look like random places on the screen. Many CGA clones use dual-ported RAM and don't suffer from "snow".

Frequently-Asked Question

Since I put this page up, various people have emailed me with the following examination question:

At a particular instant a CGA monitor has the following signal applied to it:

pin 3 = 4.5V
pin 4 = 0.5V
pin 5 = 0.8V

What colour would be produced on the screen and why?

Answer: I'm not going to do your homework for you. The information already on this page should be sufficient to produce an obvious answer. To my mind, it would be obvious-but-wrong, like most of the answers on [QI](#), but since I didn't set the question and I'm not marking the paper, my opinion on this matter isn't worth much.

Memory Maps

Text Mode

The two text modes are 40x25 and 80x25. In both, characters are 8 pixels wide and 8 pixels high. This results in either a 320x200 or 640x200 resolution.

The memory storage scheme is that two bytes of video RAM are used for each character. The first byte is the character code, and the second gives the attribute. A whole screen is either 2000 bytes (40*25*2) or 4000 bytes (80*25*2).

Since the CGA has 16k of video RAM, several screens' worth of information can be stored in it at a time. Under most operating systems, the PC BIOS divides it into separate pages (either four or eight, depending on the video mode). DOS Plus, on the other hand, uses it to implement fast hardware scrolling (rather than move the contents of the screen "up", it moves the start of display memory "down").

Character codes match whatever the font ROM in use is. Normally this is 'codepage 437' - ASCII plus a collection of accented characters, line graphics and a few other characters.



The attributes form a bitmap:

- Bit 0: Blue foreground
- Bit 1: Green foreground
- Bit 2: Red foreground
- Bit 3: Bright foreground
- Bit 4: Blue background
- Bit 5: Green background
- Bit 6: Red background
- Bit 7: Bright background; or blinking text

(On most CGA monitors, Black+Bright shows as dark grey, and Yellow without Bright shows as brown.)

Graphics Modes

In the two graphics modes, all memory is used for the framebuffer. Each row is 80 bytes. At the beginning of memory are the first set of rows (0, 2, 4, ..., 198); offset by 8k are the second set (1, 3, 5, ..., 199). This may have been to make it easier for the hardware to produce an interlaced picture, but it's a pain to program.

In low-resolution graphics mode (320x200), a byte corresponds to four pixels; in high-resolution mode (640x200), a byte corresponds to 8. In each case, the highest-numbered bits correspond to the leftmost pixel.

Register I/O

03D8h: Mode control register

The following bits are used:

Bit 5: 1 to enable blinking, 0 to disable it.

In text modes, if bit 5 is 1, characters with attribute bit 7 set will blink. If not, they will have high intensity background. This has no effect in graphics modes.

Bit 4: High-resolution graphics

If this bit is set, it selects 2-colour graphics (640 pixels wide) rather than 4-colour (320 pixel wide). In text mode, setting this bit has the following effects:

1. The border is always black.
2. The characters displayed are missing columns - as if the bit pattern has been ANDed with another value. According to reenigne.org, the value is the equivalent bit pattern from the 640x200 graphics mode.

Bit 3: Enable video output

If bit 3 is 0, screen output will not be shown (it will be exactly as if the video RAM contained all zeroes). The usual use of this is if you're reprogramming the CRTC registers; disable video output beforehand and re-enable it after.

Bit 2: Black and white

If the card is displaying on a composite monitor, this disables the NTSC color(sic) burst, giving black and white output. On an RGB monitor it has no effect except in the 320x200 graphics mode, when it selects a third palette (black/red/cyan/white). This palette is not documented, and not all of IBM's later CGA-compatible cards support it.

If this bit is set to zero in 640x200 mode, you get [colour composite mode](#).

Bit 1: Graphics mode

If this bit is set, the display RAM will be treated as bitmap graphics rather than as text.

Bit 0: High resolution

This bit should only be set in the 80-column text mode. It changes various timing parameters (to display 160 bytes per row instead of 80); the CRTC will need to be reprogrammed accordingly.

03D9h: Colour control register

The following bits are used:

Bit 5: Palette

This is only used in the 320x200 graphics mode. If it is set, the fixed colours in the palette are magenta, cyan and white. If it is reset, they are red, green and yellow. Bit 2 in the mode control register (if set) overrides this bit.

Bit 4: Bright foreground

This is only used in the 320x200 graphics mode. If set, the foreground colours display in high intensity.

Bits 3-0: Border / Background / Foreground

These 4 bits select one of the 16 CGA colours (bit 3 = Intensity, Bit 2 = Red, Bit 1 = Green, Bit 0 = Blue). In text modes, this colour is used for the border (overscan). In 320x200 graphics modes, it is used for the background and border. In 640x200 mode, it is used for the foreground colour.

Status register

This is read from port 03DAh. Its values are as follows:

Bit 0: Display enable

According to IBM's manual, this bit is 1 when the CPU is allowed to access video RAM without causing "snow".

Bit 1: Light pen trigger set.

The trigger is cleared by writing any value to port 03DBh.

Bit 2: Light pen switch status

This is the current state of the light pen switch - not latched or debounced. 0=on, 1=off.

Bit 3: Vertical retrace

Set when the screen is in a vertical retrace interval. While this bit is set, video RAM can be accessed without "snow" onscreen.

Bits 4-7: Not used.

Lightpen registers

A write to port 03DBh will clear the lightpen latch. According to various sources, writing to port 03DCh will set the latch; this is not documented in IBM's technical manual.

BIOS-supported modes

The PC BIOS supports using a CGA in 7 modes:

Mode number	Mode name	Mode bit 4	Mode bit 2	Mode bit 1	Mode bit 0	Notes
0	BW40	0	1	0	0	40x25 text. Displays in greyscale on a composite monitor, colour on an RGB monitor. Some clone BIOSes treat this the same as C040 below.
1	CO40	0	0	0	0	40x25 text. Displays in colour on a composite monitor, colour on an RGB monitor.
2	BW80	0	1	0	1	80x25 text. Displays in greyscale on a composite monitor, colour on an RGB monitor. Some clone BIOSes treat this the same as C080 below.
3	CO80	0	0	0	1	80x25 text. Displays in colour on a composite monitor, colour on an RGB monitor.
4		0	0	1	0	320x200 graphics. Displays in colour on a composite monitor, colour on an RGB monitor.
5		0	1	1	0	320x200 graphics. Displays in greyscale on a composite monitor, in alternative palette on an RGB monitor.
6		1	1	1	0	640x200 graphics. Displays in mono on a composite monitor, colour-on-black on an RGB monitor. Some clone BIOSes don't set bit 2, resulting in colour composite mode .

Undocumented modes

Mode name	Mode bit 4	Mode bit 2	Mode bit 1	Mode bit 0	Notes
160x200	1	0	1	0	On an RGB monitor, this displays the same as the 640x200 graphics mode. On a composite monitor, this can display as a low-resolution colour mode .
160x100	0	0	0	1	This is really the 80x25 text mode. The CRTIC is reprogrammed to decrease character height to two pixels, giving an 80x100 text mode. Then all character cells are filled with character 0xDE, so that the left-hand side is drawn using the background colour and the right-hand side with the foreground colour. The attribute bytes are then used to create the screen graphics. The high 4 bits of a byte give the colour of the left-hand "pixel", and the low 4 bits give the colour of the right-hand "pixel".