

# Color Graphics Adapter

This article is about computer architecture. For other uses, see [CGA](#).



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## Color Graphics Adapter

**Release date** 1981; 39 years ago

**Architecture** [Motorola 6845](#), ATI CW16800

### Cards

**Entry-level** IBM Color Graphics Adapter, ATi Graphics Solution Rev 3, ATi Color Emulation Card, Tseng Labs ColorPAK,

**Mid-range** ATi Graphics Solution plus, ATi Graphics Solution Plus SP, ATi Graphics Solution SR, Number Nine Graphics System

**High-end** ATi Small Wonder Graphics Solution, Tseng Labs EVA/480

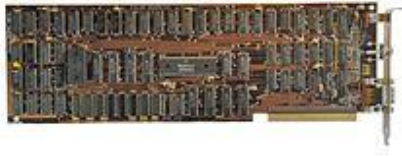
**Enthusiast** ATi Small Wonder Graphics Solution with game port

### **History**

[Plantronics Colorplus](#)

**Successor** [PCjr/Tandy Graphics Adapter](#)  
[Enhanced Graphics Adapter](#)  
[Multi-Color Graphics Array](#)

[Professional Graphics Controller](#)



Original IBM Color Graphics Adapter

The **Color Graphics Adapter (CGA)**, originally also called the *Color/Graphics Adapter* or *IBM Color/Graphics Monitor Adapter*,<sup>[1]</sup> introduced in 1981, was **IBM's** first [graphics card](#) and first color display card for the [IBM PC](#). For this reason, it also became that computer's first [color computer display standard](#).

The standard IBM CGA graphics card was equipped with 16 [kilobytes](#) of [video memory](#) and could be connected either to a dedicated direct-drive [CRT](#) monitor using a [4-bit](#) digital ([TTL](#)) [RGBI](#) interface, such as the [IBM 5153](#) color display, or to an [NTSC](#)-compatible television or [composite video monitor](#) via an [RCA connector](#).<sup>[2]</sup> The RCA connector provided only baseband video, so to connect the CGA card to a standard television set required a separate [RF modulator](#) unless the TV had a [composite video](#) input, although doing so with the former combined with an amplifier was sometimes more practical, since one could then hook up an antenna to the amplifier and get wireless video.<sup>[3]</sup>

Built around the [Motorola 6845](#) display controller,<sup>[4]</sup> the CGA card featured several graphics and [text modes](#). The highest [display resolution](#) of any mode was 640×200, and the highest [color depth](#) supported was 4-bit (16 colors).



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## Output capabilities

CGA supports:

- 320×200 in 4 colors from a 16 color hardware palette. Pixel aspect ratio of 1:1.2.
- 640×200 in 2 colors. Pixel aspect ratio of 1:2.4

(The pixel aspect ratio stems from rendering said distribution of pixels on a screen with 4:3 proportions, typical of monitors at the time.)

Text modes:

- 40×25 with 8×8 pixel font (effective resolution of 320×200)
- 80×25 with 8×8 pixel font (effective resolution of 640×200)

Extended graphics modes:

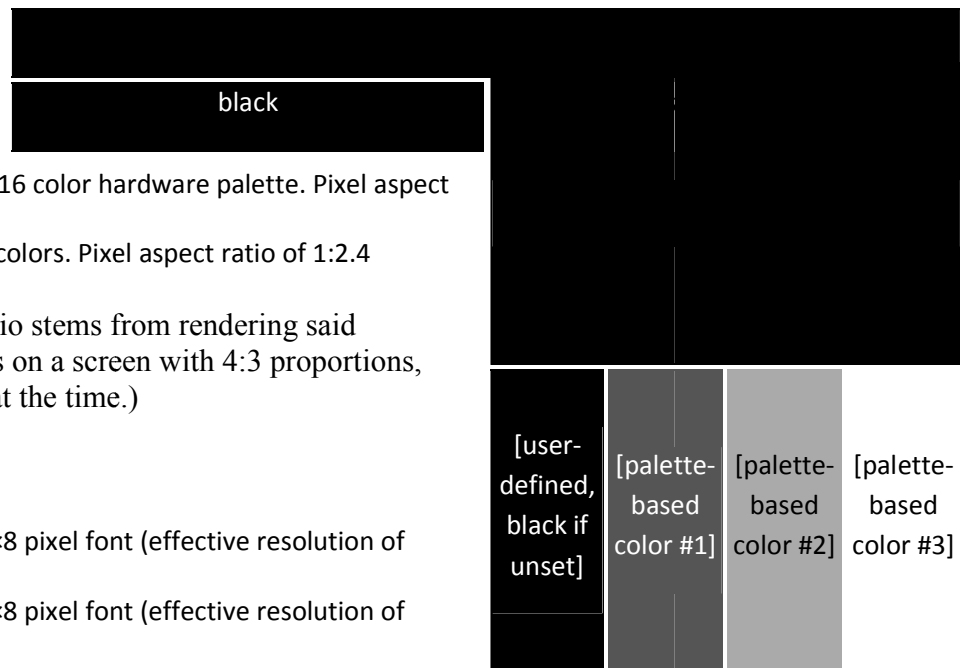
- 160×100 16 color mode
- [Artifact colors](#) using a NTSC monitor (hundreds possible, but typically presented limited to 16 colors)

IBM intended that CGA be compatible with a home television set. The 40×25 text and 320×200 graphics modes are usable with a television, and the 80×25 text and 640×200 graphics modes are intended for a monitor.<sup>[4]</sup>



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[Cga p0.png](#) CGA 320×200 in 4 colors palette 0 (red, yellow, green, black background)





[Cga p1.png](#) CGA 320×200 in 4 colors palette 1 (cyan, magenta, white, black background)



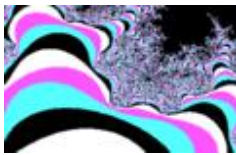
[Cga p3.png](#) CGA 320×200 in 4 colors 3rd palette (tweaked), (cyan, red, white, black background)



[Cga 640x200.png](#) CGA 640×200 in 2 colors(1-bit)



[Cga 150x100.png](#) CGA 160×100 16 color mode(4-bit)



[CGA Partial Mandelbrot Set.png](#) A partial [Mandelbrot set](#) rendered in CGA palette 1



[Arachne CGA Mode.svg](#) Screenshot of [Arachne](#) displaying its embedded frames and tables test pages in CGA 640×200 mode



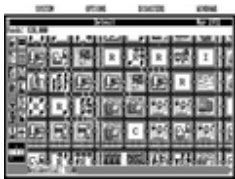
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[Paku-paku5-dos.png](#) [PakuPaku](#) in 160×100 16 color mode



•

[CGA program interface.png](#) [PCPaint](#) in 320×200 3rd palette low intensity, showing a typical low resolution interface. Note the use of dithering to overcome the CGA palette limitations.



•

[CGA 640x200 game.png](#) [SimCity](#) in 640×200 monochrome. Note the use of dithering to simulate gray tones and non-square pixel ratio that deforms the fonts.

## Color palette

Despite varying [bit depths](#) among the CGA graphics modes (see below), CGA processes colors in its [palette](#) in four bits, yielding  $2^4 = 16$  different colors. The four color bits are arranged according to the [RGBI](#) color model: the lower three bits represent red, green, and blue color components; a fourth "intensifier" bit, when set, increases the brightness of all three color components (red, green, and blue).<sup>[5]</sup> In graphics modes, colors are set per-pixel; in text modes, colors are set per-character, with an independent foreground and background color for each character.

### Full CGA 16-color palette

0	black #000000	8	dark gray #555555
---	------------------	---	----------------------

### With an RGBI monitor

These four bits are passed on unmodified to the DE-9 connector at the back of the card, leaving all color processing to the RGBI monitor connected to it. With respect to the RGBI color model described above, the monitor would use approximately the following formula to process the digital four-bit color number to analog voltages ranging from 0.0 to 1.0:

```
red := 2/3*(colorNumber & 4)/4 + 1/3*(colorNumber & 8)/8
green := 2/3*(colorNumber & 2)/2 + 1/3*(colorNumber & 8)/8
blue := 2/3*(colorNumber & 1)/1 + 1/3*(colorNumber & 8)/8
```

**dark yellow** Color 6 is treated differently; when using the formula above, color 6 would become *dark yellow*, as seen to the left, but in order to achieve a more pleasing *brown* tone, special circuitry in most RGBI monitors, including the IBM 5153 color display,<sup>[6]</sup> makes an *exception* for color 6 and changes its hue from dark yellow to brown by halving the analogue green signal's amplitude:

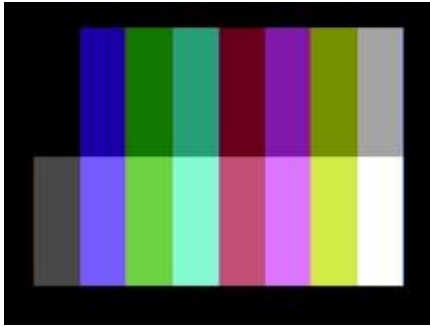
```
if colorNumber = 6 then green := green / 2
```

1	blue #0000AA	9	light blue #5555FF
2	green #00AA00	10	light green #55FF55
3	cyan #00AAAA	11	light cyan #55FFFF
4	red #AA0000	12	light red #FF5555
5	magenta #AA00AA	13	light magenta #FF55FF
6	brown #AA5500	14	yellow #FFFF55
7	light gray #AAAAAA	15	white #FFFFFF

It is this "RGBI with tweaked brown" palette, shown in the complete palette to the right, that all later PC graphics standards such as [EGA](#) and [VGA](#) have retained for compatibility as a power-on default setting of their internal palette registers and/or [DAC](#) registers.

### With a composite color monitor/television set

For the composite output, these four-bit color numbers are encoded by the CGA's onboard hardware into an NTSC-compatible signal fed to the card's RCA output jack. For cost reasons, this is not done using an RGB-to-YIQ converter as called for by the NTSC standard, but by a series of flip-flops and delay lines.<sup>[7][8]</sup> Consequently, the hues seen are lacking in purity; notably, both cyan and yellow have a greenish tint, and color 6 again looks dark yellow instead of brown. The relative luminances of the colors produced by the composite color-generating circuit differ between CGA revisions: they are identical for colors 1-6 and 9-14 with early CGAs produced until 1983,<sup>[9]</sup> and are different for later CGAs due to the addition of additional resistors.<sup>[10]</sup>



CGA's 16 colors when using the NTSC output (post-1983 card revision)

As noted however, this method only works on NTSC television sets, PAL TVs do not display the colors as expected when connected to the composite output, as PAL's superior color separation prevents artifacting from occurring.

### RGBI monitor availability

When the CGA was introduced in 1981, IBM did not offer an RGBI monitor.<sup>[11]</sup> Instead, customers were supposed to use the RCA output with an [RF modulator](#) (that they obtained separately, from a third party) to connect the CGA to their television set.<sup>[12]</sup> The IBM 5153 *Personal Computer Color Display* would not be introduced until March 1983.<sup>[13]</sup> Resulting from the lack of available RGBI monitors in 1981 and 1982, many users would use simpler RGB monitors (without provisions for the "intensifier" bit), reducing the number of available colors to eight, and displaying both colors 6 and 14 as yellow.<sup>[11]</sup> This is relevant insofar as if an application or game programmer used either one of these configurations, they will have expected color 6 to look dark yellow instead of brown.

## Standard text modes

CGA offers four BIOS [text modes](#) (called alphanumeric modes in IBM's documentation):

- **40×25 characters** in up to 16 colors. Each character is a pattern of 8×8 dots. The effective screen resolution in this mode is 320×200 pixels (a pixel [aspect ratio](#) of 1:1.2), though individual pixels cannot be addressed independently. The choice of patterns for any location is thus limited to one of the 256 available characters, the patterns for which are stored in a ROM chip on the card itself. The display font in text mode (the [hardware code page 437](#) character set) is therefore fixed and cannot be changed (although when using the original IBM CGA, it is possible to select one of two different fonts—normal or thin—by changing a [jumper](#). Many clones didn't offer this possibility). The card has sufficient video RAM for eight different text pages in this mode. BIOS Modes 0 & 1 select 40 column text modes. The difference between these two modes can only be seen on a composite monitor; mode 0 disables the color burst, making colors appear in grayscale. Mode 1 enables the color burst, allowing for color. Mode 0 and Mode 1 are functionally identical on RGB monitors and on later adapters that emulate CGA without supporting composite color output.

- **80×25 characters** in up to 16 colors. Each character is again an 8×8 dot pattern (the same character set is used as for 40×25), in a [pixel aspect ratio](#) of 1:2.4. The effective screen resolution of this mode is 640×200 pixels. Again, the pixels cannot be individually addressed. Since there are twice as many characters on the screen in this mode, the card has enough video RAM for just four different text pages. BIOS Modes 2 & 3 select 80 column text modes. As with the 40-column text modes, Mode 2 disables the color burst in the composite signal and Mode 3 enables it.

In every text mode, each character has a background and a foreground color—e.g. red on yellow text for one character, white on black for the next, etc. While the same 4-bit [nybble](#) value used for the foreground color would normally allow all 16 colors to be used for the background color, the most significant bit of the background nybble is alternatively used to denote whether or not the character should blink (a hardware effect offered by CGA independent of the CPU). When a character is blinking, its foreground dots alternate between the foreground and background color, so that during the blink off period, the character cell is filled with the background color (exactly like a space character).<sup>[14]</sup> All blinking characters on the screen blink in sync. The blinking attribute effect is enabled by default and the high-intensity background effect is disabled; disabling blinking is the only way to freely choose the latter eight-color indexes (8-15) for the background color.

Notably, the [GW-BASIC](#) and, later, Microsoft [QBASIC](#) (a lesser derivative of Microsoft [QuickBASIC](#)) programming language interpreters included with MS-DOS (which was the *de facto* PC OS while the CGA was popular) supported all the text modes of the CGA with full color control, but did not provide a normal means through the BASIC language to switch the CGA from blink mode to 16-background-color mode, though it would be possible by directly programming the hardware registers using the OUT statement of the BASIC language. In BASIC, foreground text color numbers 16-31 are the blinking versions of colors 0-15, respectively, but background colors 8-15 are identical to colors 0-7 respectively.

## Standard graphics modes

CGA offers graphics modes in two resolutions:

- **320×200 pixels**, as with the 40×25 text mode. In the graphics mode, however, each pixel can be addressed independently. The tradeoff is that only four colors can be displayed at a time. Also, only one of the four colors can be freely chosen from the 16 CGA colors. The 1:1.2 pixel aspect ratio needs to be taken into account when drawing large geometrical shapes on the screen.

BIOS Mode 4 offers two palettes (differing in the presence or absence of the blue color component): green/red/brown and cyan/magenta/white. By setting the high-intensity bit, brighter versions of these modes can be accessed. The background can be set to any of the 16 CGA colors, but is black by default.

As with Modes 0 and 2, Mode 5 disables the color burst bit to allow colors to appear in grayscale on Composite monitor. Unlike the text modes, disabling the composite color burst bit affects the colors displayed on an RGB monitor with the IBM CGA card and true compatibles. Some



programmers use Mode 5 as an unofficial third palette on RGB monitors: cyan/red/white and the background color. The intense versions of these colors can also be used and the background color may be changed, but the palette cannot be switched to palettes 0 or 1 without enabling the composite color signal again. Notably, it is not mentioned in the IBM Technical Reference manual, and some CGA clones may not support it.

Mode 4				Mode 5		
#	Palette 0		Palette 1		low intensity	high intensity
	low intensity	high intensity	low intensity	high intensity		
0	default	default	default	default	default	default
1	2 — green	10 — light green	3 — cyan	11 — light cyan	3 — cyan	11 — light cyan
2	4 — red	12 — light red	5 — magenta	13 — light magenta	4 — red	12 — light red
3	6 — brown	14 — yellow	7 — light gray	15 — white	7 — light gray	15 — white

- **640×200** pixels, as with the 80×25 text mode. All pixels can be addressed independently. This mode is monochrome with a pixel aspect ratio of 1:2.4. By default the colors are black and bright white, but the foreground color can be changed to any other color of the CGA palette. This can be done at runtime without refreshing the screen. The background color cannot be changed from black on a true IBM CGA card. BIOS Mode 6 sets up the 640×200 graphics mode. This mode disables the composite color burst signal by default. The BIOS does not provide an option to turn the color burst on in 640×200 mode, and the user must write directly to the mode control register to enable it.

In text mode, font bitmap data comes from the character ROM on the card, which is only available to the card itself. In graphics modes, text output by the BIOS uses two separate tables. The first half of the character set (characters numbered 0 through 127, corresponding to 7-bit [ASCII](#) with some added graphical symbols) is supplied by a table in the BIOS ROM chip on the computer's mainboard at the fixed address F000:FA6E (the table is still present at this location even in modern PC BIOSes; unlike the font ROM on the CGA card itself that is used for the text modes, this table provides only the "thick" font shapes, not the "thin" ones). The second half of the set (characters numbered 128 through 255, corresponding to the international, block-graphics and mathematics characters) is supplied by the location pointed to by interrupt vector 1F (the vector itself is found at memory address 0000:007C; this is not in fact a real interrupt vector, since the vector does not point to executable machine code, as real interrupt vectors on the PC's Intel 8086 CPU do). The second half of the character set is ordinarily absent (the vector 1F does not point to actual font data), and trying to display it will result in garbage or blank characters. The character data may be placed into memory manually by the user, or by a utility such as GRAFTABL.

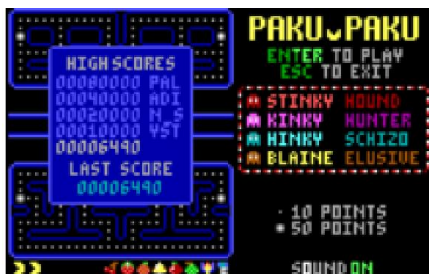
## Further graphics modes and tweaks

A number of official and unofficial features exist that can be exploited to achieve special effects.

- In 320×200 graphics mode, the background color (which also affects the border color), which defaults to black on mode initialization, can be changed to any of the other 15 colors of the CGA palette. This allows for some variation, as well as flashing effects, as the background color can be changed without having to redraw the screen (i.e. without changing the contents of the video RAM.)
- In text mode, the border color (displayed outside the regular display area—into the overscan area) can be changed from its usual black to any of the other 15 colors.
- Through precision timing, it is possible to switch to another palette while the screen is being scanned(drawn), allowing the use of any one of the six palettes per scanline. The best example of this in use is the game [California Games](#)<sup>[15]</sup> when run on a stock 4.77 MHz 8088. (Running it on a faster computer does not produce the effect, as the method the programmers used to switch palettes at predetermined locations is extremely sensitive to machine speed.) The same can be done with the background color, to create the river and road in [Frogger](#).<sup>[16]</sup> Another documented example of the technique is in [Atarisoft's](#) port of [Jungle Hunt](#) to the PC.
- Additional colors are often approximated using [dithering](#), although the low resolution makes it very apparent. In particular, many Sierra games use palette 0 at low intensity and dark blue as the background color. This gives it the three primary [RGB](#) colors to work with (as well as brown).

Some of these above tweaks can even be combined. Examples can be found in several games.<sup>[17]</sup> Most software titles did not use these possibilities, but there were a few impressive exceptions.

### 160×100 16 color mode

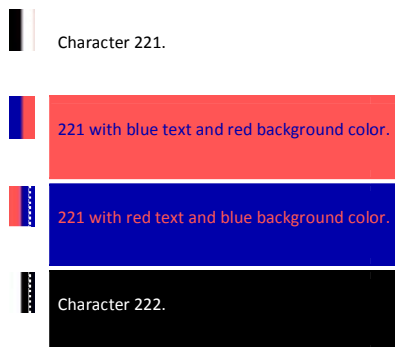


Title screen of PakuPaku, a [Pac-Man](#) clone that uses 160×100 mode



A single big "pixel" in 160×100 mode. This is the two top rows of half of character 221. Note the eight constituent non-square pixels and the overall 1:1.2 aspect ratio.

Technically, this mode is not a graphics mode, but a tweak of the 80×25 text mode. The character cell height register is changed to display only two lines per character cell instead of the normal eight lines. This quadruples the number of text rows displayed from 25 to 100. These "tightly squeezed" text characters are not full characters. The system only displays their top two lines of pixels (eight each) before moving on to the next row.



Character 221 of the CGA character set consists of a box occupying the entire left half of the character matrix. (Character 222 consists of a box occupying the entire right half.)

Because each character can be assigned different foreground and background colors, it can be colored (for example) blue on the left (foreground color) and bright red on the right (background color). This can be reversed by swapping the foreground and background colors.

Using either character 221 or 222, each half of each truncated character cell can thus be treated as an individual pixel—making 160 horizontal pixels available per line. Thus, 160×100 pixels at 16 colors, with an aspect ratio of 1:1.2, are possible.

Although a roundabout way of achieving 16-color graphics display, this works quite well and the mode is even mentioned (although not explained) in IBM's official hardware documentation.<sup>[18][19]</sup>

More detail can be achieved in this mode by using other characters, combining [ASCII art](#) with the aforesaid technique.

Because the CGA has 16 [KiB](#) (16,384 bytes) of graphics memory, not 16,000, it is just as easy to set the number of lines in this mode to 102 instead of 100 for a resolution of 160×102 (16320 pixels). This uses extra video memory that is normally unused. However, most games did

not do this, perhaps out of fear it would only work on some monitors but not others- a fear that is not unfounded as it was later found that certain compatibles have cards that either glitch or ignore any attempt to put the device into this mode.

The same text cell height reduction technique can also be used with the 40×25 text mode. This only made sense when using ASCII art, because without it the resulting resolution would only have been 80×100. [\[20\]\[21\]\[22\]](#)

## Special effects on composite color monitors

See also: [Composite artifact colors](#)

Using the NTSC TV-out instead of an RGBI monitor not only made for less attractive colors, as described above, but as is common with NTSC composite video, the separation between luminance and chrominance is far from perfect, yielding *cross-color artifacts*, or color "smearing". This is especially a problem with 80-column text:



80-column text on RGB (left) vs. composite monitor (right)

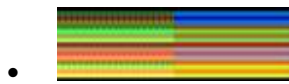
It is for this reason that each of the text and graphics modes described above exists twice: once as the normal "color" version and once as a "monochrome" version; the "monochrome" version of each mode would turn off the NTSC color decoding in the viewing monitor completely, resulting in a black-and-white picture, but also no color bleeding, hence, a sharper picture. On RGBI monitors, the two versions of each mode are identical, with the exception of the 320×200 graphics mode, where the "monochrome" version produces the third palette, as described above.

However, programmers soon found out that this flaw could be turned into an asset, as distinct patterns of high-resolution dots would "smear" into consistent areas of solid colors, thus allowing the display of completely new [artifact colors](#). Both the standard 320×200 four-color and the 640×200 color-on-black graphics modes could be used with this technique.

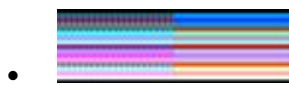
### Internal operation

*Direct colors* are the normal 16 colors as described above under "The CGA color palette".

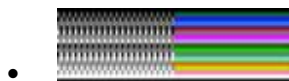
*Artifact colors* are seen because the composite monitor's NTSC chroma decoder misinterprets some of the luminance information as color, as stated before. By carefully placing pixels in appropriate patterns, the skilled programmer produces particular cross-color artifacts yielding the desired color; either from purely black-and-white pixels in 640×200 mode, or resulting from a combination of *direct* and *artifact* colors in 320×200 mode, as seen in these pictures.



320×200 palette 0



320×200 palette 1



640×200

Thus, with the choice of 320×200 vs. 640×200 mode, the choice of palette (1 or 2) and the freely-selectable color 0 in 320×200 modes (see above), plus the ability to set the foreground color in 640×200 mode freely, each one of these parameters results in a different set of artifact colors, making for a total [gamut](#) of over 100 colors, of which 16 can be displayed at the same time.

Later [demonstrations](#) by enthusiasts have increased the maximum number of colors the CGA is known to produce in a single image to approximately a thousand. Aside of artifacting, this technique involves the text mode tweak which quadruples its rows, thus offering the benefit of 16 foreground and 16 background colors. Certain ASCII characters such as U and !! are then used to produce the necessary patterns, which result in non-dithered images with an effective resolution of 80×100 on a composite monitor. <sup>[23]</sup>

### Availability and caveats

The 320×200 variant of this technique (see above) is how the standard BIOS-supported graphics mode looks on a composite color monitor. The 640×200 variant, however, requires modifying a bit (color burst disable) directly in the CGA's hardware registers, as a result, it is usually referred to as a separate "mode", often just as "the" composite color mode, since its more distinctive set of artifact colors led it to being more commonly used than the 320×200 variant.

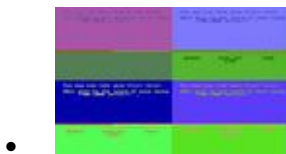
Being completely dependent on the NTSC encoding/decoding process, composite color artifacting is not available on an RGBI monitor, nor is it emulated by EGA, VGA or contemporary graphics adapters.

The modern, games-centric PC emulator [DOSBox](#) includes a CGA mode, which can emulate a composite monitor (in graphics modes). As of December 2012, the latest official version will emulate the more common 640×200 composite mode and its set of 16 artifact colors; support for the more complex 320×200 variant has been added to the DOSBox codebase for the next official build.

## Resolution and usage

Composite artifacting, whether used intentionally or as an unwanted artifact, reduces the effective horizontal resolution to a minimum of 160 pixels, more for black-on-white or white-on-black text, without changing the vertical resolution. The resulting composite video display with "artifacted" colors was thus sometimes described as a 160×200/16-color "mode", though technically it was a method, not a mode.

The low resolution of this composite color artifacting method led to it being used almost exclusively in games. Many of the more high-profile titles optionally, sometimes exclusively, offering graphics optimized for composite color monitors. [Ultima II](#), the first game in the game series to be ported to IBM PC, used CGA composite graphics. [King's Quest I](#) was innovative in its use of 16-color graphics on the PC, PCjr and Tandy 1000; even CGA owners could enjoy the 16-color graphics by using a composite color monitor or television, thanks to programmers exploiting the [inaccuracies of composite NTSC chroma decoding](#). Selecting 'RGB mode' at the title screen would instead result in the usual CGA graphics mode limited to 4 colors. In this mode, [dithering](#) was employed to simulate extra colors.



Microsoft Decathlon - Top: Game in composite mode, Bottom: Game in RGB mode, Left: with RGB monitor, Right: with composite monitor

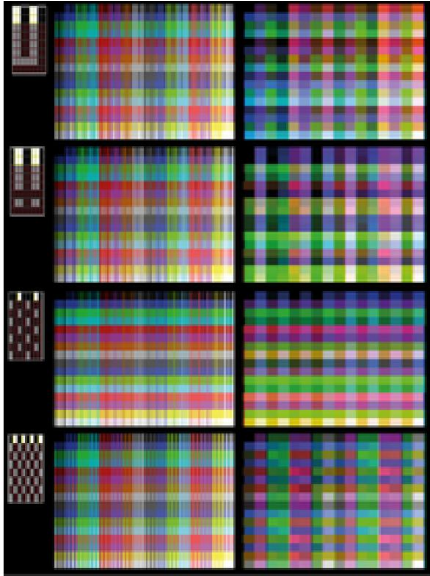


King's Quest -Top: Game in composite mode, Bottom: Game in RGB mode, Left: with RGB monitor, Right: with composite monitor



Ultima II - Left: with RGB monitor, Right: with composite monitor

## High color depth



1024 colors in composite mode

By taking advantage of the color smearing, the NTSC color clock and a method similar to that used in the 16 color mode, it's possible to display over 16 colors in composite monitors.

160 cycles of the NTSC color clock occur during the each line's pixel period so in 40 column mode each pixel occupies half a cycle and in 80 column mode each pixel uses a quarter of a cycle. Limiting the character display to the upper or upper two scanlines, and taking advantage of the pixel arrangement in certain characters of the codepage 437, it is possible to display up to 1024 colors.<sup>[24]</sup> This technique was used in the demo 8088 MPH.<sup>[25]</sup>