JOE

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Graphic Enhancement

IBM's Enhanced Graphics Adapter lives up to its name by offering better performance than other graphics cards.

People—especially computer people—are just never satisfied. They always want more. IBM, of course, is well aware of this particular human propensity and ever more frequently tries to satisfy our technological cravings with new (and enhanced) components to plug in our PCs.

The new IBM Enhanced Graphics Adapter (EGA) should satisfy a lot of cravings: it supports more displays, more modes, more memory, and more colors than either of the original PC display adapters, is more highly integrated, more flexible, more expandable, and, of course, costs more money.

The EGA is a graphics controller that supports either color or monochrome direct drive monitors in a variety of modes. The EGA supports three different display types:

- IBM Monochrome Display or equivalent 350-line high-resolution display (such as the Amdek 310 or 310A)
- IBM Color Display or equivalent 200-line TV frequency IRGB display
- IBM Enhanced Color Display

Unlike the IBM Color/Graphics Adapter (CGA), the EGA does *not* support composite monitors, VCRs, or television receivers, nor does it have a built-in printer adapter like the IBM Monochrome Display.

The EGA supports all of the display modes provided by the original IBM adapters and adds its own:

- 640-by-350, 4-color graphics on the monochrome adapter (the four colors are black, normal, bright, and blink)
- 320- and 640-by-200, 16-color graphics on standard frequency IRGB displays
- up to 640-by-350, 16-color graphics on the Enhanced Color Display
- a programmable color palette that allows any color attribute to be mapped into any of 16 colors on IRGB displays (8 colors on RGB displays), or any of 64 colors on the Enhanced Display
- a flexible, RAM-based character generator that supports up to 512 character codes, with BIOS support for alphanumeric displays of up to 43 lines of 80 columns on high-resolution (350 scan lines) displays

- hardware support for smooth horizontal and vertical scrolling
- hardware support for split screen displays (separate, noncontiguous buffers for two adjacent display regions)
- light-pen interface compatible with previous IBM adapters
- hardware support for fast display updates, multiple modes for writing to display memory, and capability for interrupt on vertical retrace

The most obvious improvements are the new color palette, monochrome graphics, and the Enhanced Color Display. These and other features should be examined from several viewpoints: functional, physical, architectural, experimental, and financial.

The functional aspect of the EGA depends on the type of display used with it. The visual attributes vary with the display and the amount of graphics memory installed.

The monochrome display has only two video inputs, video and intensity, which gives four possible combinations. Although four intensity levels might be expected, the intensity input by itself displays as black, so only three colors are assigned to the monochrome display as is shown in table 1.

The color-display column in this table shows the parameters for standard TV-frequency displays. The IBM Enhanced Color Display is a dual-mode display, with the horizontal frequency controlled by the polarity of the vertical retrace signal. A negative polarity vertical retrace operates the Enhanced Color Display in high-resolution mode.

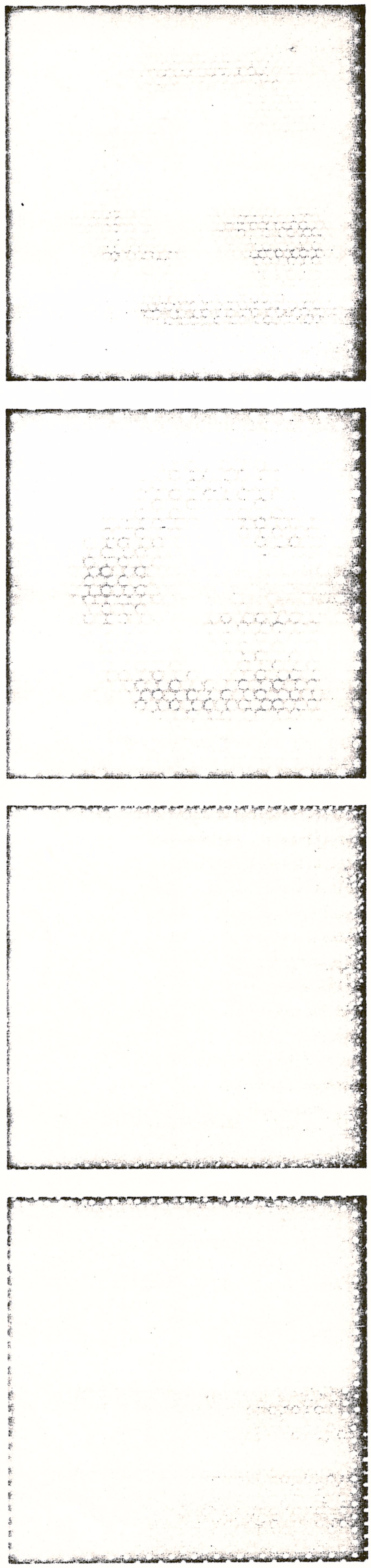
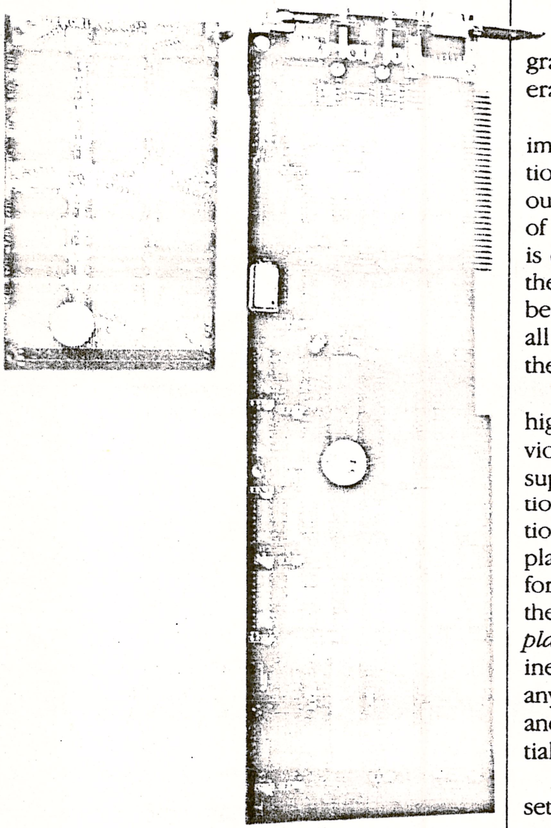
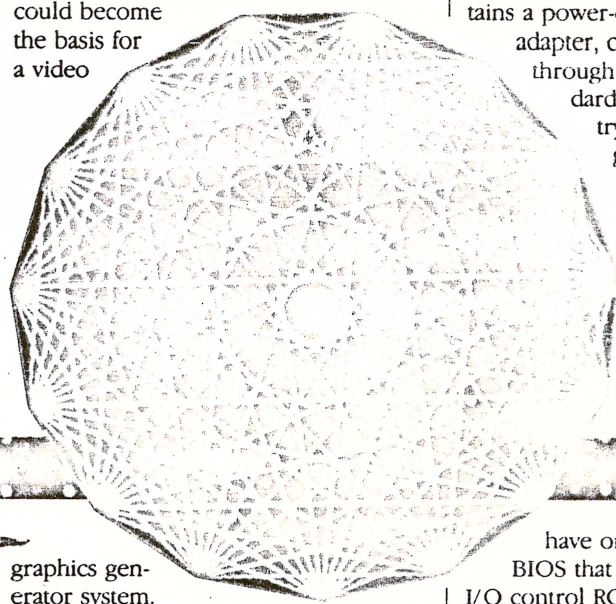


Table 2 shows the video operating modes supported by the EGA BIOS. Modes 0 through 7 are compatible with like-numbered modes in the original PC BIOS, but with enhancements. Mode 7 supports eight pages on the monochrome display. Modes 0 through 3 (color alphanumeric) display high-resolution 8-by-14 characters on the Enhanced Display if the EGA configuration switches are set for enhanced operation. CGA black-and-white modes 0, 2, and 4 are identical to EGA modes 1, 3, and 5. CGA did not generate a colorburst signal in the composite video output for black-and-white modes.

Physically, the EGA looks like any other full-size PC adapter. The rear panel has a nine-pin D connector for attaching a direct drive monitor, two RCA phono jacks not currently supported by the EGA hardware, and a hole through which four DIP switches can be accessed. The card contains two jumpers, a connector for the piggyback memory card, and a "feature connector."

Extreme close-ups show the difference between standard resolution (200 lines) and high resolution (350 lines) in text and graphics modes. Improved vertical resolution makes the individual horizontal scan lines all but invisible. All four photos were taken from an IBM Enhanced Color Display.





By using custom LSI circuits, the EGA (below left) packs more function in fewer chips than the Color Graphics Adapter. To the right of the EGA is the 64KB piggy back graphics memory expansion card. At right, a 16-sided polygon with all of its diagonals is shown in 640-by-350 graphics mode.

The feature connector provides a place where all monitor signals (six color bits, horizontal and vertical syncs, and blanking) and related adapter signals could meet the outside world. A feature board could supply an external sync and video information to the EGA, or it could combine the EGA signals with external sources. Thus, the EGA could become the basis for a video graphics generator system.

The adapter is packaged with an impressive set of installation instructions and manual update pages for various PCs (regular and AT) and versions of the *Guide to Operations*. Everything is clearly marked, but wading through the literature to find a particular version becomes a little tedious. The reason for all this trouble is those little switches at the rear of the card.

The on-board BIOS provides a high degree of compatibility with previously defined PC display modes, plus support for the new modes and functions. Unfortunately, the PC configuration switches have only two bits for display type. The EGA set-up procedure for PCs and XTs requires that the motherboard switches be set for *no display*. The EGA BIOS initialization examines the EGA switches to determine if any other display adapter is installed, and if so, which adapter is to be the initially active device.

It is *essential* that the switches be set correctly. Incorrect switch or jumper settings can result in damage to displays or adapters. The IBM Monochrome Display is notoriously sensitive to incorrect sync frequency or polarity.

One of the two 2-position jumpers on the card must be set one way for the Enhanced Display, the other way for monochrome or standard color. The second jumper sets the I/O addresses for the card to 2xxH instead of the standard 3xx. Thus, two EGAs can be installed in the same system. The supplied BIOS deals only with the card at 3xx; additional support has to be provided for the second card.

The EGA card has a 16KB ROM BIOS (which is twice the size of the entire PC system board BIOS) that contains a power-on self test for the adapter, code to support video I/O through interrupt 10H, the standard BIOS video function entry point, and character generator patterns for both alphanumeric and graphics modes. The EGA BIOS is located at segment C000H in the processor address space.

Because the EGA's BIOS is on the controller card, the PC must have on the system board a BIOS that automatically scans for I/O control ROMs. All ATs, XTs, Portable PCs, and new PCs have the correct BIOS. A PC with BIOS dated before 10/27/82 can be upgraded for about $30 from any IBM dealer.

The demonstration programs supplied to *PC Tech Journal* by IBM had creation dates between 9/83 and 10/84. The BIOS in the loaner board was a masked ROM dated 11/3/83, indicating that EGAs have existed for well over a year. The technical reference section for the EGA has August 2, 1984, printed at the bottom of each page. The BIOS listing in the technical reference is dated 9/13/84, which matches the version in the EGAs delivered to *PC Tech Journal* in January 1985. These adapters have Intel 27128 PROMs instead of masked ROMs. The IBM press release announcing the EGA was issued 9/10/84, three days before the latest BIOS revision.

FUNCTIONAL LITERACY

But enough archaeology. What can this tool do for us in modern times? A good place to start is with the functions provided by BIOS. The EGA initialization procedure places its own address in the INT 10H vector, after copying the original vector to the vector for INT 42H. The EGA BIOS can then call on the original BIOS for support of the old cards. This is the same technique used by the fixed-disk adapter to insinuate itself into the diskette service routines.

The accompanying sidebar, "EGA BIOS Functions," describes the functions provided via the EGA BIOS handler for INT 10H. Some of the new functions may look familiar to those who have seen the PCjr or PC/AT BIOS. The Set Palette Registers (Function AH=10H) is the same as on the PCjr, and Write String (AH=13H) is supported by the AT's system BIOS.

The two completely new functions are in support of the RAM-based character generator. In the previous display adapters, alphanumeric modes used the character codes in the display buffer to address a character generator ROM on the adapter. This ROM could not be read by the processor, thus the need for a copy of the character patterns in the BIOS ROM to enable software character generation in graphics modes.

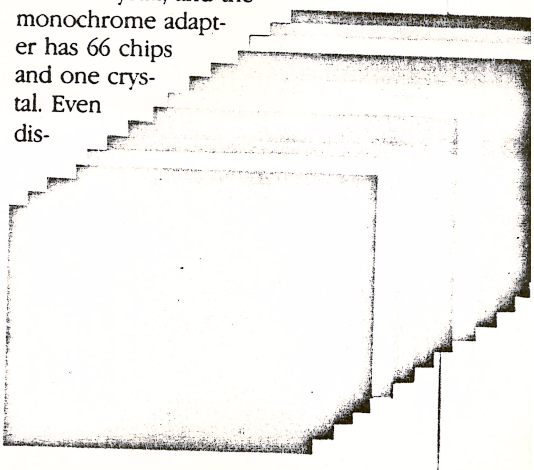
The EGA BIOS contains two character pattern sets, one 8-by-14 for high-resolution displays, and the other an 8-by-8 set for TV frequency displays. Whenever an alphanumeric mode is selected (via function AH=0), BIOS copies the appropriate patterns into part of the EGA's memory, where the EGA hardware will access it just like the old adapters did their ROM character generators. But now the patterns can be anything the user wants—foreign languages, graphics symbols, etc.

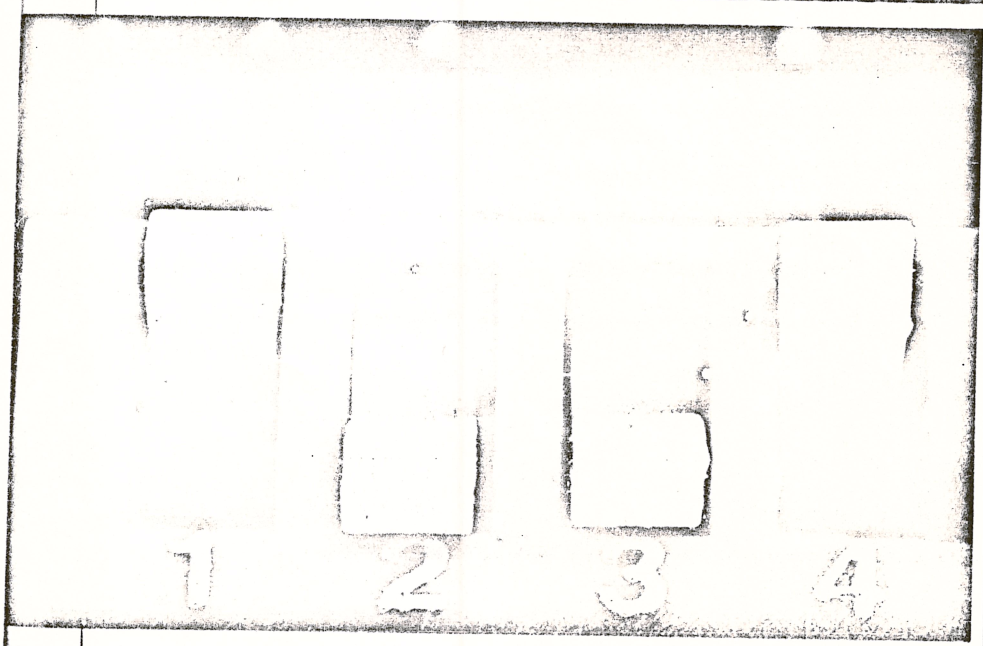
Function AH=11H supports loading the RAM character generator from the BIOS ROM or from a user-specified place. The second set of functions will load the generator and recalculate the number of rows that will fit on the screen, after which BIOS will display text in the new format. This facility can be used to produce very readable 43-line-by-80-column displays on 350-line, high-resolution monitors by calling for the 8-by-8 character font. Listing 1 demonstrates how to do this and still have the underscore in the right place (a combination documentation/BIOS bug leaves underline register set one line past the bottom of the character cell when this function call is used).

A related function in AH=12H replaces the print screen routine (through INT 5) with one that knows about the flexible screen dimensions.

The EGA BIOS uses the standard BIOS data areas (and additional areas) in segment 40H to record display-related information. Table 3 shows the EGA video parameter storage layout. One nice feature is the save area pointer at 40:00A8H. This double word pointer points to a table of pointers to user-selectable save areas in which BIOS stores the current values of additional parameters, such as the palette registers. This allows programs to work with the current values used by BIOS, many of which would otherwise be lost in write-only hardware registers. Table 4 shows the organization of save areas.

The major components of the Enhanced Graphics Adapter consist of custom large-scale integrated circuits (LSI), reducing the chip count of the EGA to 52, plus one crystal and a few miscellaneous resistors and capacitors. By way of comparison, the CGA has 69 chips and no crystal, and the monochrome adapter has 66 chips and one crystal. Even discounting the duplicated CRT controllers and the printer adapter logic, the EGA does more than the other two cards combined with well under half the silicon. Three years of technology (not to mention a significant investment in custom logic) certainly makes the difference.





The EGA switches are used to set the initial operating mode. The 16 rectangles (shown above, right) show the three primary colors—red, green, blue— and gray in each of four intensities—off, low, medium, and bright; 64 combinations are possible.

The major functional elements of the EGA are the CRT controller, the sequencer, two graphics controllers, the attribute controller, and the display buffer memory. The block diagram in figure 1 shows the relationship among these elements. The sidebar, "EGA I/O Register Summary," explains the I/O address map for all of the EGA registers.

The CRT controller generates the horizontal and vertical timing signals for controlling the CRT display, and the addresses for accessing the display buffer memory. The CRTC also generates cursor and underline timing signals and refreshing for the dynamic RAMs. The CRTC used in the EGA is a custom chip with some similarity to the Motorola 6845 used in the earlier IBM display adapters. Sufficient differences exist, however, so programs that try to set up the display dimensions directly, or adjust the image centering by fooling with the horizontal sync position, will probably end up with no visible picture.

The sequencer is another custom LSI device that generates the basic memory timings for the dynamic RAMs and the character clock for display refreshing. It coordinates memory access by the processor during active display times and contains a mask register that allows individual memory planes to be protected from possibly being written to by the processor.

The two graphics controllers direct the data from memory to the attribute controller and the main processor. In graphics modes, memory is sent in serial fashion to the attribute controller. In alphanumeric modes, the memory data are sent in parallel to the character generator plane or the attribute chip directly, bypassing the graphics controller. Each of the graphics controller chips handles two of the four bit planes. The graphics controllers work in parallel and share common I/O addresses.

The attribute controller is the fifth custom LSI device on the EGA board. It provides a palette of 16 colors, each of which can be set separately to control the six color outputs. This chip also controls the blinking and underlining functions according to the attribute bits in the display memory.

The display buffer memory is implemented using 64KB RAM chips that have an internal organization of 16KB by 4 bits. These are type 4416 chips, and are *not* the same 64KB RAM chips usually found in PC memory, which are typically organized as 64KB by 1 bit. The EGA card has eight 4416 RAMs, arranged in four groups of two. Each pair constitutes a 16KB bit plane. Additional display memory can be added on the piggyback memory expansion card. Each 64KB expansion (the card can hold up to three sets) adds another 16KB to each memory plane. The maximum memory supported is 256KB or four 64KB planes.

In order to support the variety of alpha, old graphics, and new graphics modes, the EGA has considerable flexibility with respect to memory access by the processor and display refresher logic. To begin with, the address of the buffer in the processor address space is programmable through the graphics controller miscellaneous register (port 3CF.06 bits 3 and 2) as follows:

Bit 3	Bit 2	Buffer Segment Address
0	0	A000H for 128KB—*Not used by BIOS*
0	1	A000H for 64KB *New graphics modes (D-10)*
1	0	B000H for 32KB Monochrome alpha mode (7)
1		B800H for 32KB *CGA compatible modes (0-6)*

Bit 1 of this register has a further effect on memory addressing. When set to 0, all four planes occupy the same

TABLE 1: IBM Monitor Parameters

	MONO-CHROME	COLOR/ENHANCED (TV frequency)	ENHANCED (High resolution)
Horizontal scan rate	18.432 kHz	15.750 kHz	21.850 kHz
Vertical scan rate	50 Hz	60 Hz	60 Hz
Video bandwidth	16.257 mHz	14.318 mHz	16.257 mHz
Displayable colors	3	16	64
Character size	7 × 9 pixels	7 × 7 pixels	7 × 9 pixels
Character box size	9 × 14 pixels	8 × 8 pixels	8 × 14 pixels
Maximum resolution	720 × 350	640 × 200	640 × 350
Alphanumeric modes	7	0,1,2,3	0,1,2,3
Graphics modes	F	4,5,6,D,E	10

The display used with the EGA determines its visual attributes. Features of the three IBM monitors that can be used with it are shown above.

TABLE 2: EGA Operating Modes

BIOS MODE	TYPE	ALPHA FORMAT	BOX SIZE	PIXEL RESOLUTION	BUFFER START	COLORS	PAGE SIZE	MAX PAGES
0	Alpha	40 × 25	8 × 8	320 × 200	B800	16	2,048	8
1	Alpha	40 × 25	8 × 8	320 × 200	B800	16	2,048	8
2	Alpha	80 × 25	8 × 8	640 × 200	B800	16	4,096	8
3	Alpha	80 × 25	8 × 8	640 × 200	B800	16	4,096	8
4	Graphic	40 × 25	8 × 8	320 × 200	B800	4	16,384	1
5	Graphic	40 × 25	8 × 8	320 × 200	B800	4	16,384	1
6	Graphic	80 × 25	8 × 8	640 × 200	B800	4	16,384	1
7[1]	Alpha	80 × 25	9 × 14	720 × 350	B000	3	4,096	8
*8	Reserved							
*9	Reserved							
*A	Reserved							
*B	Reserved—Used by BIOS to load character generator (color)							
*C	Reserved—Used by BIOS to load character generator (mono)							
*D	Graphic	40 × 25	8 × 8	320 × 200	A000	16	8,192	2/4/8[2]
*E	Graphic	80 × 25	8 × 8	640 × 200	A000	16	16,384	1/2/4
*F	Graphic	80 × 25	8 × 14	640 × 350	A000	3	32,768	1/2
*10	Graphic	80 × 25	8 × 14	640 × 350	A000	4/16[3]	32,768	1/2

[1] *Monochrome alpha mode 7 supports three pixel intensities, but has eight attribute bits per character, which provide blink and underline in addition to foreground and background intensity selection.*
[2] *Max pages for modes D, E, F, and 10 depend on total graphics memory. First number is for 64KB, second for 128KB, third for 256KB.*
[3] *Mode 10 requires 128KB or more memory for 16 colors.*

Modes 8, 9, A, B, C, D, E, F, and 10 (with asterisks) are supported by EGA. Modes 7 and F are for 50-Hz monochrome displays. Others are for 60-Hz color displays. Color modes with 350 lines require the Enhanced Color Display.

region of the processor's memory address space and can be written simultaneously. In this mode the read map select register in the graphics controller (3CF.04) selects the plane to be read by the processor. When bit 1 is set to 1, map chaining is selected. This has the effect of placing plane 1 after plane 0, and plane 3 after plane 2, which doubles the available address space from the processor's viewpoint.

Bit 2 of the sequencer's memory mode register (3C5.04) controls sequential or odd/even interleaving. When set to 0, even processor addresses go to maps 0 and 2, and odd addresses go to maps 1 and 3. When this bit is 1, the data in all planes is accessed sequentially. Odd/even mode is used in conjunction with chaining in the alpha modes and the CGA-compatible graphics modes except mode 6 (640-by-200, two-color), which only requires a single bit plane. Chaining also is used (with sequential addressing) in the high-resolution graphics modes (F and 10) when only 64KB is installed to allow the processor to see a full 32KB buffer. Since this set-up has only two planes, high-resolution color graphics is limited to four colors with 64KB. With expansion memory installed, BIOS will set the memory for four parallel planes, giving full 16-color capability.

The important point here is that the compatible modes look the same from the processor's point of view as they always did, so programs that go poking around in screen memory will continue to work. (The CGA odd/even scan line offset of 8KB is controlled by the CRTC compatibility mode bit). One quickly develops a healthy respect for the job BIOS does in masking the hardware differences, which are considerable, between the adapters.

Figure 2 shows the memory organization and pixel arrangement for the EGA's new 16-color graphics modes. GRAPH16.BAS (listing 2) is a program for writing eight pixels at once for rapid painting on byte boundaries. Before running the GRAPH16 program, the E mode must be set by executing the SETMODE.ASM program that is shown in listing 3.

One of the nicer features of the EGA is its support for simultaneous display of any 16 colors from a palette of 64 colors. The CGA can also display 16 colors, but only those produced by combining the red, green, blue, and intensity signals.

The alpha foreground attribute field (the low order four bits of the attribute byte following the character code) can be used to illustrate the workings of the palette registers. In the CGA the attribute bits are sent directly to the I, R, G, and B pins of the monitor at the appropriate times, producing the specified color.

In the EGA the attribute bits are used as an index into the palette register array. The contents of the palette register is then sent to the monitor pins. Thus, the color that shows up on the EGA display depends on the contents of the selected palette register, not on the attribute bits directly. So, in a case where all of the palette registers are set to 0, the screen will be black, no matter what the attributes say.

Table 5 shows the arrangement of the bits in the palette register, and the corresponding pin positions on the direct drive monitor connector. When operating in enhanced mode (negative vertical sync and 350 lines) the IBM Enhanced Color Display recognizes six inputs corresponding to the six color outputs from the palette (see table 6). The R, G, and B signals produce dark colors, the R', G', and B' signals produce brighter colors, and the combinations produce still brighter colors. Thus, the four combinations of each color-signal pair produce four intensity levels for each color—64 combinations.

When the Enhanced Display is operating in compatible low-resolution mode, it treats the color inputs as IRGB and ignores the two additional inputs. This allows the display to be used on the old adapters, and it allows the same palette set-up to display on either monitor in the compatible modes. But this removes the ability to display the additional colors in low-resolution modes. For this reason, the BIOS routines automatically switch to high resolution for the standard alphanumeric modes on the Enhanced Display—besides giving better looking text, the palette functions are fully available.

The palette operates all the time,

TABLE 3: *EGA BIOS RAM Usage*

LOC	NAME	SIZE	COMMENT
BASE	**SYSTEM BIOS**		
449	CRT_MODE	Byte	; Current BIOS mode
44A	CRT_COLS	Word	; Number of character columns
44C	CRT_LEN	Word	; Length of buffer in bytes
44E	CRT_START	Word	; Offset of current page
450	CURSOR_POSN	Word*8	; Cursor (col, row) for each of 8 pages
460	CURSOR_MODE	Word	; Current cursor mode setting
462	ACTIVE_PAGE	Byte	; Current page being displayed
463	ADDR_6845	Word	; Base I/O address for CRTC
465	CRT_MODE_SET	Byte	; Simulated value of CGA 3×8 register
466	CRT_PALETTE	Byte	; Simulated value of CGA 3×9 register
EGA	**BIOS**		
484	ROWS	Byte	; Number of character rows-1
485	POINTS	Word	; Bytes per character
487	INFO	Byte	; Miscellaneous info:
			; D7 High bit of mode (1 => no clear)
			; D6 Memory 00 = 64KB 01 = 128KB
			; D5 Memory 10 = 192KB 11 = 256KB
			; D4 Reserved
			; D3 0=EGA active, 1=EGA not active
			; D2 0=Write anytime
			; 1=Wait for display enable
			; D1 1=EGA has monochrome attached
			; D0 0=Emulate cursor type
			;
488	INFO_3	Byte	; Feature bits (D7-D4)
			; DIP switches (D3-D0)
4A8H	SAVE_PTR	Dword	; Points to table of pointers to save
			; areas
			; (see table 4 for layout)

This table shows some additional features of EGA's BIOS. Note especially the save area pointer that is located at 4A8H.