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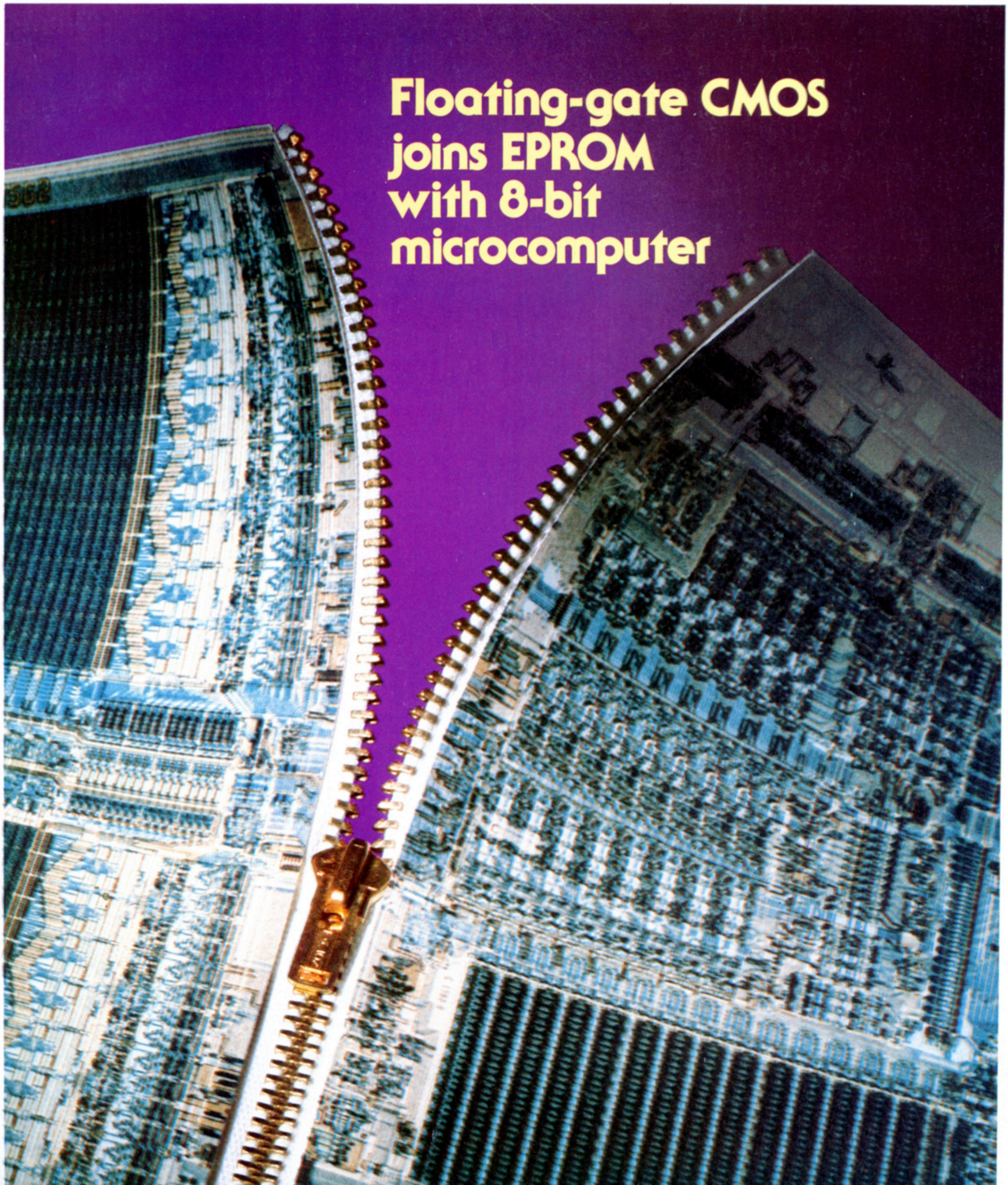

Floating-gate CMOS joins EPROM with 8-bit microcomputer

By evaluating five important factors, systems designers can choose accurately nine times out of ten the display that will do the job with the greatest efficiency and at the least cost.

Picking the best display: An easy-to-follow guide

With a host of display technologies competing for attention, only a rare system engineer can pick the best for an application without careful analysis. Each display technology meets some needs better than others and no existing technology meets all requirements.

To narrow the choices, the engineer must first come up with a fairly precise specification of the system's display needs. Then those display characteristics should receive primary attention:

- Information content
- Reading distance
- Power availability
- Environmental requirements
- Cost

Nine times out of ten, the best decision will result if the display requirements are examined in this sequence.

Information determines geometry

Information content and reading distance determine what the display should look like—its gross geometric characteristics. They are the most fundamental considerations in choosing a display.

The amount of power available and the environmental requirements deserve attention next. It turns out that display technologies fall into convenient groups that provide clearcut choices in these areas. There is little sense in wasting time on consideration of other specifications if special power-supply or environmental requirements allow only one display possibility.

Finally, the price, as always, is a major consideration. Here an entirely new method based on display information density—a combination of information content and display size—can be used to estimate the cost-effectiveness of various displays for a given application.

Today light-emitting-diode (LED), cathode-ray-tube (CRT), electromechanical, gas-discharge, incandescent, vacuum fluorescent, and liquid-crystal-display (LCD) technologies are each finding their niche. Other technologies are emerging—such as electroluminescent and electrochromic displays—though they are not yet in the mainstream of available products.

Some display types usually need not be considered for typical electronic systems—for example, electromechanical and incandescent displays, which find their primary niche in such applications as scoreboards and marquees, where the characters must be large and readability in bright sunlight may be required.

Several years ago it was much simpler for the electronics designer to choose a display. Most needs could be met by either LED or gas-discharge displays on the one hand, or by a CRT on the other. A CRT provided the only solution when large amounts of information had to be displayed. Conversely LEDs and gas-discharge displays were the best choice when the quantity of information was smaller or when there were limitations on space, power, and price. Present needs, however, require consideration of several more display characteristics and many more display technologies. A systematic specifying approach begins with the information that the display will convey.

How much information?

The information content depends on the number of characters and their font. For example, a clock-timer module containing four seven-segment digits and a colon has a relatively standard information content. But such standard formats are rare. Overall there is more variety than uniformity between the display requirements of different products.

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The first step for the engineer is to prepare an inventory of the information to be displayed. The inventory should be as accurate as possible because, all else remaining equal, the ultimate cost will be a function of the information content. With the inventory in hand, display selection can begin.

Look first at the character font. Available displays can be grouped into a progression of increasingly complex character fonts (Fig. 1). Each font in the series has a higher information content that meets more sophisticated requirements.

Most numeric applications can be satisfied with a seven-segment display font. However, a hexadecimal code output, which includes some alphabetic characters, requires a modified dot-matrix font, in which several of the dots can be omitted.

If the messages to be displayed are alphanumeric, several options are available. When only upper-case characters are needed, a 14- or 16-segment "starburst" font is often sufficient. In fact, a somewhat distorted lower-case capability is also possible with a 16-segment display. Usually, however, a dot-matrix display will be needed for full alphanumeric capability. Many alphanumeric requirements—with upper- and lower-case letters and some special symbols—can be satisfied by a 5 by 7 dot-matrix font. Other requirements—including subscripts, superscripts, and underlining—will necessitate a font of higher information content, such as 5 by 12 dots. In the extreme case, where extensive graphics capability is needed, a screen of equally spaced dots must be specified.

The number of characters in the display—the other component of information density—can often be made smaller than may seem necessary at first. For example, abbreviation may be able to shorten the longest item in the inventory of messages, thus allowing use of a shorter display. Time multiplexing allows even more compression. Long messages can be put in small displays by scrolling (shifting the message across the display one character at a time) or by rolling (shifting the message through the display one line at a time).

The range of information content available for various display technologies is shown in Table 1. After the information content has been determined for a particular application, the table can be used

Table 1. Information content and character height for commercial displays

	LED	Twisted nematic LCD	Vacuum fluorescent	Gas discharge	CRT
Fonts	7-segment; 14/16-segment; 4 × 7, 5 × 7 modified; dot matrix; 5 × 7 dot-matrix; custom; graphics	7-segment; 14/16-segment; 5 × 7 dot matrix; 5 × 8 dot-matrix; custom; graphics	7-segment; 9-segment; 14-segment; 5 × 7 dot matrix; 5 × 12 dot-matrix; custom; graphics	7-segment; 14/16-segment; 5 × 7 dot-matrix; custom; graphics	flexible
No. of characters	1-16+ 1,2,4,8 character modules stackable to any string length	1-320*	1-240*	1-960*	< ≃ 10K
Maximum information content (pels)	≃ 50k	≃ 20k	≃ 65k	≃ 250k	≃ 1000k
Character height	2.5-50.8 mm (0.1-2 in.)	2.5-50.8+ mm (0.1-2+ in.)	4.2-30.0 mm (0.17-1.18 in.)	5.1-88.0 mm (0.2-3.3 in.)	2.5+ mm (0.1+ in.)

*For displays organized into discrete characters. Some complex graphics panels allow a larger number of 5 × 7 characters in a 6 × 8 cell.

to identify the technologies remaining as candidates.

Note that in Table 1 the maximum information content for each display technology is listed in pels, as well as in the more familiar terms of font styles and number of characters. The pel (picture element) is a display dot, segment or annunciator.

Pels provide a very precise measurement of information content. Though most system designers do not think of messages as requiring, say, 64 pels (eight seven-segment digits plus eight decimal points), this form of measurement has great value in systematic display selection. Also, the concept is really quite simple and can be easily related to the more commonplace thinking in terms of font style and character count.

How big should it be?

Once an engineer has decided how much display he needs, the next specification to consider is size. Note that larger characters are not necessarily more expensive. So at this stage size should be specified objectively—without any attempt to economize by compromising on size.

The required character size depends primarily on the expected viewing distance. For a human observer, the smallest distinguishable detail subtends about one minute of arc at the eyes; a complete character can be resolved if it has a visual angle of six or seven minutes of arc. However, those are best-case values. The prudent designer will allow a visual angle of about 14 minutes of arc for the average character.

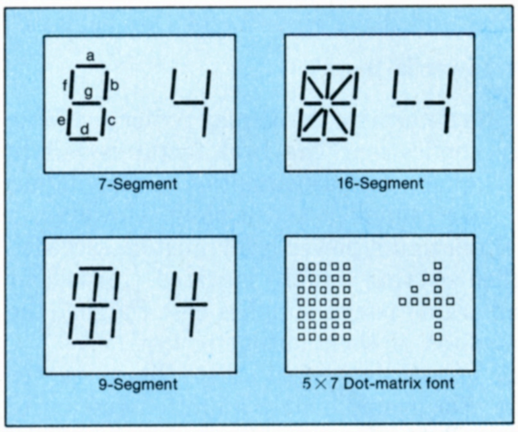
Conversion from visual angle to viewing distance for a given character height is straightforward. The results for some typical character heights are in Table 2. As can be seen, the values conform to expectations based on everyday experience.

Of course, character recognition depends on factors other than the eye's resolving power. Character heights much larger than the acceptable minimum can draw attention to the displayed information by separating it from background information. Also, the brightness and perceived contrast of the display contribute to the visibility and legibility.

With the required information content, character size and available space, the system designer will have a fairly clear idea of what the display will eventually look like. A glance at Table 1, however, shows substantial overlap among the competing display technologies at this stage of the selection process. Knowing what a display should look like does not nail down the selection—unless the very large information content of a CRT is required.

The third major selection criterion—the power available—begins to separate one display technology from another. Typical power consumptions for various commercial display technologies are compared in Table 3. As can be seen, the passive LCD readouts consume less power than the active light-emitting types. This makes sense, because actually generating light takes more energy than modifying the passage of ambient light through an LCD cell.

For LED, vacuum fluorescent, and gas-discharge displays, power consumption is roughly proportional to the brightness of the display and the size of the



1. Increasingly more complex character fonts are required for versatility in presenting different types of information. Whereas a simple seven-segment display is often adequate for numeric characters, a dot-matrix type will be needed when upper- and lower-case alphabetic characters must be displayed.

Table 2. Character height and reading distance

Typical character height	Comfortable viewing distance* (at 14 arc-min. visual angle)	Representative applications
2.5 mm (0.1 in.)	0.6 m (2 ft)	Handheld calculator-terminal
3.8 mm (0.15 in.)	0.9 m (3.1 ft)	Desktop computer
5.1 mm (0.2 in.)	1.2 m (4.1 ft)	
7.6 mm (0.3 in.)	1.9 m (6.1 ft)	Benchtop instrument
10.9 mm (0.43 in.)	2.7 m (8.8 ft)	
14.1 mm (0.56 in.)	3.5 m (11.5 ft)	Appliances
20.3 mm (0.8 in.)	5.0 m (16.4 ft)	
25.4 mm (1.0 in.)	6.2 m (20.5 ft)	

*Maximum distance for reliable viewing is approximately twice this value.

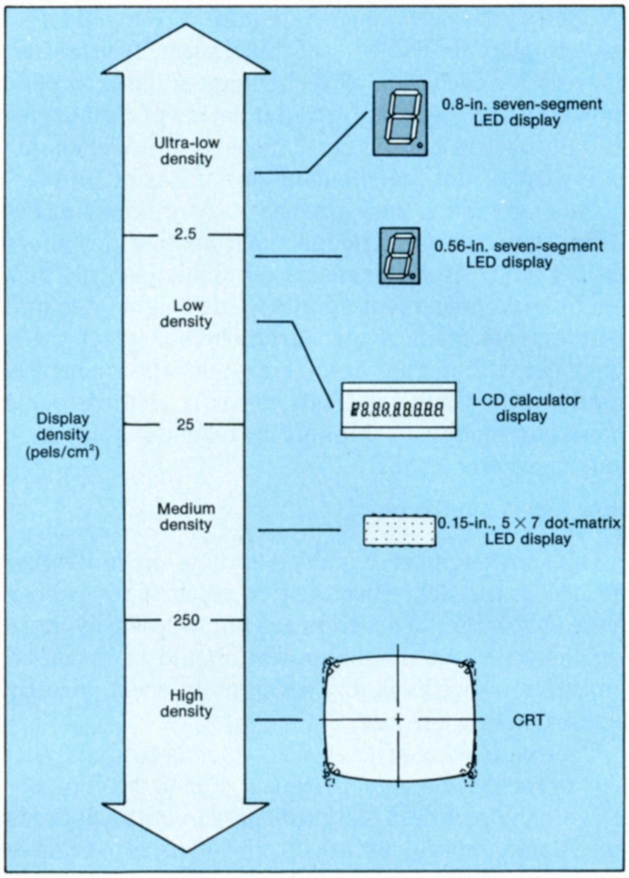
pels. More light requires more power; a large, bright segment consumes more power than a smaller or dimmer dot. Also, LEDs come in two classes of efficiency: newer colors (green, yellow and high-efficiency red) consume much less power than the original red versions for a given brightness. For an LCD, the power consumption per pel depends on its area. For a CRT, the consumption per pel depends on the brightness. Remaining variations in power consumption result from differences in the design, manufacture, and drive circuitry of the displays.

How much power is there?

Two factors determine the display power available in a given application. The first factor is purely economic. Higher power consumption implies higher costs for power supplies and cooling. However, a substantial minimum power level must be exceeded before higher costs are actually incurred. Up to about 50 W, comparable power supplies cost roughly the same, regardless of their output power.

Physical constraints can also limit power availability. For example, only a limited amount of power is available in portable equipment. Thus power consumption may actually determine whether an application is even feasible. Of course, when feasibility depends on minimizing the power, LCDs provide the obvious choice.

The environmental requirements of an application can also strongly favor one type of display over another. For example, LEDs, because they are solid-state devices, can be made significantly more rugged than other displays, which may require large glass



2. Display density provides a convenient way of characterizing the complexity—and hence the cost—of a display for a particular application. It is defined as the number of picture elements divided by the frontal area of the display package. Though examples are shown for each level of density, other display types also may be suitable.

Table 3. Power consumption and supply voltages for commercial displays

	LED	Twisted-nematic LCD	Vacuum fluorescent	Gas discharge	CRT
Typical power consumption per pel (including drive electronics)	1-200 mW	0.3-100 μW	1-100 mW	3-250 mW	Not applicable*
Supply voltage**	2.0-8 V	3-10 V	12-60 V (plus filament voltage of 1-12 V)	130-250 V	5-25 KV

*A typical 12-in. black-and-white CRT monitor consumes 30 to 60 W

**Supply voltage for anode only; most displays (except LEDs) require multiple voltages envelopes or sheets. LEDs are outstanding when it comes to temperature cycling, mechanical shock, thermal shock, vibration, and impact resistance. They therefore provide clearcut advantages in such harsh applications as automobiles, trucks, farm equipment, military and commercial avionics, and military ground equipment.

Though the environmental capabilities of LEDs are well documented, it is often difficult to get comparable data for other display technologies. Head-to-head comparisons of various technologies are impeded because of different test methods or simply because of a lack of data.

One category of environmental data has been documented, however. As shown in Table 4, the operating and storage temperatures are specified for all commercially available displays. The table shows that, in general, LEDs can be used over a broader temperature range than other displays.

LCDs have some environmental characteristics that are quite unusual. One limitation, in particular, becomes important as the information content of the display increases. With LCDs, the increased multiplexing rate needed for addressing large amounts of information causes a reduced viewing angle and a reduced range of operating temperatures. Also, the response time of LCDs slows as the temperature falls. Typical response times at −30°C range from 0.5 to 1 s.

Now comes the final—and the biggest—question: cost. Though cost depends on the other characteristics considered, a new approach makes it surprisingly easy to predict the most attractively priced choice for a particular task. The approach, as mentioned earlier, is based on the concept of display information density, a combination of information content and display size.

A new way to compare costs

To apply the new method, display information density (or simply "display density") is defined as the number of pels divided by the frontal area of the display package. Then, display density is expressed in pels/cm^2. Some examples of display density for various types of displays are in Fig. 2.

One possible drawback of the definition for display density is that the display packaging may lead to different density values for similar displays with characters of the same size. For example, if a display has a small border around the characters, its display density will be higher than that of an otherwise identical display with larger borders. Fortunately the problem is quite minor in determining the cost-effectiveness of displays.

A couple of examples will show how vastly different display densities may be required. First, consider a digital clock-timer. Its display requires approximately 30 pels (four digits times seven segments plus a colon). Typically such a display will have to be readable from a distance of several yards, so the pels are usually spaced to provide a digit height of a half inch or more. The result is a relatively low display density.

Next, consider a word-processing system. The display must handle upper- and lower-case characters, subscripts, superscripts, and underlining for

Table 4. Operating and storage temperature ranges

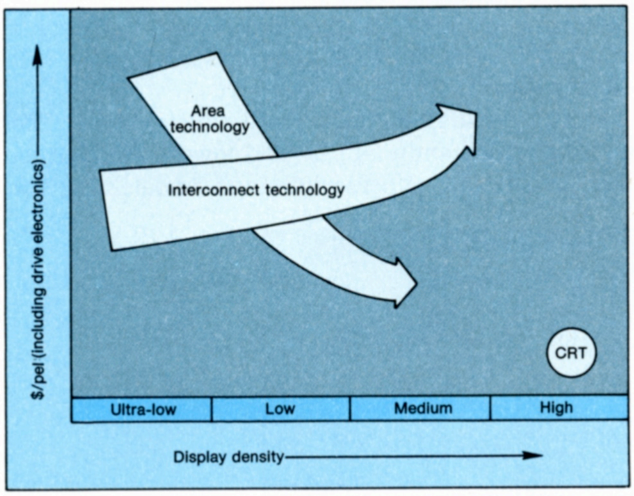
Temperature (°C)	Commercial LED	Hi-rel LED	Twisted-nematic LCD		Vacuum Fluorescent	Gas discharge	CRT
			direct drive	1:16 MUX			
Maximum operating	70 to 85	100	40 to 90	50	55 to 85	50 to 70	55
Minimum operating	−40 to −20	−55	−40 to 0	0	−40 to −10	−20 to 0	0
Maximum storage	85 to 100	100 to 125	60 to 95	60	70 to 100	70 to 125	65 to 70
Minimum storage	−55 to −20	−65 to −55	−55 to −20	−20	−40 to −20	−55 to −40	−40

many lines of text. Displays of more than 300,000 pels are commonly used in word processing. Also, since a word processor is operated at arm's length, the pels are closely spaced. As a result, the display has relatively high density.

Display density largely determines the relative cost of a technology. However, the nature of the relationship between display density and cost are not the same for all technologies.

Table 5. A checklist of secondary considerations

Viewing quality	Color Contrast and crispness of the character Viewing angle Brightness Compatibility with the front panel
Design considerations	Electronic partitioning Package size Compatibility with the manufacturing process Product maturity and availability of drivers, mounting hardware, etc. Design flexibility Applications support
Procurement policy	Reputation of manufacturer Second-sourcing



3. Excluding the CRT, displays can be grouped into two major categories: area and interconnection technologies. Usually area technologies, such as LCDs, become more cost-effective with increasing display density, whereas interconnection technologies, such as LEDs, gradually become less cost-effective.

For some technologies—such as LCD, gas-discharge and vacuum fluorescent—the cost is very nearly proportional to the area of the display. These are called "area" technologies. As the density increases (more pels in the same area), the cost per pel declines until the limits of the technology are reached.

Other displays, such as LEDs, have costs that are more closely proportional to the number of pels used. These can be described as "interconnect" technologies. Over quite a large range, the cost per pel for an interconnect technology is largely independent of density.

The difference between area and interconnect technologies has an important impact on their relative costs as display density changes. For example, to upgrade a numeric display from a character height of 0.3 in. to 0.56. in. (in other words, to lower drastically the display density), an LCD manufacturer greatly increases the area of glass that must be processed—and hence the cost. Under the same circumstances, an LED manufacturer's costs are essentially unchanged. This relationship is depicted graphically in Fig. 3. As can be seen, inherent manufacturing constraints favor interconnect technologies at low densities and area technologies at higher ones.

Familiar use confirms the pattern of relative costs in Fig. 3. For example, large digital clocks and TV channel indicators with character heights of 0.5 in. or greater tend to use LED displays; so also do automotive clocks and radios with character heights of around 0.3 in.

At a somewhat greater density, a 16-segment LED display (such as HP's HDSP-6300) can still provide cost-effective solutions for small-character alphanumeric applications. Similarly an interconnect technology, such as LED, also has a cost advantage when information is distributed over the face of a panel, with a few annunicators here, some numeric digits there, and so on.

On the other hand, equipment with higher information densities, such as an automated bank teller, tends to use area technologies (gas-discharge and vacuum-fluorescent displays). Such an application typically has six 40-character lines of a 5 by 7 dot-matrix font, which gives a density of 30 to 100 pels/cm². Here the strengths of area technology become apparent. The cost of the dead space between pels becomes insignificant relative to the cost of interconnecting LEDs.

Of course, the world of displays is not so black and white that it will allow an engineer to define a precise density point where the costs of area and interconnect technologies cross over. Manufacturing costs tend to have a broad distribution around any theoretical value, and marketing people have a way of moving prices around for reasons unrelated to actual cost. Thus, as in Fig. 3, the price-density function must be expressed in broad bands.

Other factors may make a difference

If an engineer finds that the required display falls in an area where various technologies overlap in capability, it is still possible to keep the selection process reasonably structured. The next step is to consider secondary factors that can tilt the balance and provide a final choice. A checklist of items to be considered is shown in Table 5.

Each of the various technologies has some of these second-order advantages. After narrowing the selection to a few types, the system designer should learn as much as possible about the finalists. Display manufacturers will be only too happy, naturally, to provide literature that describes the advantages of their display technologies.

As an example of secondary strengths, consider LED displays. LEDs are available off the shelf in a wide range of colors (including green, yellow, and various shades of red). Also, LEDs can be constructed so that the color of an element may be changed from red to yellow or red to green, for example. Known for the crisp appearance of their characters, LED displays can be used with filters to allow viewing in direct sunlight. Furthermore, LED displays are extremely compact and may require as little as 20% of the space that other technologies need.

On the other hand, one interesting advantage of area displays, such as LCDs, is that they can be constructed as custom panels, incorporating displays and annunciators. Several microwave ovens use this capability to reduce parts.

Finally, choosing a display vendor is, in itself, a serious matter. A good vendor will understand the strengths and weaknesses of his own technology.□

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How useful?

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