HEWLETT PACKARD

APPLICATION NOTE 964

Contrast Enhancement Techniques

Why Contrast Enhancement?

The most important attribute of any equipment utilizing a digital readout is the ability to clearly display information to an observer. A person viewing the display must be able to quickly and accurately recognize the information being displayed by the instrument. The display, usually front panel mounted, must be visible without difficulty in the ambient light conditions where the instrument will be used.

Since most ambient light levels are sufficiently bright to impair the visibility of an LED display it is necessary to employ certain techniques to develop a high viewing contrast between the display and its background. Since the quality of visibility is primarily subjective, it is not easily measured or treated by analytical means. Thus, human engineering plays a very important role in display applications. The best judge of the viewing esthetics of a display is the human eye. In short, is the final display design pleasing to the eye when viewed in the end use ambient?

This application note presents various criteria and techniques that a display designer should consider to obtain optimum contrast enhancement for red, yellow and green LED displays. A representative list of filter manufacturers and available filters is given at the end of this discussion.

Basic Concepts

The objective of contrast enhancement is to maximize the contrast between display "On" and display "Off" conditions. This is accomplished by (1) reducing to a minimum the reflected ambient light from the face of the display and (2) allowing a maximum of the display's emitted light to reach the eye of a viewer. The goal is to achieve a maximum contrast between "On" segments and "Off" segments as well as a maximum contrast between "Off" segments and display package and background.

Let us begin by defining the following basic terms:

Contrast Ratio, CR, may be defined as follows:

$$CR = \frac{\text{Source Luminance} + \text{Background Luminance}}{\text{Background Luminance}}$$

Contrast Improvement Ratio, CIR, may be defined as follows:

$$CIR = \frac{\text{CR (With Filter)}}{\text{CR (Without Filter)}}$$

It is desirable to have as high a CR as possible. One is able to measure the improvement in contrast enhancement by the CIR.

Contrast Ratio is usually applied to the face of a display as a whole. However, with stretched segment displays, such as Hewlett-Packard's 5082-7750 and 5082-7760 displays, it is difficult to achieve a high value of segment on/off contrast while effectively concealing the display package from view. For example, a display with a black package is easily concealed from view, however, the "Off" segments will be visible. This is due to the difference in reflectivity between the "Off" segments and the black package.

A reduction in the reflectivity difference between the "Off" segments and the package of a stretched segment display may be obtained by adding a small amount of dye to color tint the segments, and the display package may be colored to match the off segment color. With the addition of an appropriate optical filter placed in front of the display, the "Off" segments tend to be indistinguishable from the background. The trade-off is that a colored package is more visible than a black package. Because of this trade-off a designer has to decide which is more important, concealing "Off" segments or concealing the display package. Since the usual choice is to conceal "Off" segments, Hewlett-Packard is using this colored package technique on its 5082-7600 series High-Efficiency Red, Yellow and Green Stretched Segment Displays.

Contrast enhancement under artificial lighting conditions may be accomplished by use of selected wavelength optical filters. Under bright sunlight conditions contrast enhancement becomes more difficult and requires additional techniques such as the use of louvered filters combined with shading of the display. The effect of a wavelength optical filter is illustrated in Figure 1. The filtered portion of the display can be easily read while the "Off" segments are not apparent. By comparison, reading the unfiltered portion of the display is difficult.

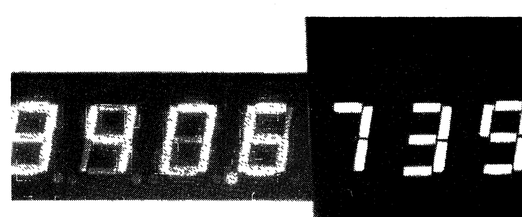

Figure 1. Effect of wavelength optical filter on LED display.

Eye Response, Peak Wavelength and Dominant Wavelength

The 1931 CIE (Commission Internationale De L'Eclairage) standard observer curve, also known as the photopic curve, is shown in Figure 2. This curve represents the eye response of a standard observer to various wavelengths of light. The vivid color ranges are also identified in Figure 2. The photopic curve peaks at 555 nanometers (nm) in the yellowish-green region. This peak corresponds to 680 lumens of luminous flux (lm) per watt of radiated power (W).

Two wavelengths of the LED emission are important to a user of LED displays; Peak Wavelength and Dominant Wavelength. **Peak Wavelength** (λ_p) is the wavelength of the peak of the radiated spectrum. The peak wavelength may be used to estimate the approximate amount of display emitted light that is passed by an optical filter. For example, if an optical filter has a relative transmission of 40% at a given λ_p, then approximately 40% of the display emitted light at the peak wavelength will pass through the filter to the viewer while 60% will be absorbed. This gives a designer an initial estimate of the amount of loss of display emitted light he should expect.

Dominant Wavelength (λ_d) is used to define the color of an LED display. Since an LED approximates a monochromatic light source, the dominant wavelength of an LED may be defined as the single wavelength which is perceived by the eye to match the complete radiated spectrum of the device. As an example, the dominant wavelength of Hewlett-Packard's "Yellow" Display, which has a peak wavelength of 583 nm, is 585 nm. As shown in Figure 2, the actual color corresponding to λ_d = 585 nm is yellowish-orange. Therefore, an optimum wavelength filter will be one that is yellowish-orange (or amber) in color.

Both peak wavelength and dominant wavelength are listed in the electrical-optical characteristics on the data sheets for Helwett-Packard's LED display and lamp products.

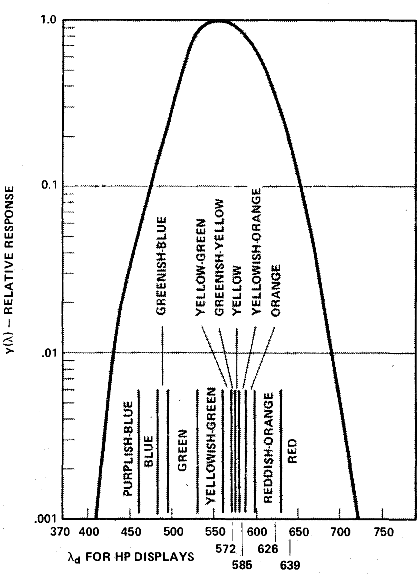

Figure 2. CIE Standard observer eye response curve (photopic curve), including CIE vivid color ranges.

Filter Transmittance

The relative transmittance of an optical filter with respect to wavelength is:

$$T(\lambda) = \frac{\text{Luminous Flux with Filter at Wavelength } \lambda}{\text{Luminous Flux without Filter at Wavelength } \lambda}$$

Most manufacturers of wavelength filters for use with LED displays provide relative transmittance curves for their products. Sample transmittance curves are presented in Figures 3, 4, 5 and 6. These curves represent approximate filter characteristics which may be used in various ambient light levels. The total transmittance curve shape and wavelength cut-off points have been chosen in direct relationship to the LED radiated spectrum. Each filter curve has been empirically determined and is similar to commercially available products. The higher the ambient light[1], the more optically dense the filter must be to absorb reflected light from the face of the display. Because the display emitted light is also strongly absorbed, the display must be driven at a high average current to be readily visible. For dim ambient light, the filter may have a high value of transmittance as the ambient light will be at levels much less than display emitted light. The display can now be driven at a low average current.

Listed on each filter transmittance curve (Figures 3, 4, 5 and 6) are empirically selected ranges of relative transmittance values at the peak wavelength which may give satisfactory filtering. For example, a filter to be used with a yellow display in moderate ambient lighting could have a transmittance value at the peak wavelength [$T(\lambda_p)$] between 0.15 and 0.30. The filter wavelength cut-off should occur between 530 and 550 nm for best results.

When selecting a filter, the transmittance curve shape, attenuation at the peak wavelength and wavelength cut-off should be carefully considered in relationship to the LED radiated spectrum and ambient light level so as to obtain optimum contrast enhancement.

[1] Dim ambients are in the range of 3 to 20 footcandles (32 to 215 lux), moderate ambients are in the range of 20 to 100 footcandles (215 to 1076 lux), and bright ambients are in the range of 100 to 500 footcandles (1076 to 5382 lux). Footcandle = (lm/ft^2) and lux = (lm/m^2).

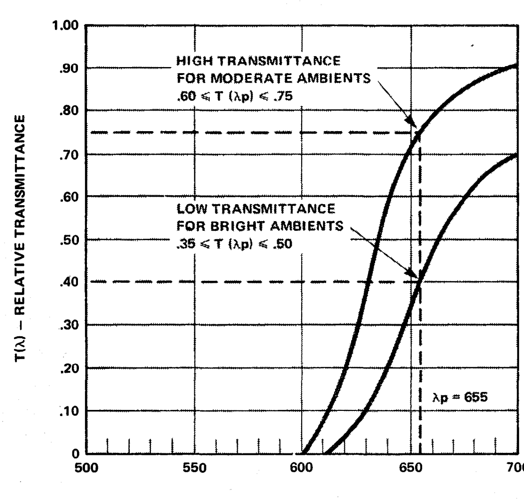

Figure 3. Typical transmittance curve for filters to be used with HP standard GaAsP red displays.

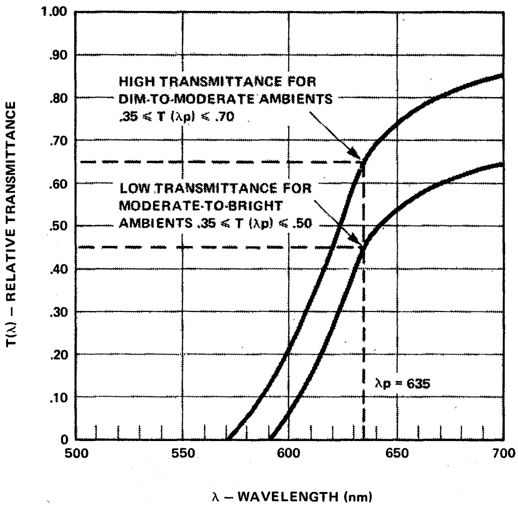

Figure 4. Typical transmittance curves for filters to be used with HP high-efficiency red displays.

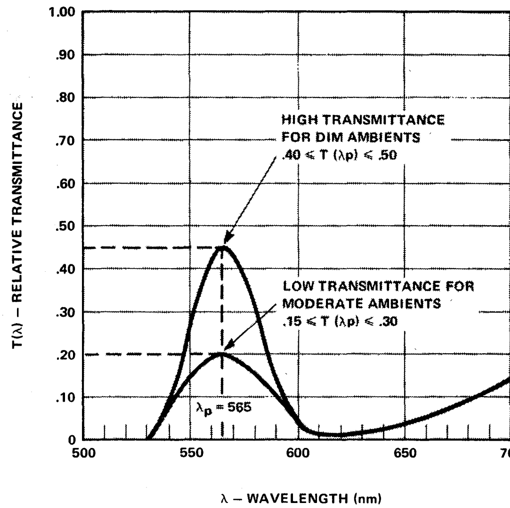

Figure 6. Typical transmittance curves for filters to be used with HP green displays.

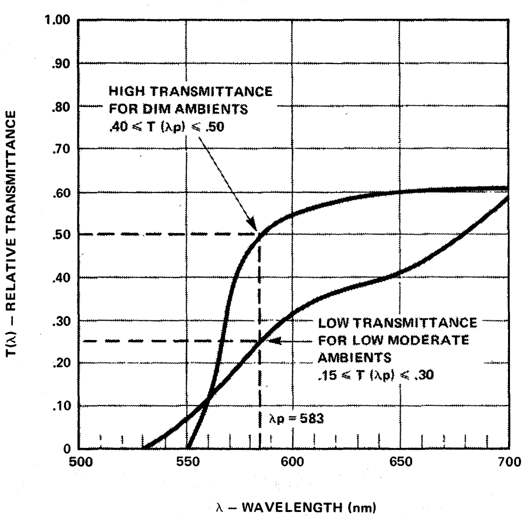

Figure 5. Typical transmittance curves for filters to be used with HP yellow displays.

Wavelength Filtering

The application of wavelength filters as described in the previous section is the most widely used method of contrast enhancement under artificial lighting conditions. Wavelength filters are very effective in artificial lighting. However, they are not very effective in daylight due to the high level ambient light. Filtering in daylight conditions is best achieved by using louvered filters (discussed in a later section).

Figures 7, 8, 9 and 10 show the relationship between artificial lighting and the spectra of LED displays, both unfiltered and filtered. Figures 7a through 10a show the relationship between the various LED spectra and the spectra of daylight flourescent and incandescent light. The photometric spectrum (shaded curve) is obtained by multiplying the LED radiated spectrum [f(λ)] by the photopic curve [y(λ)]. Thus, photometric spectrum = f(λ)•y(λ). Figures 7b through 10b demonstrate the effect of a wavelength filter. The filtered photometric spectrum is what the eye perceives when viewing a display through a filter (shaded curve). Thus, filtered photometric spectrum = f(λ)•y(λ)•T(λ). The ratio of the area under the filtered photometric spectrum to the area under the unfiltered photometric spectrum is the fraction of the visible light emitted by the display which is transmitted by the filter:

$$\text{Fraction of Available Light from Filtered Display} = \frac{\int f(\lambda)\cdot y(\lambda)\cdot T(\lambda)\cdot d\lambda}{\int f(\lambda)\cdot y(\lambda)\cdot d\lambda}$$

In addition to attenuating a portion of the light emitted by the display, a filter also shifts the dominant wavelength, thus causing a shift in the perceived color. For a given display spectrum, the color shift depends on the cut-off wavelength and shape of the filter transmittance characteristic. A choice among available filters must be made on the basis of which filter and LED combination is most pleasing to the eye. A designer must experiment with each filter as he cannot tell by transmittance curves alone. The filter spectra presented in Figures 3, 4, 5 and 6 are suggested starting points. Filters with similar characteristics are commercially available.

Filtering Red Displays (λp = 655 nm) Filtering out reflected ambient light from red displays is easily accomplished with a long wavelength pass filter having a sharp cut-off in the 600 nm to 625 nm range (see Figures 3 and 7b). Under bright flourescent light, a red filter is very effective due to the low concentration of red in the flourescent spectrum. The spectrum of incandescent light contains a large amount of red, and therefore, it is difficult to filter red displays effectively in bright incandescent light.

Filtering High-Efficiency Red Displays (λp = 635 nm) The use of a long wavelength pass filter with a cut-off in the 570 nm to 590 nm range gives essentially the same results as is obtained when filtering red displays (see Figures 4 and 8b). The resulting color is a rich reddish-orange.

Filtering Yellow Displays (λp = 583 nm) The peak wavelength of a yellow LED display is in the region of the

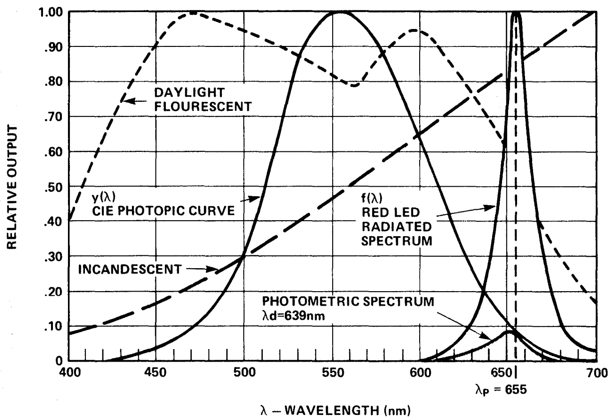

Figure 7A. **Relative relationship between standard GaAsP red LED display spectrum, photopic curve and artificial lighting.**

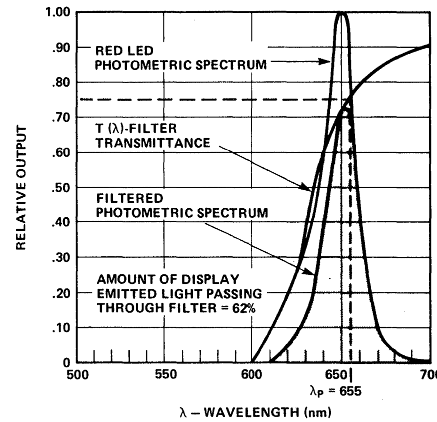

Figure 7B. **Effect of a long pass wavelength filter on red LED displays.**

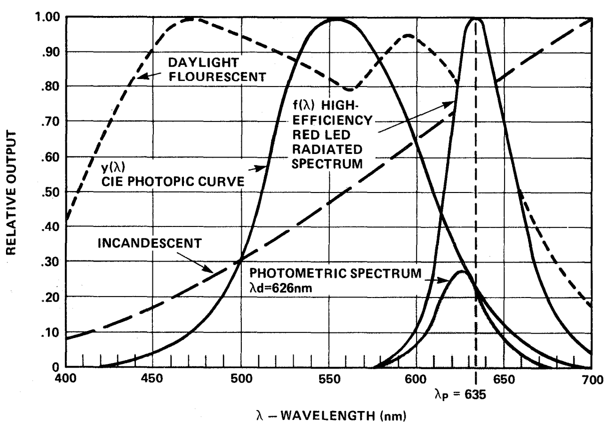

Figure 8A. **Relative relationship between high-efficiency red LED display, photopic curve and artificial lighting.**

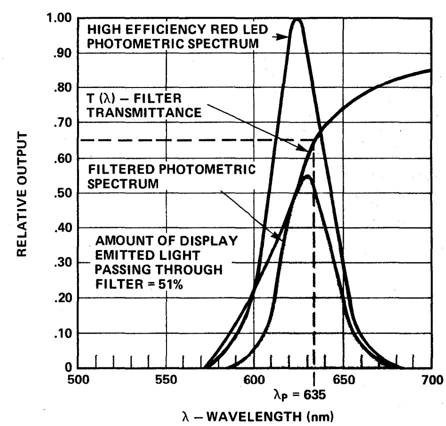

Figure 8B. **Effect of a long pass wavelength filter on high-efficiency red LED displays.**

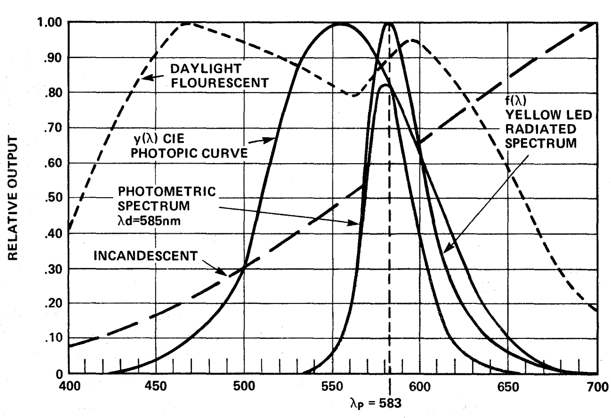

Figure 9A. **Relative relationship between yellow LED displays, photopic curve and artificial lighting.**

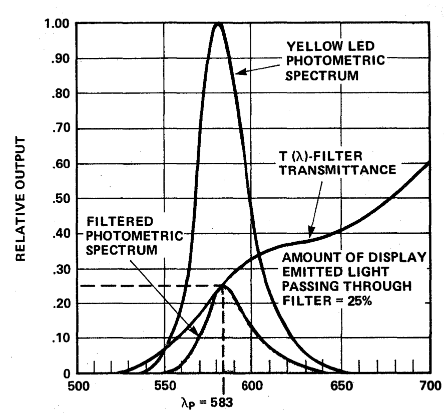

Figure 9B. **Effect of a long pass wavelength filter on yellow LED displays.**

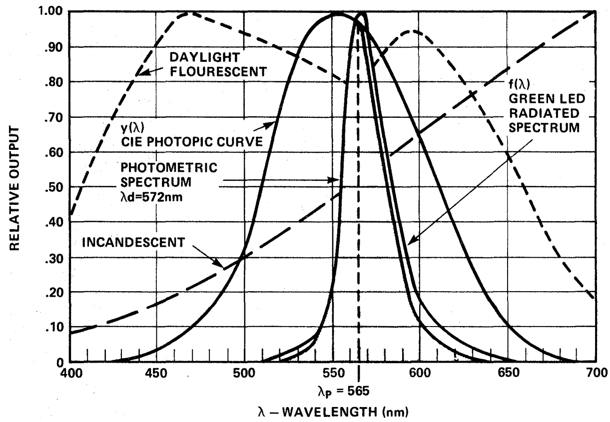

Figure 10A. Relative relationship between green LED displays, photopic curve and artificial lighting.

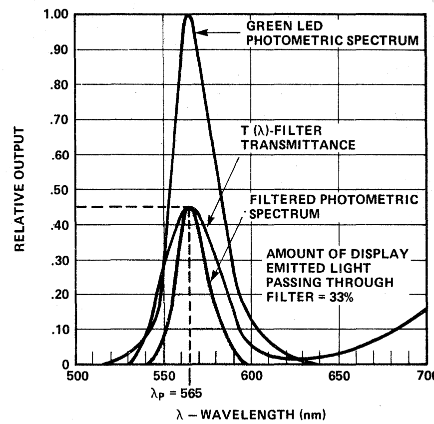

Figure 10B. Effect of a bandpass wavelength filter on green LED displays.

photopic curve where the eye is most sensitive (see Figure 9a). Also, there is a high concentration of yellow in the spectrum of flourescent light and a lesser amount of yellow in incandescent light. Therefore, filters that are more optically dense than red filters at the peak wavelength are required to filter yellow displays. The most effective filters are the dark yellowish-orange (or dark amber) filters as shown in Figure 5. The use of a low transmittance yellowish-orange filter, as shown in Figure 9b, results in a similar color to that of a gas discharge display. Pure yellow filters provide very little contrast enhancement.

Filtering Green Displays (λp = 565 nm) The peak wavelength of a green LED display is only 10 nm from the peak of the eye response curve (see Figure 10a). Therefore, it is very difficult to effectively filter green displays. A long wavelength pass filter, such as is used for red and yellow displays, is no longer effective. An effective filter is obtained by combining the dye of a short wavelength pass filter with the dye of a long wavelength pass filter, thus forming a bandpass yellow-green filter which peaks at 565 nm as shown in Figure 6. Pure green filters peak at 520 nm and drop off rapidly in the 550 nm to 570 nm range and are not recommended. The best possible filters for green LED displays are those which are yellow-green bandpass, peaking at 565 nm and dropping off rapidly between 575 nm and 590 nm. As shown in Figure 10b, this filter passes wavelengths 550 to 570 while sharply reducing the longer wavelengths in the yellow region. To effectively filter green LED displays in flourescent light would require the use of a filter with a low transmittance value at the peak wavelength. This is due to the high concentration of green in the flourescent spectrum. It is easier to filter green displays in bright incandescent light due to the low concentration of green in the incandescent spectrum, see Figure 10a.

Three manufacturers of wavelength filters are **Panelgraphic Corporation** (Chromafilter®), **SGL Homalite** and **Rohm & Haas Company** (Plexiglas). The LED filters produced by these manufacturers are useable with all of Hewlett-Packard's display and lamp products. Table 2 lists some of the filter manufacturers and where to go for further information. Table 3 lists some specific wavelength filter products with recommended applications.

Louvered Filters

Louvered filters are very effective in reducing the amount of bright artificial light or daylight reflected from the face of a display, without a substantial reduction in display emitted light. The construction of a louvered filter is diagrammed in Figure 11. Inside a plastic sheet are thin parallel louvers which may be oriented at a specific angle with respect to the surface normal. The zero degree louvered filter has the louvers perpendicular to the filter surface.

The operation of a louvered filter is similar to a venetian blind as shown in Figure 12. Light from the LED display passes between the parallel louvers to the viewer. Off-axis ambient light is blocked by the louvers and therefore is not able to reach the face of the display to be reflected back to the viewer. This results in a very high contrast ratio with minimal loss of display emitted light at the On-axis viewing angle. The trade-off is a restricted viewing angle. For example, the zero degree louvered filter shown in Figure 11 has a horizontal viewing angle of 180°; however, the vertical viewing included angle is 60°. The louver aspect ratio (louver depth/distance between louvers) determines viewing angle. A list of louver option possibilities is given in Table 1.

Some applications require a louver orientation other than zero degrees. For example, an 18 degree louvered filter may be used on the sloping top surface of a point of sale terminal. A second, is the use of a 45 degree louvered filter on overhead instrumentation to block out ambient light from ceiling mounted lighting fixtures.

Louvered filters are effective filters for enhancing the viewing of LED displays installed in equipment operating under daylight ambient conditions. In bright sunlight, the most effective filter is the crosshatch louvered filter. This is essentially two zero degree neutral density louvered filters oriented at 90 degrees to each other. Red, yellow and green digits may be mounted side by side in the same display. Using only the crosshatch filter, all digits will be clearly visible and easily read in bright sunlight as long as the sunlight is not parallel to the viewing axis. The trade-off is restricted vertical and horizontal viewing. The effective viewing cone is an included angle of 40° degrees (for a filter aspect ratio of 2.75:1).

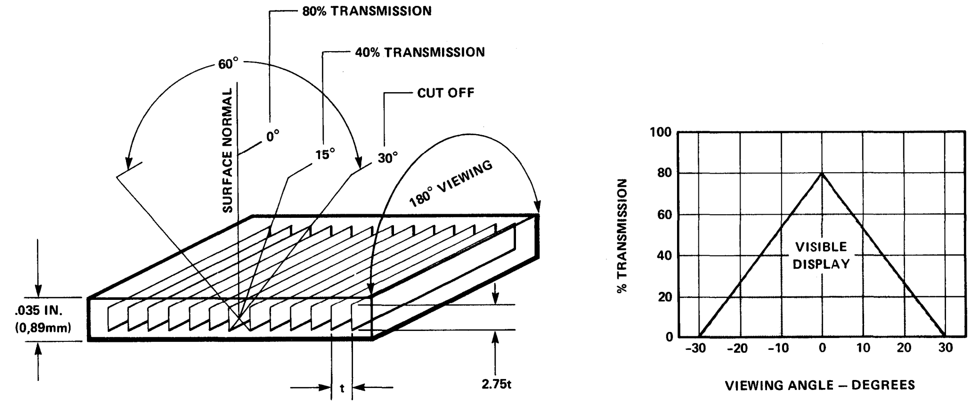

Figure 11. Construction characteristics of 0° neutral density louvered filter.

Table 1. Available Options for Louvered Filters — Any Combination is Possible

Aspect Ratio and Viewing Angle	Louver Angle	Louver Color
2.75:1 = 60° 2.0:1 = 90° 3.5:1 = 48°	0° 18° 30° 45°	Opaque Black Translucent Gray Transparent Black

Example: 2.75:1 — 18° — Transparent Black

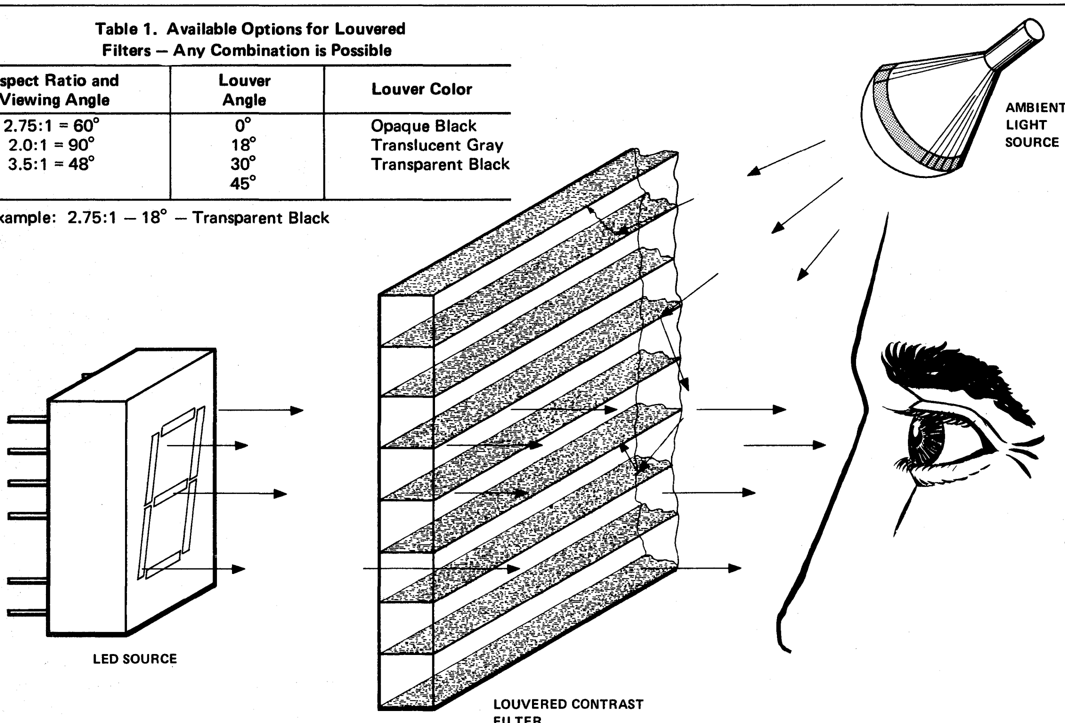

Figure 12. Operation of a louvered filter.

Neutral density louvered filters are effective by themselves in most bright ambient lighting conditions without the aid of a secondary wavelength filter. However, colored louvered filters may be used for additional wavelength filtering at the expense of display emitted light.

3M Company, Light Control Divison, manufactures louvered filters for LED displays. Their product trade name is "Light Control Film", which is useable with all of Hewlett-Packard's LED display and lamp products.

Circular Polarizing Filters

Circular Polarizing Filters are effective when used with LED displays that have specular reflecting front surfaces. Specular reflecting surfaces reflect light without scattering. Displays that have polished glass or plastic facial surfaces belong to this category. Circular Polarizing Filters are effective when used with Hewlett-Packard's 5082-7010, -7100 and -7300 series displays.

The operation of a circular polarizer may be described as follows. As shown in Figure 13, the filter consists of a laminate of a linear polarizer and a quarter wave plate. A quarter wave plate has its optical axis parallel to the flat surface of the polarizer and is oriented at 45° to the linear polarization axis. Non-polarized light is first linearly polarized by the linear polarizer. The linearly polarized light has x and y components with respect to the quarter wave plate.

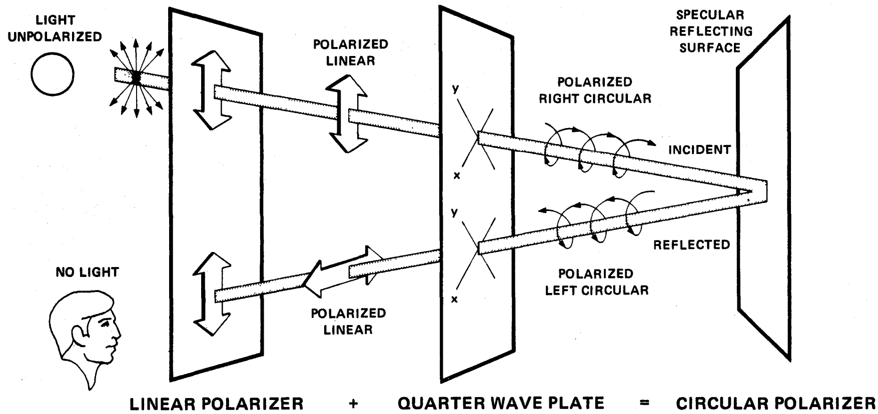

Figure 13. The operation of a circular polarizer.

As the light passes through the quarter wave plate, the x and y components emerge 90° out of phase with each other. The polarized light now has x and y forming a helical pattern with respect to the optical path, and is termed circular polarized light. As this circular polarized light is reflected by the specular reflecting surface, the circular polarization is reversed. When the light passes back through the quarter wave plate it becomes linearly polarized at 90° to the linear polarizer. Thus reflected ambient light is blocked.

The advantage of a circular polarizer is that reflected ambient light is reduced more than 95%. However, the trade-off is that display emitted light passing through the circular polarizer is reduced by approximately 65% at the peak wavelength. This then necessitates an increased drive current for the display, more than that required for a wavelength filter.

Circular polarizers are normally colored to obtain additional selected wavelength filtering. **One Caution:** outdoor applications will require the use of an ultraviolet, uv, filter in front of the circular polarizer. Prolonged exposure to ultraviolet light will destroy the filter's polarizing properties.

Polaroid Corporation manufactures circular polarizing filters in the United States. In Europe, E. Käseman of West Germany produces high quality circular polarizers.

Anti-Reflection Filters, Mounting Bezels and Other Suggestions

Anti-reflection filters: A filtered display still may not be readable by an observer if glare is present on the filter surface. Glare can be reduced by the addition of an anti-reflection surface as part of the filter. Both sections of the display shown in Figure 14 are filtered. The left hand filter has an anti-reflection surface while the right hand filter does not.

An anti-reflection surface is a mat, or textured, finish or coating which diffuses incident light. The trade-off is that both incident ambient and display emitted light are diffused. It is therefore desirable to mount the filter as close to the display as possible to prevent the display image from appearing fuzzy.

Panelgraphic Chromafilters® come standard with an anti-reflection coating. SGL Homalite offers two grades of a molded anti-reflection surface. 3M Company and Polaroid also offer anti-reflection surface options. Optical coating companies will apply anti-reflection coating for specialized applications, though this is usually an expensive process. Three companies of many which do commercial filter coating are: Optical Coating Labs, Inc., Santa Rosa, California; Optics Technology, Inc., Redwood City, California; Valpey Corporation, Holliston, Massachusetts.

Mounting bezels: It is wise to take into account the added appearance of a front panel that has the display set-off by a bezel. A bezel of black plastic, satin chrome or brushed aluminum, as examples, will accent the display and attract the eye of the viewer. The best effect can be achieved by a custom bezel. Commercial black plastic bezels for digits up to .3 inch (7.62 mm) tall are available, see Table 2.

Other suggestions: When designing the mounting configuration of a display, consider recessing the display and filter 0.25 inch (6.35 mm) to 0.5 inch (12.7 mm) to add some shading effect. If a double sided printed circuit board is used, keep traces away from the normal viewing area or cover the top surface traces with a dark coating so they can not be seen. Mount the display panel in such a manner as to be easily removed if service should become necessary. If possible, mount current limiting resistors on a separate board to reduce the ambient temperature in the vicinity of the displays.

Figure 14. Effect of anti-reflection surface on an optical filter.

Table 2. List of Filter and Bezel Product Manufacturers

Manufacturer	Product
Panelgraphic Corporation 10 Henderson Drive West Caldwell, New Jersey 07006 Phone: (201) 227-1500	Chromafilter® — Wavelength filters with anti-reflective coating; Red, Yellow, Green
SGL Homalite 11 Brookside Drive Wilmington, Delaware 19804 Phone: (302) 652-3686	Wavelength filters; two optional anti-reflective surfaces; three plastic grades; Red, Yellow, Green
3M - Company Visual Products Division 3M Center, Bldg. 235-2E Saint Paul, Minnesota 55101 Phone: (612) 733-5747	3M - Brand Light control film; louvered filters
Glarecheq, Ltd. 1-4 Christina St. London EC2A 4PA England Phone: (44) 1-739-6964	Spectrafilter
Rohm and Haas Independence Mall West Philadelphia, Pennsylvania 19105 Phone: (215) 592-3000	Plexiglass; sheet and molding powder; wavelength filters, sold as Oroglas in Europe
Polaroid Corporation Polarizer Division 549 Technology Square Cambridge, Massachusetts 02139 Phone: (617) 864-6000	Circular polarizing filters
E. Käsemann GmbH D 8203 Oberaudorf West Germany Phone: (08033) 342	Circular polarizing filters
Norbex Division Griffith Plastics Corporation 1027 California Drive Burlingame, California 94010 Phone: (415) 344-7691	DIGIBEZEL®; Plastic bezels for LED displays
Industrial Electronic Engineers, Inc. 7720-40 Lemona Avenue Van Nuys, California 91405 Phone: (213) 787-0311	Plastic bezels for .30 inch (7,62mm) tall LED displays
Rochester Digital Displays, Inc. 120 North Main Street Fairport, New York 14450 Phone: (716) 223-6855	Complete mounting kits for H.P. 5082-7300, -7700 and -7600 displays.

Table 3. Specific Wavelength Filter Products

Filter Product	Type of LED Display	Ambient Lighting
Panelgraphic Chromafilter® With Anti-Reflection		
Ruby Red 60 Dark Red 63	Standard Red	Moderate Bright
Scarlet Red 65	High-Efficiency Red	Moderate
Yellow 27	Yellow	Moderate
Green 48	Green	Moderate
Gray 10	All Colors	Sunlight
SGL Homalite, Grade 100		
H100-1605	Standard Red	Moderate
H100-1670	High-Efficiency Red	Moderate
H100-1726 H100-1720	Yellow	Dim Moderate
H100-1440 H100-1425	Green	Dim Moderate
H100-1266 Gray	All Colors	Sunlight
Anti-Reflection LR-72: 0.5 inch (12.70mm) Mounting Distance From Display LR-92: Up to 3.0 inch (76.20mm) Mounting Distance From Display		
Rohm & Haas		
Plexiglas 2423 Oroglas 2444	Standard Red	Moderate
3M Company — Visual Products Division Louvered Filters		
R6510	Standard Red	Indirect Sunlight
R6310	High-Efficiency Red	Indirect Sunlight
A5910	Yellow	Indirect Sunlight
G5610	Green	Indirect Sunlight
N0220 25% N.D. Gray	All Colors	Sunlight
Anti-Reflective Matte or Very Light Matte Front Surface Finish		
Glarecheq Spectrafilter		
110	High-Efficiency Red	Moderate
118 112	Standard Red	Moderate Bright
106	Yellow	Moderate
107	Green	Moderate
105	All Colors	Sunlight

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