Filter Design for AMLCD Full-Color Displays Compatible with Night Vision Devices

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ABSTRACT

Active Matrix Liquid Crystal Displays (AMLCD) require a properly chosen light source and built-in pixel color filters to produce a full-color display. The red end of the full-color spectrum from the display conflicts with the response of night vision devices, and therefore both must be filtered to be mutually compatible. The design of such filters is straightforward once the appropriate data has been gathered and the engineering trade-offs have been made. Although the limitations of interference filter design must be properly considered, the filter design process is heavily dependant upon choosing the proper lamp, pixel filters, and system design scheme. Two filter system approaches are considered here. One, which is in common use, is to use a short wave pass edge filter at the display to limit the output light to wavelengths less than ~650 nm, and to have a long wave pass filter at the night vision device which transmits only wavelengths longer than ~650 nm. The second approach is to use a filter to pass a narrow band of red light which may be at wavelengths even longer than 650 nm, and then to use a complementary narrow band blocking notch filter at the night vision device to prevent the entrance of conflicting light. Some trade-off examples and efficiencies are shown.

INTRODUCTION

Active Matrix Liquid Crystal Displays (AMLCD) are in common use in laptop computers, television displays, aircraft cockpit displays ("glass cockpits"), etc. In order to be full color displays, these systems need a light source, such a fluorescent lamp with adequate blue, green, and red emissions; and they need a pattern of blue, green, and red pixel filters built into the AMLCD. These pixel filters are usually of the absorption type so that they can be easily processed with typical semiconductor/flat panel techniques. The choice of lamps and pixel filters determines the gamut of colors which can be displayed or the "pallet". The general appearance of most laptop displays shows that the goals of a satisfactory pallet and sufficient brightness have been reasonably achieved.

When such displays are adapted to commercial aircraft there are no peculiar problems to overcome, but when adapted to military aircraft which employ night vision (NVIS) devices, there is a conflict which needs to be resolved. The human response to the display is from ~380 to ~780 nm, and red is generally perceived in the wavelengths longer than ~620 nm. The NVIS devices without any filtering are responsive from ~450 to ~900 nm. The NVIS will amplify any such light which reaches it by several orders of magnitude. This can allow aircraft pilots to "see in the dark" (or nearly so) with such binoculars. However, even small amounts of offending light from the spectral region of overlap of the display and the NVIS can cause saturation and temporary blinding of the NVIS device (and possibly its user). Figure 1 shows the relative amount of light by wavelength (dotted curve) in the typical night sky according to data from the Marconi [1] web site. The response of a bare (unfiltered) Generation 3 NVIS device is shown in the upper solid curve [2].

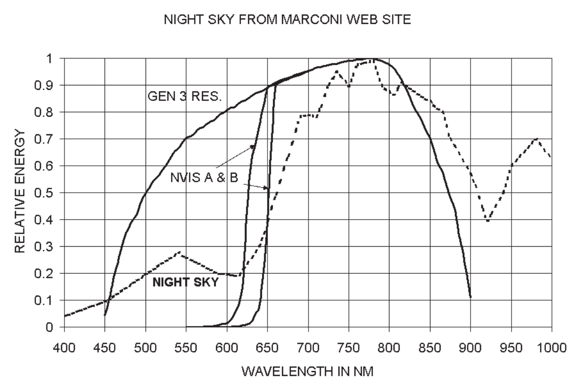

Figure 1: Typical night sky illumination (dotted), the response of a Generation 3 night vision device, and the response of NVIS-A and -B devices.

Two of the more common NVIS devices in use at this time are referred to as meeting specifications A or B of military specification MIL-L-85767A. These have incorporated long wave pass (LWP) filters to give the truncated short wavelength responses also seen in Figure 1. If the cockpit display has a short wave pass (SWP) filter for A at ~620 nm or for B at ~650 nm, then little or no offending light will pass from the display to the NVIS. Thus the conflict is resolved at the expense of not having the truly red light of the display available to the observer. The practice is for the pilot to look ***under*** his NVIS goggles to observe the display the same as crewmen in the cockpit who may not be wearing goggles.

This first solution looses any light response benefit from the "foothill" of night sky and Gen 3 sensitivity at wavelengths

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shorter than 620-650 nm and has limited red light due to the SWP filter. The second approach suggested by Cohen and Scoughton [3] would be to start with an unfiltered Gen 3 tube and add filters to the display which would pass only narrow (but hopefully energetic) bands of energy from the lamp and pixel filters and otherwise block other wavelengths. Then the Gen 3 tube would be provided with narrow blocking notch filters which would obstruct the light from these narrow bands. This seems to have the potential to be more efficient in its use of the Gen 3 tube response and available night sky light, and it would provide the potential for more red light.

SYSTEM DESIGN

Figures 2 and 3 show the spectral energy versus wavelength for two different lamps whose data can be found on the internet [4,5]. Figure 2 shows a lamp spectrum with blue, green, and orange peaks which would work well with even a 620 nm SWP filter but would not include a deep red color. Figure 3 shows a lamp spectrum which might be better suited to the second approach, since it has a strong red peak at 660 nm. This would provide more red light, but would not be well suited to either a 620 nm or a 650 nm SWP filter.

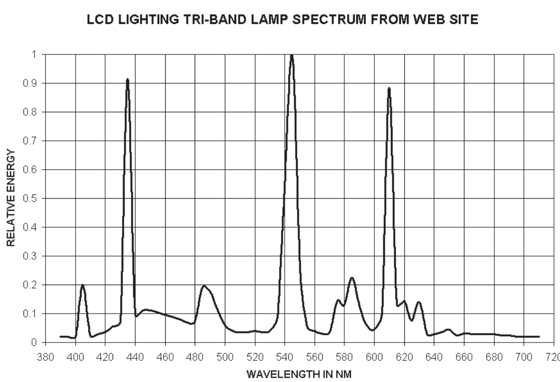

Figure 2: Spectral energy versus wavelength for a Tri-Band fluorescent lamp from LCD Lighting.

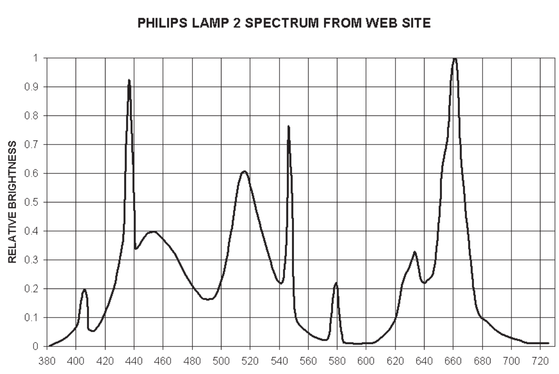

Figure 3: Spectral energy versus wavelength for a Philips "Lamp 2".

Figures 4 and 5 show the spectral transmittance of two different sets of blue, green, and red pixel filters which have been used in AMLCD displays [6]. The filters in Figure 5 have less overlap between colors, and these can potentially provide more saturated primary colors for a broader pallet of colors. In fact, it would be desirable to have no overlap in the green and blue pixel filters.

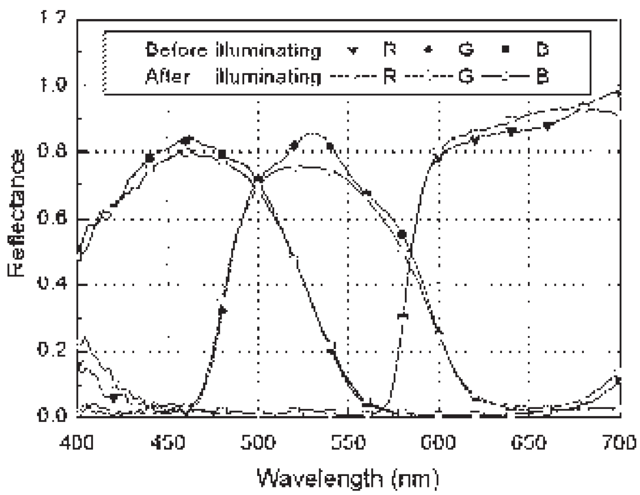

Figure 4: Typical blue, green, and red pixel filters [7].

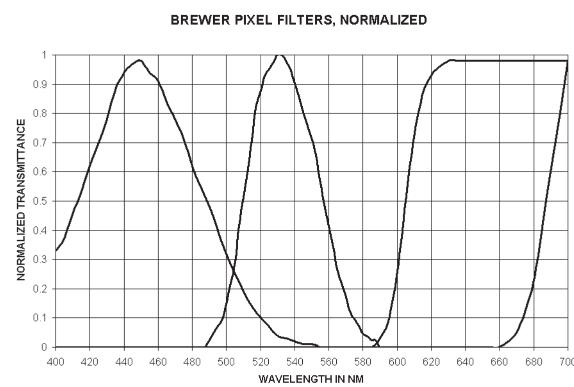

Figure 5. Brewer blue, green, and red pixel filters.

Figures 6 and 7 show the combination of the Brewer filters of Figure 5 with the two lamps of Figures 2 and 3, respectively. Without any filters for NVIS compatibility, these would represent the spectral output of the associated AMLCD displays. The dotted line in Figure 7 shows the product of the Gen 3 tube response times the night sky light.

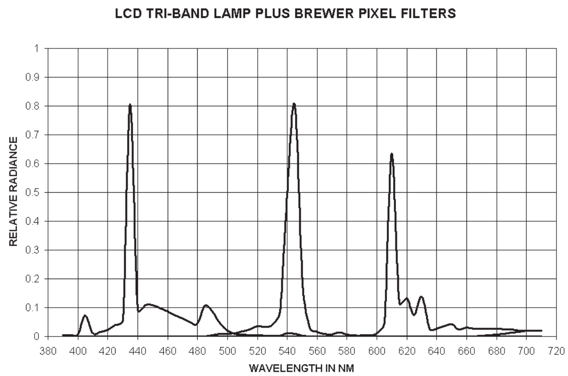

Figure 6: Brewer Science pixel filters combined with LCD Lighting lamp.

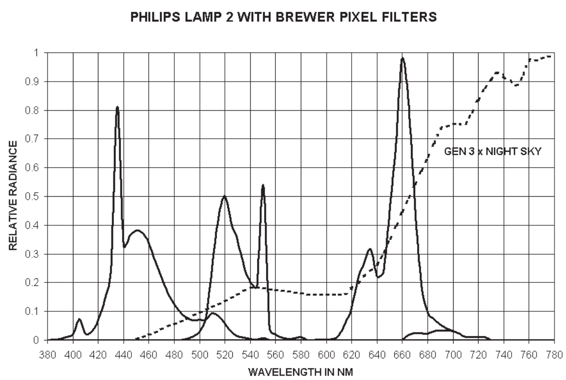

Figure 7: Brewer Science pixel filters combined with Philips Lamp 2.

FILTER DESIGN

In order to make the display of Figure 7 night vision compatible by the second approach, it is necessary to design filters which are more complex than the simple LWP and SWP filters. The first filter to design would be one such as shown in Figure 8. This filter is designed to pass the three color bands of blue, green, and red which emanate from the unfiltered display at approximately 420-460 nm, 500-550 nm, and 615-675 nm. A starting design with 36 layers of the form (1H 8L 1H 1L)9 at a design wavelength of 525 nm generally provides the pass bands needed. Here the H and L indices of refraction are 2.3 and 1.46 applied on a glass substrate.

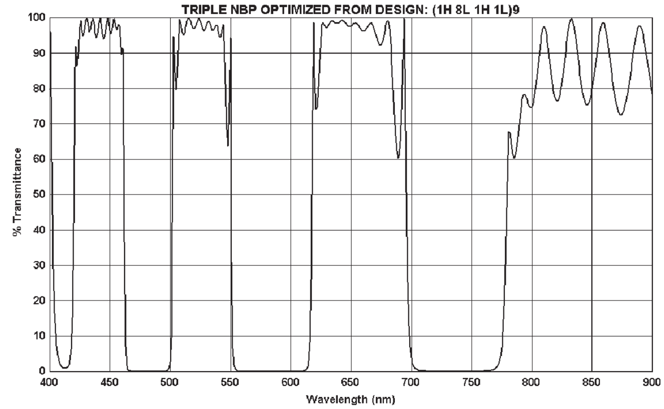

Figure 8: Three band filter designed to pass the three color bands shown in Figure 7 from the Philips Lamp 2.

High blocking is needed for the benefit of NVIS compatibility, therefore the choice of 9 multiples of the 4-layer set to give optical density (OD) greater than 4.0 in the blocked bands. Figure 8 gives the result of optimizing all 36 layers with respect to the desired pass bands. A SWP filter as shown in Figure 9 is added to narrow the red band to about 615-670 nm. This filter needs an OD in the 4-5 range over the blocked band from 680-900 nm to prevent offending light from reaching the NVIS. This design is (1L 1H)20 with 5 matching layers optimized on both sides for high transmittance in the pass band. This combination of two filters provides the needed high transmittance for the three primaries of the full color display and high blocking outside those three pass bands where the NVIS is sensitive.

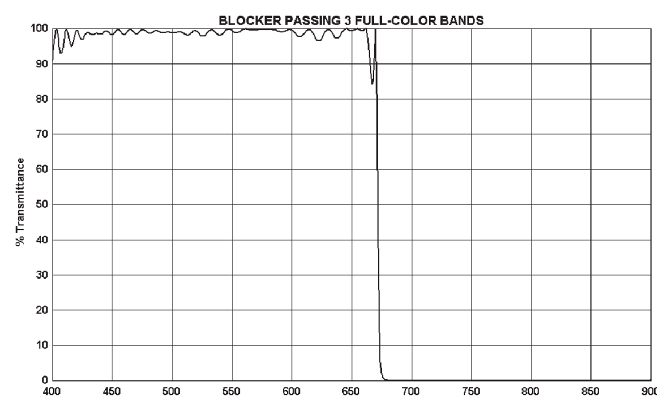

Figure 9: SWP filter designed to work with filter in Figure 7 to provide a red narrow band pass from 615-670 nm.

The filters needed at the unfiltered Gen 3 tube of the NVIS must block the red and green color bands emitted by the display. The tube has no significant response to the blue color band. Although it is possible to design a single rugate filter to block the red and green bands, more present-day facilities are capable of producing filters where the design is for two separate notch filters for these bands. Figure 10 shows a blocker for the red band and Figure 11 for the green band. These designs are both (1L 1H)10 at 1927.6 nm and 1590 nm respectively, with 5 matching layers optimized on both sides for high transmittance in the pass bands. In both designs, they are optimized to pass night sky light to the NVIS except in the red and green bands. This requires as high a transmittance as practical from 550-615 nm and 680-900 nm.

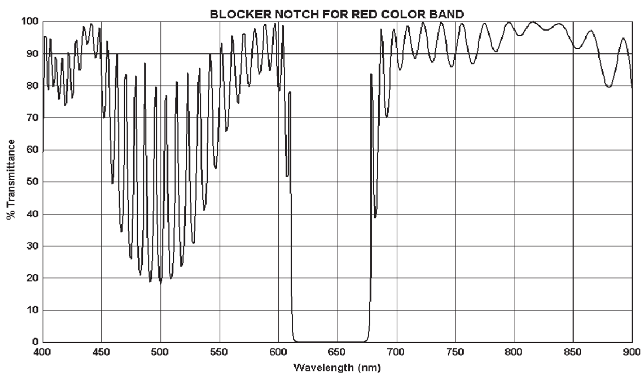

Figure 10: Notch filter to block the red band of the display from the NVIS and pass night sky light.

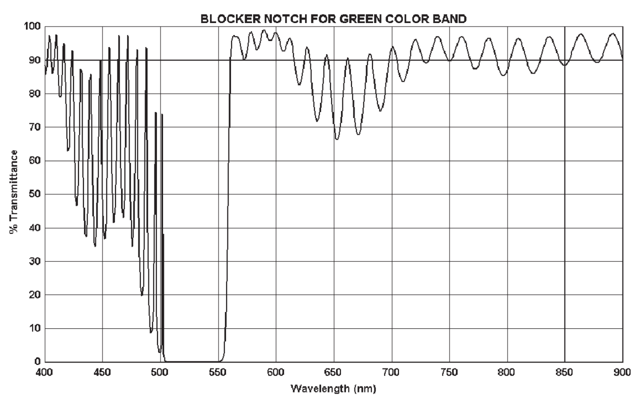

Figure 11: Notch filter to block the green band of the display from the NVIS and pass night sky light.

The combined OD for all four filters was tested to ensure that no significant light would leak to the NVIS between the passing and blocking bands. Slight adjustments of design wavelengths were made as needed.

RESULTS

Figure 12 shows the color performance of three systems on a CIE Chromaticity Diagram. The Philips Lamp 2 with Brewer pixel filters only as in Figure 7 is plotted as a medium width solid triangle. The red primary of this case is deep in the red. The widest solid triangle is the same Philips lamps system with the new interference filter system added. Here the red and green primaries are mostly unchanged. However, the blue-purple primary has expanded the pallet as a result of the narrowing effect of the first filter blocking wavelengths between 460 and 500 nm.

The dashed triangle in Figure 12 shows the results of the first approach using the LCD Lamp with an orange primary and SWP blocking filter at 630 nm. The pallet is somewhat more limited in the green due to the lamp, and is even more limited at the red end due to the lamp choice. However, this first approach is NVIS compatible by using only one SWP filter at the display and the commonly used “B” LWP filter at the NVIS.

Referring to Figure 1, the NVIS efficiency of the first approach, which is represented by the NVIS-B curve, as compared to the Gen 3 tube response (both multiplied by the available night sky energy) is calculated to be 84.2%%. The second approach which allows the NVIS to use some of the night sky light between 550 and 620 nm, but provides much more red light to give the viewer full color than the first approach, has a calculated efficiency of 82.6%. Note also that this latter efficiency number is predicated on the supposed ability to further refine the two notch filter designs of Figures 10 and 11 to the point where there are negligible transmittance losses from 680 to 1000 nm.

DISCUSSION

A method has been described to implement the filter system of the second approach described by the Cohen and Scoughton [3] patent. The efficiency loss of this particular design over the first approach of a SWP and LWP filter combination was 82.6% versus 84.2%. However, the primary gain here is in providing a true full-color display. A trade-off might be made to reduce the width (and thereby power) of the red pass band to gain more night sky light. This would be at the expense of the brightness available in the red primary. One goal of a display system is probably to gain a maximum white brightness capability. It is likely, when all pixels of an AMLCD are activated to “full on”, that the transmittance of the pixels of the AMLCD for one or two of the primaries would have to be reduced to match the third (and weakest) primary in order to produce a white display. If the red primary were one that needed to be reduced in this case, then it should be possible to narrow the red pass band and gain some NVIS efficiency. This could be most simply done by shifting the SWP at the display to shorter wavelengths until primary balance was achieved. The notch filter for the red band at the NVIS would then need to be redesigned to match the red pass band.

It appears that the principal possible benefits here are an increased color pallet by using deeper red phosphors. However, it is also worth considering an improvement in the blue and green pixel filters to remove the spectral overlaps and move the pallet into the green and purple corners of the chromaticity diagram.

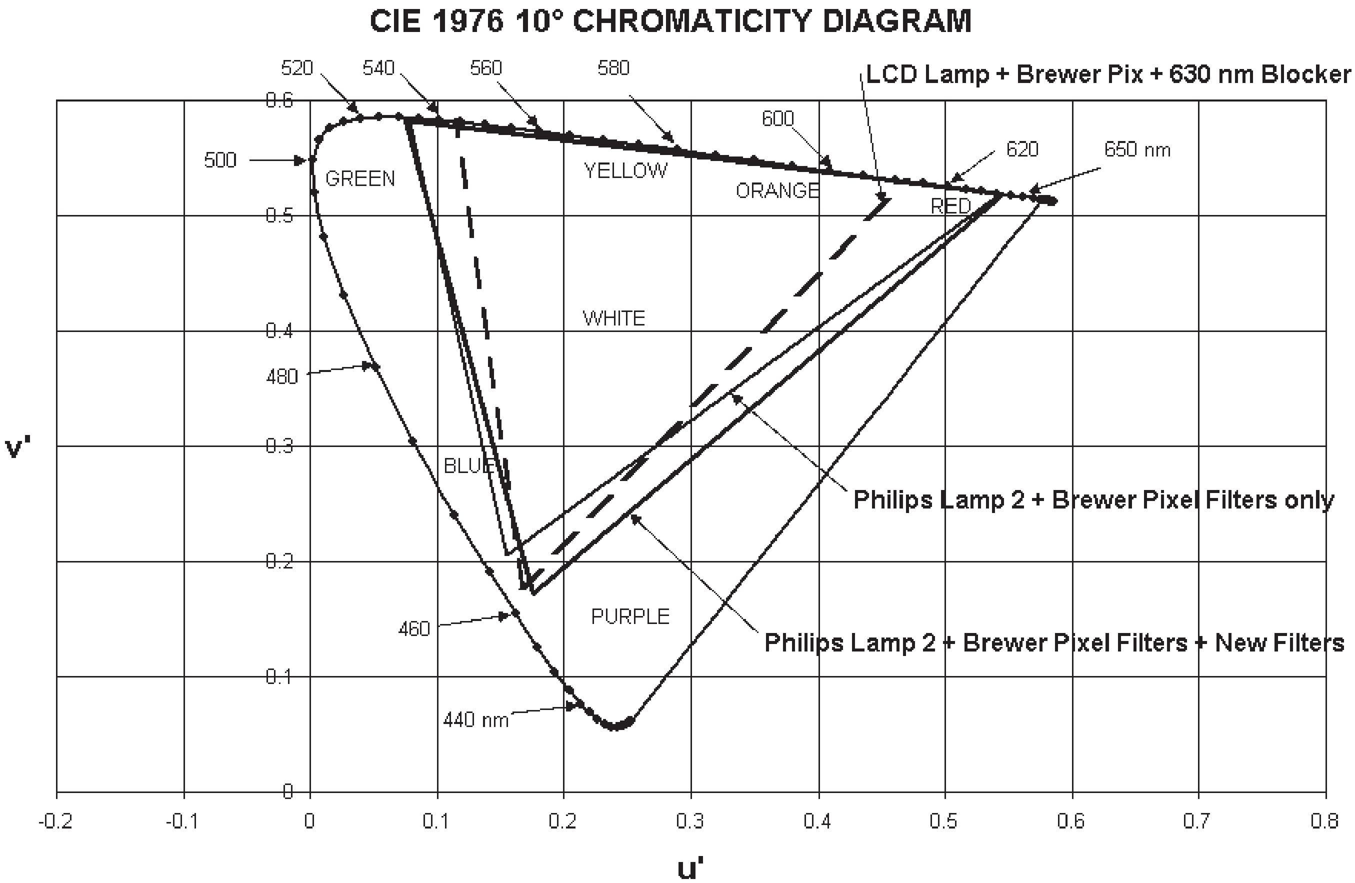

Figure 12: CIE Chromaticity Diagram showing the performance of three systems. Medium line triangle is Philips Lamp 2 plus Brewer pixel filters; Heavy line is above plus filters of Figures 8 and 9; and dashed triangle is LCD lamp with pixel and 630 nm SWP filters.

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