PCT

WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 5 : G02F 1/1335, G02B 5/20

A1

(11) International Publication Number: WO 94/20879

(43) International Publication Date: 15 September 1994 (15.09.94)

(21) International Application Number: PCT/US94/02668

(22) International Filing Date: 4 March 1994 (04.03.94)

(30) Priority Data:
08/027,300 4 March 1993 (04.03.93) US

(71) Applicant: HONEYWELL INC. [US/US]; Honeywell Plaza, Minneapolis, MN 55408 (US).

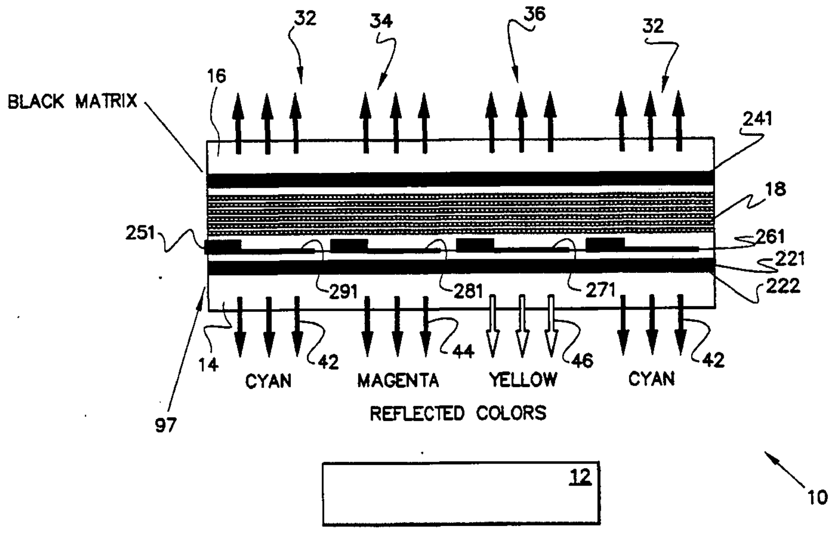
(72) Inventors: NELSON, Larry, A.; 15930 N.E. 6th Street, Bellevue, WA 98008 (US). WOOD, Teddy, J.; 144 Target Road, Corrales, NM 87048 (US).

(74) Agent: LERVICK, Craig, J.; Honeywell Inc., Honeywell Plaza-MN12-8251, Minneapolis, MN 55408 (US).

(81) Designated States: CA, JP, KR, European patent (AT, BE, CH, DE, DK, ES, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).

Published
With international search report.
Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.

(54) Title: PATTERNED DICHROIC FILTERS FOR COLOR LIQUID CRYSTAL DISPLAY CHROMATICITY ENHANCEMENT



(57) Abstract

A color liquid crystal display (10) using a matrix of dichroic color filters in addition to conventional gel or dye color filters. A thin film transistor (251) liquid crystal display using indium tin oxide pixels (261) incorporates a matrix of absorptive filters (241) and a matrix of dichroic filters (221). The absorptive filters (241) absorbs unwanted color from ambient light while the dichroic filters (221) transmit desired colors from a backlight (12). The dichroic filters and absorptive filters are patterned to match the liquid crystal display pixel pattern. The absorptive filter and the dichroic filters are combined in various ways. The dichroic filter can be located on one side of the liquid crystal display, the absorptive filter can be on the other side, or they both can be on the same side of the liquid crystal display.

FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AT	Austria
AU	Australia
BB	Barbados
BE	Belgium
BF	Burkina Faso
BG	Bulgaria
BJ	Benin
BR	Brazil
BY	Belarus
CA	Canada
CF	Central African Republic
CG	Congo
CH	Switzerland
CI	Côte d'Ivoire
CM	Cameroon
CN	China
CS	Czechoslovakia
CZ	Czech Republic
DE	Germany
DK	Denmark
ES	Spain
FI	Finland
FR	France
GA	Gabon
GB	United Kingdom
GE	Georgia
GN	Guinea
GR	Greece
HU	Hungary
IE	Ireland
IT	Italy
JP	Japan
KE	Kenya
KG	Kyrgystan
KP	Democratic People's Republic of Korea
KR	Republic of Korea
KZ	Kazakhstan
LI	Liechtenstein
LK	Sri Lanka
LU	Luxembourg
LV	Latvia
MC	Monaco
MD	Republic of Moldova
MG	Madagascar
ML	Mali
MN	Mongolia
MR	Mauritania
MW	Malawi
NE	Niger
NL	Netherlands
NO	Norway
NZ	New Zealand
PL	Poland
PT	Portugal
RO	Romania
RU	Russian Federation
SD	Sudan
SE	Sweden
SI	Slovenia
SK	Slovakia
SN	Senegal
TD	Chad
TG	Togo
TJ	Tajikistan
TT	Trinidad and Tobago
UA	Ukraine
US	United States of America
UZ	Uzbekistan
VN	Viet Nam

PATTERNED DICHROIC FILTERS FOR COLOR LIQUID CRYSTAL DISPLAY CHROMATICITY ENHANCEMENT

This invention relates to liquid crystal displays (LCD) and, more particularly, to a method for dramatically improving the saturation of the primary colors in an LCD with minimal impact on transmittance.

BACKGROUND OF THE INVENTION

A prior art color LCD locates an appropriately-colored absorbing filter at each picture element of the panel. Each of these absorbing color filters is placed, as a part of a mosaic array of such elements, inside the panel, on the inner face of the LCD glass nearest the viewer. The depth of color and the saturation achievable with these filters is limited by a number of factors, primarily driven by the need to trade off display luminance against color saturation.

The LCD display chromaticity is determined primarily by the LCD filter transmittance and the backlight spectral emissions. The spectral emissions of the phosphors used in avionic LCD fluorescent lamps are typically narrow band. However, if the LCD color filter for a given color has a bandwidth which overlaps an adjacent color, the advantage of the narrow band phosphors is lost. The red filter overlaps into the green spectrum sufficiently to desaturate the red emission.

It is, therefore, the motive of the invention to complement these absorbing filters with a second set of picture-element-sized dichroic filter components that improve the color saturation, conserve light energy normally lost by absorption in conventional constructions, and maintain good color at off-normal viewing angles.

SUMMARY OF THE INVENTION

The invention provides dichroic filters, located in cooperation with absorbing filters on an LCD display. The dichroic filters improve the saturation of the transmitted colors by acting with the absorbing filters to narrow the spectrum of the light emitted by each pixel. A display made with this combination of filters maintains good color even when viewed from angles other than normal to the display surface. The added filters cause less of the incident light to be transmitted through the display. Generally, this effect is small because the absorbing color filters can be thinner (less absorbance in band) when this performance out of band is augmented by the dichroic filters. However, this reduction in the transmitted light is accompanied by a decrease in unwanted light. Light of the unwanted color is reflected back into the light source cavity. This reflected light is available to offset the transmittance loss due to the increased saturation.

Other objects, features and advantages of the present invention will become apparent to those skilled in the art through the Description of the Preferred Embodiment, Claims, and Drawings herein wherein like numerals refer to like elements.

BRIEF DESCRIPTION OF THE DRAWINGS

To illustrate this invention, a preferred embodiment will be described herein with reference to the accompanying drawings.

Figure 1 shows a schematic diagram of the color liquid crystal display of the invention.

Figure 2 shows a color liquid crystal display utilizing the apparatus of the invention to provide dichroic filters opposite absorptive filters on a liquid crystal display.

Figure 3 shows a color liquid crystal display wherein the absorptive filters and the dichroic filters are on the same side of the liquid crystal display.

Figure 4A shows a schematic cross section of a color liquid crystal display where absorptive filters and dichroic filters are on the backlight side of the liquid crystal display.

Figure 4B shows a schematic of the specular reflective material used in the apparatus of the invention.

Figure 5A shows a diagram of the various components of the active matrix liquid crystal display of the invention.

Figure 5B shows a detailed schematic diagram of the thin film transistor.

Figure 6 graphically shows a measured reduction in light as a function of exposed surface area by a particular absorber as commonly found in LCD displays.

Figure 7 illustrates one example of a reflecting backlight cavity as contemplated for use in the invention.

Figure 8 shows the placement of color filters made from gels in an assembly, the filters being substantially absorbing and made from photographic tape having 4% reflectivity placed on a .060" soda line glass substrate.

Figure 9 illustrates an alternative front glass for one embodiment of the invention that was constructed using color separation filters placed in a film matrix.

Figure 10 shows the special characteristics of Kodak Wratten gel filters.

Figure 11 shows the spectral characteristics of dichroic filters used in one aspect of the invention to reflect out-of-band light into the backlight assembly while transmitting light which falls within the pass band of the filter.

Figure 12 schematically illustrates the liquid crystal display utilizing a reflective polarizer in accordance with one aspect of the invention.

Figure 13 schematically illustrates increased contrast for traditional LCDs under high ambient illumination.

Figure 14 is a simplified illustration of loss of an LCD's traditional advantage under high ambient illumination.

Figure 15 graphically shows the opportunity for increased display luminance based upon changing the elements of the display so that they accomplish their function in a manner which conserves radiant energy.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Now referring to Figure 1, Figure 1 shows a schematic of the liquid crystal display of the invention. Ambient illumination 37 is composed of a red radiation 32, green radiation 34, and blue radiation 36. Each color set is transmitted through front polarizer 2 which polarizes the incoming light along the page. The light then is transmitted to absorbing red filter 121, absorbing green filter 123, and absorbing blue filter 125. Each of these filters are provided on top of corresponding pixels. The red pixel 112 receives light polarizing in the direction of the paper 62. Also the absorbing filter transmits a small amount of non-red light. In theory the absorbing filter 121 will absorb all but the red band of radiation. The example of Figure 1 shows an "off" pixel 112 which provides for a liquid crystal reflection of the light.

The pixel 112 polarizes the light perpendicular to the plane of the page and the rear polarizer 4 absorbs it. Reflecting radiation 64 and the non-red wavelength that is green and blue is transmitted back and is reabsorbed by the absorbing filter 121. The dichroic or reflecting filter 122 provides for reflection of non-red frequencies and transmittance of red frequencies.

The operation of an "on"-pixel can be explained with reference to pixel 114 where green incoming radiation 34 is polarized with polarizer 2 hitting absorbing filter 123, and is polarized along the page. Green bundle 66 is then transmitted through dichroic filter 124. Dichroic filter 124 will then reflect the non-green components 68 and the absorbing filter 123 on the front end will absorb the reflected light. The apparatus of the invention provides for a black display when the pixel is off. The black display is a result of the polarization nature of the liquid crystal and the inclusion of a rear-polarizer. Backlight 12 provides illumination of the display wherein white light is propagated in a similar manner from the backlight through the filters. The detailed description of this illumination technique will be described with reference to Figures 2, 3 and 4.

Now referring to Figure 2, Figure 2 shows a cross section of a liquid crystal display that is configured to provide a composite color signal. The color liquid crystal display 10 is composed of a number of planar components. The front glass 16 covers the surface of the liquid crystal display 10. The front glass 16 is placed over an absorptive filter 241 which provides a method of absorbing a frequency band of radiation. The absorptive filter 241 is composed of a number of pixel sized color filters. The absorptive filter 241 covers a liquid crystal 18 which is controlled by thin film transistor pixel controllers 261. The thin film transistor pixels are addressed with lines 251. The thin film transistor pixels 261 are planarized using a planarization technique well known in the art. The next layer is a dichroic filter layer 221 which provides a patterned dichroic filter for each pixel tuned to the color of the pixel. For example, red light 32 is provided by dichroic filter 222, absorptive filter 241, and thin film pixels 261.

In operation, the color liquid crystal display 10 uses the backlight 12 to provide white light to the back glass 14. The white light from the back glass 14 enters a dichroic filter layer 221 and, depending upon the color tuning of the dichroic filter, will either transmit red, green or blue. In the example of pixel 291, red will be transmitted. The dichroic filter reflects frequencies other than the tuned frequency, in this case red 32. The red 32 radiation enters the thin film liquid crystal pixel 291 and is either transmitted or absorbed back, depending upon the state of the shutter in the pixel 291. If the pixel 291 is open, the red light enters the front glass and is projected to the viewer. Incoming white light is absorbed by the absorptive filter 241 so it is not available to detract from the red emission of the backlight. Light entering from outside the liquid crystal display and passing through the absorptive filter participates in enhancing the performance of the liquid crystal display because it is reflected in the interior chamber and re-radiated out only through the red dichroic filter pixels. Likewise, the other colors of green and blue operate similarly.

Now referring to Figure 3, Figure 3 shows a cross section of a color liquid crystal display of the invention. The liquid crystal display 20 is comprised of a number of layers. The front glass 16 covers an absorptive filter 242 which is patterned in a predetermined pattern to cover the liquid crystal display pixels. The absorptive filters 242 immediately contact dichroic filters 222. In this configuration of the invention, the absorptive filters absorb light incident from the front glass and transmit only the light of a desired wavelength to enhance the display. The dichroic filters in conjunction with the absorbing filters allow only the transmission of the desired frequencies out of the front glass. As in the example of Figure 2, Figure 3 provides a liquid crystal display 20 which is comprised of thin film transistor pixels 262. The liquid crystal display of Figure 3 also includes a backlight by providing a white light source filtered by the dichroic and absorptive filters. The embodiment of Figure 3 also includes reflective specular structures 97 over both the thin film transistors and the array addressing apparatus in order to provide as much of a reflective environment as possible.

Now referring to Figure 4A, Figure 4A shows a cross section of the liquid crystal display of the invention in an alternate embodiment. In Figure 4A, the absorptive filters 243 are in direct contact with the dichroic color filters 223. The dichroic color filters are attached to the back glass 14 instead of the front glass 16 as in the configuration of Figure 3. The backlight 12 provides white light to the dichroic and absorptive filters which only permit a desired pre-determined color to be transmitted through each pixel. The absorptive filters prevent the reflection of unwanted radiation from the cell due to the ambient environment. This enhances the color of the liquid crystal display.

The invention can be used as a display in an aircraft. Since avionic displays are subjected to full daylight operation, the effect of having a reflective filter in the display must be considered. As seen in Figure 4A, ambient light 39 will enter the display 30, passing through the front polarizer and absorptive filter 243 before striking the dichroic reflective filter 223. The front filter 243 absorbs most of the energy reflected from the dichroic filter 24. The red filter absorbs blue and green which will be reflected by the red dichroic filter 243. Any energy reflected from the dichroic filter 223 must pass through the front filter 243 again, where even more of the unwanted color is absorbed.

The red cell 131 in Figure 4A illustrates an "off" pixel in a normally black LCD construction. The greatly reduced blue and green spectrums pass through the liquid crystal 18 material twice and experience a 180 polarization change due to the dichroic filter 223 reflection. The red spectrum will pass through the dichroic filter 223. However, the polarization of the red light which passes through the dichroic filter is crossed relative to the rear polarizer 134 and is absorbed.

The green cell 133 in Figure 4A is shown to be "on" or transmitting. The liquid crystal 18 in the green cell does not change the polarization and allows the green light to pass into the lighting cavity, where it can be redirected toward the viewer. The red and blue spectrums are reflected with a 180 degree polarization rotation, but are greatly reduced by the front green filter 243 absorption.

The end result is that the absorptive filter 243 provides a high contrast display when exposed to full daylight operations. The front filter absorbs the unwanted ambient photopic spectrum reflected from the dichroic filter. Light of the desired chromaticity is allowed to pass into the lighting cavity 100, where it may be redirected toward the observer.

The dichroic/absorptive filter LCD 30 provides a significant advantage over prior art LCDs using traditional filter techniques. The invention minimizes absorption and therefore reduces power consumption for equivalent luminance outputs. Not only is the chromaticity improved, but out-of-band energy is not absorbed by the dichroic filters 223; rather, out-of-band energy is reflected back into the lighting cavity 100, where it is redistributed. Experimental data indicates that the chromaticity saturation may be increased with little or no cost in total luminance output. Another significant advantage of the dichroic/absorptive filter combination is the ability to tailor the chromaticity of the display. The dichroic filter transmissions can be selected to provide very specific display color palettes. The development of new absorptive filters is a long, expensive, trial-and-error process. The addition of dichroic filters to modify the display chromaticity will provide an alternative to absorptive filter development.

The patterned dichroic filters are created in a matrix aligned with the absorptive filters. The patterned dichroic filter plate is placed into the TFT substrate. The TFTs are built directly on top of the dichroic filters 223. The basic matrix of dichroic filters is constructed so that there is no space between the dichroic filters. To the maximum extent possible, the dichroic filters 223 will cover the rear of the LCD active area.

An alternative approach is to place specular reflective material 97 between each dichroic color filter. This increases the specular reflections from the rear of the LCD. Since 40-50% of the active display area is non-transmissive, this 40-50% can be covered with specular reflective material to decrease the amount of absorption in the LCD glass assembly. This approach has a slight advantage over covering the entire surface with dichroic filter material. The dichroic filters will reflect 50-60% of the light in the non-transmissive area versus >90% from a specular reflective area.

The Reflective/Absorptive color filter LCD can be constructed with the following methods:

1. Dichroic filters under the active pixel area, with or without specular reflective material between the active color pixel areas as shown in Figure 2.

2. Dichroic filters on top of the absorptive color filters, with or without specular reflective material between the active color pixel areas as shown in Figure 3.

3. Reversal of the LCD structure to place the color filter plate to the rear (toward the backlight), the dichroic filter under the absorptive color filters, with or without specular reflective material between the active color pixel areas as shown in Figure 4A.

Now referring to Figure 4B, Figure 4B shows the apparatus of 4A speculative reflective coating. The speculative reflective coating 908 is provided to enhance the radiant energy conservation in the backlight area. As can be seen by Figure 4B, the red pixel 131 is surrounded by specular reflective material. The blue pixel 132 is also surrounded by specular reflective material 908. The green pixel 133 is also surrounded by specular reflective material 908. The theoretical basis for creating the radiant energy conservation apparatus is discussed below. The various pixels are arranged in a predetermined fashion to arrive at a red, green, blue color display 30.

The active matrix liquid crystal display structure of the invention is shown in a three dimensional schematic in Figure 5A. The front glass 16 is shown at the top. The front glass 16 covers the absorbing filters 24. The absorbing filters then cover a liquid crystal 18. The liquid crystal 18 covers a planarization layer 72, which planarizes the thin film transistor pixels underneath. The thin film transistor pixels are shown better in Figure 5A. The dichroic color filters 22 are shown beneath the thin film transistor array 50. The rear glass 14 is shown beneath the dichroic color filters. This configuration corresponds closely with the color liquid crystal display disclosed in Figure 1.

Now referring to Figure 5B, Figure 5B shows a detailed schematic of the thin film pixel structure used in the liquid crystal displays of the invention. The thin film pixel 50 is comprised of a source bus 54 and a gate bus 52. The source bus and gate bus control a thin film transistor 58. The thin film transistor 58 controls the indium tin oxide pixel 26. A thin film pixel 50 is provided at each pattern location in the liquid crystal display. Each thin film pixel 50 is provided with a tuned color absorbing filter and a tuned color dichroic color filter.

Those skilled in the art will recognize that alternate filters, such as photo-resist based material, may also be used in the color LCDs of Figures 2, 3 and 4. These filters improve the color saturation. In an alternate embodiment, improved color saturation is obtained by removing the unwanted spectral emissions of the backlight. This may be accomplished through phosphor selection, backlight filtering, or both.

Fluorescent lamp phosphors, which are capable of producing saturated primary chromaticities when used in conjunction with sharp cut-off LCD filters, are employed. However, the filters do not have extremely sharp cut-off. Some lamps have unwanted emissions between 570 and 600 nanometers which desaturate both the red and green colors. This unwanted emission is primarily a side band emission of the green phosphor.

Backlight filtering techniques, including use of interference and absorptive filters, improve chromaticity. Tri-band absorptive filters, commonly used on avionic CRT color displays, are also an alternative. However, the overall transmission of absorptive filters must be low if saturated colors are to be achieved.

The viability of using band rejection filters to modify the LCD primary chromaticity is dependent on the basic performance of the LCD filters and the background leakage. The filters must have very low transmissions outside of the color of interest, for example, no blue leak in the red filter. Dark area transmittance (blue and green off) must be minimized for high contrast and good color saturation.

The background emission has two predominant factors. First is the polarizer efficiency. The polarizers which are being considered are very high efficiency (extinction ratios greater than 500:1). The second factor, cell spacing, is particularly sensitive in the normally black displays. In normally black construction, the black intensity is controlled by insuring that the light passing through the LCD is rotated 90 degrees to the front polarizer orientation. The 90 degree rotation is controlled by the cell spacing of the LCD and the birefringence of the material. If this is not carefully controlled, the LCD will exhibit low contrast and chromaticity desaturation.

Lab tests show that black background variations do produce chromaticity variations. Looking at the spectral emissions of the red versus black, about one-third of the stray blue emission is due to the black leakage. However, the red filter is the major contributor to color desaturation.

Dichroic filters can provide fairly sharp cut-off lowpass, highpass, bandpass and band-rejection filters. These filters work very well at the viewing angle for which the filter is designed. Typically, the filter is designed for viewing normal to the filter surface. The viewing angle can be optimized for off-axis viewing at the expense of performance at the normal viewing angle.

Absorption filters have the advantage of being very angle-insensitive. The primary type of filters used by the prior art are dye-based. The filter materials include organic materials, polyimides and photo-resists. The general movement in industry is away from the organic materials and dyes toward more stable pigments and deposition materials such as polyimides. The photo-resist materials have the advantages of well known processing requirements and equipment availability.

The result of increased color saturation is higher power dissipation due to increased absorption of the LCD or backlight filters. The invention reduces absorption in the LCD while increasing color saturation by exploiting advantages of both dichroic and absorptive filters. The dichroic filter that passes only the appropriate band of wavelengths is placed behind each pixel. For example, red dichroic filters 223 are located behind each red pixel 131 filter (toward the backlight). In this case the red dichroic filter 223 cutoff frequency can be selected to remove the unwanted orange lamp emission and ensure that there is no blue leak to desaturate the red. The cut-off frequency of the dichroic filter will shift to the blue spectrum as the display 30 is viewed from off-axis. The result is a slight red desaturation at off-axis viewing angles. The desaturation is limited to the absorbing filter transmission since it is not angular sensitive.

However, since the red dichroic filter 223 is only over the red pixel 131, this does not adversely affect the green or blue chromaticity, as would be the case with a dichroic filter over the entire backlight assembly. The cut-off frequency of the dichroic filter is approximately 40 nanometers greater (toward the red spectrum) than the main spectral emissions of the lamp 12. This is done intentionally to ensure that the angular effects of the dichroic filter do not cause luminance loss at extreme viewing angles.

In order to promote a better understanding of the invention, a description of the theory for increasing liquid crystal display (LCD) brightness through conservation of radiant energy is provided hereinbelow. In conventional LCDs, around 90% of the light energy created in the fluorescent lamps used for backlighting is converted to heat through absorption by materials within the display. The interaction of radiant energy with materials is described by transmission, reflection, or absorption.

Experiments conducted at Honeywell Inc., Defense Avionics Systems Division in Albuquerque, New Mexico, used a commercially available integrating sphere to measure absorption of various materials found in typical backlighted displays. Such materials included, for example, fluorescent bulbs, diffusers, and other components. The goal of the experiments performed by Honeywell was to characterize these materials and develop an understanding of their effect on the efficiency of the backlight cavity.

By conservation of energy, the total radiant energy which exits an integrating sphere must equal the sum of the input radiant energy minus the amount of energy lost to absorption. For any particular integrating sphere, calibration of the loss can be done using a known luminous source. Such sources are well known in the art. One important characteristic to be noted is that the integrating sphere need not be perfect in order to be characterized and used. In fact the only requirement is that the sphere be calibrated to account for loss by absorption.

The backlight assembly for an LCD may be regarded as an integrating sphere with a huge exit aperture. The backlight assembly of an LCD contains materials with less than ideal reflective properties.

There are several other factors which limited the accuracy of the Honeywell experiment. One of these is the lack of spherical symmetry and therefore lack of uniformity of luminous flux within the integrating cavity. Also, a fluorescent bulb used as the LCD's light source cannot accurately be represented as a point source within the lighting cavity. These two factors make the amount of energy absorbed a function of material placement and shape. These effects can be reduced by using diffuse reflecting surfaces instead of specular reflecting surfaces and by paying some attention to the size and distribution of the fluorescent light source within the reflecting cavity. This description details how to use an integrating sphere to measure the absorbance of materials. The absorbance obtained is scaled to apply to a backlight assembly design. The effects which may be achieved if certain absorptive elements are changed into perfectly reflective elements is quantified. The result is a family of opportunity curves shown in Figure 15 which quantify the potential advantage of using radiant energy conservation techniques.

Experimental Procedure and Data

Honeywell light absorption experiments measured the decrease in light as the amount of absorptive material was increased within a luminance integrating sphere purchased from Hoffman Engineering model number LS-65-8C.

Light absorbing material was made in two different shapes: spheres and disks. Each shape was fabricated from metal and made in various diameters which were sandblasted to achieve a rough texture and painted flat black to achieve approximately 100% absorption of incident visible light. Each sphere or disk was individually placed inside of the integrating sphere, and the light was measured through the exit aperture of the integrating sphere using a Pritchard 1980A photometer. Figure 6 shows the measured reduction in light intensity as a function of the exposed surface area of the particular absorber.

The vertical axis 90 of Figure 6 is the measured luminance plotted as a percentage of the integrating sphere's light output, normalized to 100% for the condition where no additional absorptive materials are added to the integrating sphere. The horizontal axis 92 of Figure 6 is the surface area of the added absorber divided by the internal surface area of the integrating sphere expressed as a percentage. The horizontal axis 92 was selected to allow for extrapolation of the measured data to LCD lighting cavity applications.

The squares 94 on Figure 6 represent the measured data for sphere-shaped absorbers, and the circles 96 represent the data for the disk shaped absorbers. A first curve 98 was plotted for the measured sphere data and a second curve 1100 was plotted for the measured disk data. The difference between the first and second curves indicates the effect of absorber shape within the experimental apparatus.

Modeling of Absorptive Materials Within an Integrating Sphere

The continuous curve 98 underlying the measured disk data shown in Figure 6 is predicted data for the integrating sphere with an average internal reflectance of 96.5%.

The basis for calculations used in the experiment is found in two references: Illumination Engineering, J. B. Murdoch, 1985, pp 45-48, and "Applied Optics", Volume I, L. Levi, 1968, pp 31-32.

Murdoch presents an equation which calculates the exitance at the integrating sphere's exit aperture. The exitance, having units of lumens per unit area, and the luminance, having units of candela per unit area, are directly proportional at the integrating sphere's exit aperture. Murdoch's equation is

$$E = (p\,\Phi) / (A_t (1 - p))$$

where E is the exitance, p is the average reflectance of the sphere, Φ is the luminous flux of the sphere's light source, and A_t is the internal surface area of the integrating sphere.

By placing absorptive materials inside of the integrating sphere, the average reflectance (p) of the sphere is decreased. The reflectance of the sphere is dependent upon two factors:

(1) the reflectance of the wall of the sphere, p_m; and

(2) the less reflective surfaces within the sphere (i.e., the exit aperture, and the light source entrance aperture).

The reflectance of the sphere with no absorbers added can be estimated using the following equation,

$$p = p_m - (A_o / A_t)$$

where A_o is the area of the sphere's exit aperture. Loss due to the exit aperture must be normalized by internal reflecting area because it determines the flux density at the exit aperture.

To calculate the effect of adding light absorbers, another decrease to average reflection is introduced as in the next equation,

$$p = p_m - (A_o / A_t) - (A_a / A_t)$$

where A_o is the exposed surface area of the absorber. For the spheres, A_a is equal to the surface area of the sphere and for the disks it is equal to the area of one side of the disk.

Substituting this expression for reflectance into

Murdoch's equation for exitance yields

$$E = \{\Phi[p_m - (A_o / A_t) - (A_a / A_t)]\}/\{A_t[1 - p_m + (A_o / A_t) + (A_a / A_t)]\}.$$

The flux, Φ, is a constant as long as the light source does not change, and the quantities (A_o / A_t) and p_m are constant for the integrating sphere. Thus the exitance is a function of the absorber's surface area relative to the integrating sphere's surface area.

The variable, (A_a / A_t), for the horizontal axis of Figure 6 is in both the numerator and denominator of the above expression. The predicted data of Figure 6 was calculated using this expression with p_m equal to 0.965.

Application of Model

Figure 15 graphically exhibits the extension of this energy loss model to the conditions expected for a typical avionics display. This application is intended to serve only as an illustration to aid in understanding the invention and the invention is not limited to this specific display. The bottom curve 310 reflects the operating condition for a conventional display. The other curves 302 - 308 represent the potential gains associated with the addition of the proposed perfect reflective optical components. For example, curve 308 represents the addition of a reflective aperture matrix. Curve 306 represents the addition of reflective polarizers to the display of curve 308. Curve 304 represents the addition of reflective color filters to the display of curve 308. Curve 302 represents a display having reflective aperture masks, reflective color filters and a reflecting polarizer such as a wire grid polarizer.

For each curve of Figure 15 the effective exit aperture, A_o, is changed to indicate the best case performance when adding the new reflective components. For the purposes of this disclosure, an effective exit aperture is defined as a component wherein light which is completely absorbed can be regarded as having passed out of an exit aperture. Substituted materials which reflect absorbent light can be modeled by reducing exit aperture area.

The lighting cavity's size was assumed to be 6 x 8 x 2.3 inches to calculate the internal surface area of the integrating cavity (A_t). The average reflectance of the cavity, p_m, was assumed to be 1.0, and the horizontal axis variable, (A_a / A_t), was expressed as a percentage ranging from 0% to 10%. The bottom curve 310 was calculated with A_o equal to the area of the display surface, about 48 sq. in. This assumes that all light incident on the rear polarizer of the LCD module is either absorbed or transmitted. The normalized luminance of 100% is established as a reference based on the prior art exhibited by curve 310.

By making the row and column address lines reflective on an LCD with an aperture ratio of 55%, the transmitted light increases as shown with curve 308 of Figure 15. The effective exit aperture, A_0 decreases to 26.4 square inches for this condition.

Curve 306 reflects the potential gain associated with adding a wire grid polarizer to an LCD module using a reflective row and column address structure. The effective aperture is decreased to 13.2 square inches based upon the assumption that the light previously lost in the rear polarizer is now recovered by reflection within the lighting cavity. Previously the lost light amounted to about 50% of the total light produced by the backlights.

To understand the effect of particular components or materials which are included within the backlight cavity, the absorption of each component can be quantitatively estimated. This can be accomplished by repeating the integrating sphere experiment using the components or representative pieces of the components to measure the light loss. From this measured data an equivalent black disk surface area can be determined. This equivalent surface area can then be scaled to the ratio of the proper size for the material which will be present within the lighting cavity divided by the size of the measured piece.

Measurements were made to determine which optical element within an LCD's optical assembly was the largest consumer of radiant energy. These measurements showed the tremendous potential gains in luminous efficiency which result from radiant energy conservation. They also revealed that the rear polarizer was the most significant absorptive component. Figure 1 shows the relative absorption of a fluorescent bulb, diffuser, and traditional polarizer.

Table 1 hereinbelow shows the light loss for sections of an ATSD (Honeywell Air Transport Systems Division) "D" size fluorescent lamp where the bulb's inner diameter is 0.476". For each lamp length, the lamp was fitted, prior to insertion into the integrating sphere, with end caps made of Spectralon (TM). The length shown in table 1 is the distance between the two Spectralon end caps.

TABLE 1

Fluorescent Bulb Lengths	Percentage of Light Decrease
0.9925	2.13
2.071	3.83
2.79	5.0

Because the lamp absorption scales approximately with lamp surface area, the absorption of a 48.3 inch long lamp with a 0.476" inner diameter can be calculated based upon this measured data. Dashed line 312 at 2.88% represents the amount of relative absorption associated with a fluorescent lamp having a 15 mm diameter, and 1226.6 mm length.

A section of a milky white diffuser was placed inside of the integrating sphere and the light loss was measured. The diffuser piece had an exposed surface area of 1.565 square inches. The measured loss was 5.96% for this piece. A black disk with a surface area of 0.3219 square inches will exhibit this percentage of loss from the Hoffman Engineering integrating sphere. Scaling the loss for a diffuser which is 48 square inches and placed inside of the lighting cavity gives 6.15% of absorptive material relative to the lighting cavity. Taken together, the fluorescent bulb and the diffuser result in 9.03% of absorptive material within the lighting cavity.

The predicted gains associated with the addition to one example display of 1) the reflective row and column structure and 2) the reflective color filters, are shown by curve 304, representing an effective aperture = 6.6 sq. in. Curve 304 assumes the aperture is equal to the area of the red pixels on the display surface.

Curve 302 represents an effective aperture = 3.3 sq. in and is the predicted performance for a display employing a wire grid polarizer, reflective color filters, and a reflective row and column structure. The effective aperture is reduced by a factor of 2 because the loss associated with the rear polarizer may advantageously be approximately 50 %.

It should be noted that the data shown in Figure 15 are for perfectly efficient conditions. All light that is incident is either transmitted or reflected and all light which is reflected is assumed to be re-incident to the LC glass surface after reflection.

Apparatus and Method of the Invention

Having described the theory of the invention, several example embodiments and elements of the invention are presented hereinbelow. The examples described are intended to illustrate the principles of the invention and the invention is not limited to the specific embodiments described herein.

Referring now to Figure 7, one example of a reflecting backlight cavity as contemplated by the invention is illustrated. A reflecting backlight cavity 700 was constructed using Spectralon (TM) material to coat inside wall 706. Spectralon (TM) was selected because of its excellent diffuse reflectance properties across the visible spectrum. A fluorescent bulb 720 was installed to provide a representative source of illumination. To demonstrate the effects of a conventional LCD structure, a front glass 710 was constructed with 1 by 1 inch pixels in a 6 x 8 inch active area 702.

Figure 8 shows the placement of color filters 402 made from Kodak Wratten gels in a front glass assembly 400 that was substantially absorbing made from photographic tape placed on a 0.060 inch soda lime glass substrate. The photographic tape had 4% reflectivity. This is intended to simulate the approximate aperture ratio (51 %) and absorbance of matrix displays with RGB color filter structure and about 170 pixels per inch aperture density. Such a front glass surface represents the conventional approach to manufacturing flat panel displays, in this case with a flat field white image displayed.

Figure 10 shows the spectral characteristics of the Kodak Wratten gel filters used in the construction of the front glass assembly 400. Note that the vertical axis 500 represents transmittance and the horizontal axis 502 represents wave length in nanometers. Curves 504, 506 and 508 respectively represent blue, green and red light transmittance characteristics. Note the substantial overlap area at point 510 between the blue and green filters. Such an overlap blurs color distinctions and is undesirable because of the resultant de-saturated primary colors.

Referring now to Figure 9, an alternative front glass 800 was constructed using color separation filters 802, available from OCLI of California, placed in a commercially available 3M brand Silverlux (TM) film matrix 806 (not shown) having greater than 95% reflectivity. All surfaces, generally designated 804, which are not within RGB squares are reflective of incident light arriving from the back lighted side of the glass 800.

Figure 11 shows the spectral characteristics of the OCLI filters 802. Note that the vertical axis 600 represents transmittance and the horizontal axis 602 represents wave length in nanometers. Curves 604, 606 and 608 respectively represent blue, green and red light transmittance characteristics. The overlap area at point 610 between the blue and green filters is substantially less than for the absorbing glass assembly 400 as graphically illustrated in Figure 15 at point 510. These filters are of dichroic construction, so they reflect out-of-band light into the backlight assembly while transmitting light which falls within the pass band of the color filter.

Another front glass assembly was constructed to hold an absorbing polarizer Sanritsu model 9218. Each of the front glass assemblies 400, 800 were placed in front of the backlight assembly as shown in Figure 7.

Measured Increases Due to Utilization of Radiant Energy Conservation

Referring again to Figure 7, to confirm the potential gains which are obtained through the conservation of radiant energy in a back lighted display, a macro scale model was constructed to provide a means of measuring the increased display luminance for a constant luminous input such as the lamp 720. The model is considered to be a "macro scale" model because the glass plates 710 were made having approximately 1/170 times the aperture density of an LCD designed for a typical avionic application. The macro scale model had individual color apertures which were approximately one inch square distributed on a 6 x 8 inch glass substrate in a RGGB mosaic.

Relative areas between the active pixels and the interconnection areas were proportionately maintained (i.e., the model's plates had an aperture ratio of approximately 50%). The lighting cavity 700 itself was the same size as the lighting cavity planned for use in an avionics application.

Two methods of measurement were used to measure the effects of adding the reflective color filters and reflective aperture mask. The first method of measurement used a calibrated 1980A Pritchard photometer located normal to the display surface and focused on a single green aperture of the glass plate under measurement. This method is referred to as the "green pixel" method hereinbelow.

The second method utilized a 40 inch diameter integrating sphere to collect the radiant energy emitted by the display surface in all directions. This was accomplished by affixing the face of the display to the sphere's large aperture such that all of the radiant energy from the display surface was emitted into the integrating sphere's cavity, which is coated with a diffuse, highly reflective material such as Spectralon (TM). Another much smaller aperture on the integrating sphere was used to measure the radiant energy emitted by the display surface. A calibrated Pritchard 1980A photometer was focused onto the small aperture to measure the emitted radiation. This method of measurement eliminates the issue of direction from radiant energy measurements, and will be referred to as the "sphere" method of measurement hereinbelow.

A glass plate made of absorptive color filters, namely, Kodak Wratten gels, and black photographic tape was used to represent present art construction techniques for LCDs. The black photographic tape was used to represent the opaque row and column interconnection area on an LCD. The glass plate is referred to hereinbelow as the absorptive glass plate.

A second glass plate was constructed from reflective color filters, namely, OCLI's color separation filters, and reflective tape, namely, 3M Silverlux (TM) tape. The second glass plate was utilized to simulate the construction of a display using the concepts described in this patent application. The second glass plate included reflective color filters and a reflective aperture mask.

Key for Measurement Table:

Box is defined to be the lighting cavity 700, the light source 720 and the electronics required to activate the light source.

Abs is defined to be the absorptive glass plate described above.

Ref is defined to be the reflective glass plate described above.

Pol is defined to be the absorptive polarizer (Sanritsu model 9218) glass plate described above.

The order of glass plate components listed below describes the physical location in front of the light source which was used for the particular measurement. For example, Box + Abs + Ref, indicates that the absorptive plate was placed between the reflective glass plate and the light source within the box (i.e., the viewer saw the reflective plate's surface).

Multiple glass plates were used to eliminate gains associated with the higher in band transmission of the reflective color filters, and to maintain approximately the same color gamut. Multiple plates also enabled the insertion of the absorptive polarizer.

Measurement Condition	Green Pixel	Sphere
Box + Abs	77.7	92.8
Box + Ref	979	547
Box + Abs + Ref	71.7	16.0
Box + Ref + Abs	325	33.7
Box + Pol + Abs	34.6	9.3

Box + Pol + Ref	118.5	24.7
Box + Pol + Abs + Ref	27.6	No Measurement
Box + Pol + Ref + Abs	40.4	No Measurement

As can be seen above for every condition, insertion of the reflective plate in place of the absorptive plate or between the light source (Box) and the absorptive plate resulted in significant increases in the measured display luminance. An increase of 1260% for the green pixel measurement method was demonstrated for the (Box + Ref) versus (Box + Abs) condition. The sphere measurement method showed an increase of 590% for this same comparison. The smallest gain measured with the sphere method was 211% for the (Box + Pol + Abs) versus (Box + Pol + Ref) condition. The smallest measured increase for the green pixel method was 146% for the (Box + Pol + Abs + Ref) versus (Box + Pol + Ref + Abs) conditions.

Description of Wire Grid Polarizer

Any polarizer which has minimal absorption of the incident radiant energy can be used to increase AMLCD luminous efficacy if it is used as described herein. Such a polarizer may be constructed from a grid of thin conductive wires which are aligned parallel to one another. The approximate width of the conductors needed to polarize the visible spectrum is 0.1 micrometers. These conductive wires must be aligned parallel to one another with a spacing of approximately 0.3 micrometers between wires.

The reflective polarizer described in this patent application will offer the desirable feature of having a good extinction ratio for a broad angle of incidence of radiance. However, the most desirable feature is reflection of the incident radiation which is not aligned with the reflective polarizer's transmissive polarization axis. This presents the opportunity of returning this energy to the system by redirecting and "re-polarizing" the radiation such that it may pass through the reflective polarizer and the traditional polarizers to the display's observer.

Until the present invention, no wire grid polarizer has been constructed for operation in the visible spectrum. The wire grid polarizer is only one type of reflective polarizer which conserves radiant energy by returning untransmitted energy through reflection, and other equivalent devices may be employed to accomplish the objectives of the instant invention. Wire grids have traditionally functioned as polarizers where their application has migrated upward along the electromagnetic spectrum as the technological improvements enabled devices with progressively smaller dimensions. This progression has continued for two reasons. The first reason is driven by the need for finer and finer detailed metallic structures for use within the semiconductor industry. Secondly, the high conductivity of metals has been maintained at the wavelengths of radiation previously considered. The conductivity of commonly available metals will decrease in the visible spectrum making this more of a limiting characteristic.

Wire grid polarizers manufactured in accordance with the present invention exhibit good extinction ratios over a broad spectrum as is shown, for example, in Figure 15 of "The Wire Grid as a Near-Infrared Polarizer" by G. Bird and M. Parrish in Journal of the Optical Society of America, Volume 50, Number 9, pp 886-891, in 1960. The extinction ratio is controlled by the conductivity of the metal used to create the wire grid. The more conductive the wire material is, the broader the angle over which the polarizer's extinction ratio is acceptable. The first choice of common metals based upon this selection criterion is silver, however, those skilled in the art will recognize that any metal which maintains a high fairly constant conductivity over the visible spectrum, aluminum for example, could be used.

A wire grid polarizer made in accordance with the invention may be manufactured using well-known lithographic techniques such as employing, for example, an electron beam process for etching. Typical pitch between conductors for a reflective wire grid polarizer which will work in the visible spectrum should be approximately ¼ the wavelength of the radiation (~ .2μm for green light).

Referring now to Figure 12, an LCD utilizing a reflective polarizer in accordance with one aspect of the invention is schematically illustrated. The apparatus shown in Figure 12 includes an LCD display 2100, including a conventional LCD assembly 102, an absorbing rear polarizer 104, a reflecting wire grid polarizer 106, a backlight cavity 108, and a fluorescent light source 110 of known serpentine construction. The conventional LCD assembly may include liquid crystal cells, a polarizer and a display glass. Ray 1112, which extends from the fluorescent bulb source to surface 120 of the reflecting wire grid polarizer 106, represents emitted light from the fluorescent light source 110 having both p and s polarization. Ray 1114, which extends from surface 120 to back plate 1122, represents reflected light of s polarization only. Ray 116, which extends from the wire grid polarizer 106 to outside of the view surface 1102, represents transmitted light of p polarization only.

In one embodiment of the invention, the backlight cavity is advantageously light tight and coated with diffusely reflective material. As a result, the reflected light of ray 1114 is scrambled by the diffusely reflective material 107 which coats the backlight cavity 108, including back plate 1122. In this embodiment, the polarization axes of the wire grid polarizer 106 are aligned with the polarizing axes of the absorbing polarizer 104.

The reason for aligning a reflective polarizer with an absorbing rear polarizer as shown in Figure 12 may be better understood by examining an LCD's inherent ability to increase its contrast under high ambient illumination as illustrated by Figures 13 and 14.

Referring now to Figure 13, a simplified illustration of increased contrast for traditional LCDs under high ambient illumination is schematically illustrated. Shown is a reflective backlight cavity 108, a first absorbing polarizer 130, a transmissive liquid crystal cell 132, a non-transmissive liquid crystal cell 134, and a second absorbing polarizer 136. The liquid crystal cells are advantageously polarization-twisted in a well known manner. The first absorbing polarizer 130 transmits p polarized light. The second absorbing polarizer 136 transmits s polarized light. Ray 140 represents ambient illumination which enters the second absorbing polarizer and is reflected out along ray 144 after being reflected off of the backlight cavity 108. Ray 142 represents ambient illumination absorbed in the first polarizer 130.

Referring now to Figure 14, a simplified illustration of loss of an LCD's traditional advantage under high ambient illumination is shown. In contrast to Figure 13, only a reflective polarizer 150 is used here between the backlight cavity and the liquid crystal cells. Shown in combination are a reflective backlight cavity 108, a reflective polarizer 150, a transmissive liquid crystal cell 132, a non-transmissive liquid crystal cell 134, and an absorbing polarizer 136. The liquid crystal cells are polarization-twisted in a well known manner. The reflective polarizer 150 transmits p polarized light. The absorbing polarizer 136 transmits s polarized light. Ray 152 represents ambient illumination which enters the absorbing polarizer and is reflected out along ray 154 after being reflected off of the backlight cavity 108. Ray 156 represents ambient illumination reflected by the reflecting polarizer 150 to an observer along ray 158, thus eliminating a traditional LCD's increased contrast under high ambient illumination.

The reflecting polarizer is aligned with the traditional absorbing rear polarizer to maintain an LCD's inherent increased contrast in ambient illumination. Reflective metal used in the reflecting wire grid polarizer must maintain high conductivity over the visible spectrum to ensure performance independent of wavelength. It is advantageous to vary the duty cycle of the reflecting polarizer by minimizing the width of the reflective portion to provide high transmission. Further improvement in the wire grid polarizer may be achieved by use of very conductive materials to achieve good extinction ratios and broad operable angle. Such a reflecting polarizer results in high effective transmission through an LCD when combined with an efficient reflective backlight cavity.

This invention has been described herein in considerable detail in order to comply with the Patent Statutes and to provide those skilled in the art with the information needed to apply the novel principles and to construct and use such specialized components as are required. However, it is to be understood that the invention can be carried out by specifically different equipment and devices, and that various modifications, both as to the equipment details and operating procedures, can be accomplished without departing from the scope of the invention itself.

CLAIMS

1. An optical filter apparatus comprising:

(a) a transmissive color filter means (132) for transmitting radiation of a predetermined color; and

(b) an absorptive color filter means (134) for absorbing radiation not of the predetermined color, wherein the absorptive color filter means (134) is positioned to receive radiation from, or transmit radiation to, the transmissive color filter means (132).

2. The optical filter apparatus of claim 1 further including at least one polarizing means (136) for polarizing radiation positioned to polarize radiation received from or transmitted to the transmissive color filter means (132).

3. A display apparatus comprising:

(a) programmable shutter means (261, 271, 281, 291) for shutting out or transmitting radiation the programmable shutter means (261, 271, 281, 291) having a display side and a back side;

(b) transmissive color filter means (133, 132, 131) for transmitting radiation of a predetermined color positioned to receive radiation from and transmit radiation to the programmable shutter means (261, 271, 281, 291); and

(c) absorptive color filter means (243) for absorbing radiation not of the predetermined color positioned to receive radiation from or transmit radiation to the transmissive color filter means (132).

4. The display apparatus of claim 3 wherein the transmissive color filter means (132) comprises a dichroic filter.

5. The display apparatus of claim 3 wherein the transmissive color filter means (132) comprises a trichroic filter.

6. The display apparatus of claim 3 wherein the transmissive color filter means (132) is on an opposite side of the programmable shutter means (261, 271, 281, 291) from the absorptive color filter means (243).

7. The display apparatus of claim 3 wherein the transmissive color filter means (132) is on the same side of the programmable shutter means (261, 271, 281, 291) as the absorptive color filter means (243).

8. The display apparatus of claim 3 wherein the programmable shutter means (261, 271, 281, 291) comprises a liquid crystal display means.

9. The display apparatus of claim 3 wherein the display comprises a plurality of pixels (262) wherein the predetermined color is a primary color.

10. The display apparatus of claim 3 further including at least one polarizing means (136) for polarizing incoming radiation positioned to receive and transmit the radiation.

11. The display apparatus of claim 3 further including a backlight means (12) to illuminate the back side.

12. The display apparatus of claim 3 further including a radiant energy conservation means comprising:

(a) a cavity means having a highly reflective, diffusing interior surface;

(b) means for backlighting (12) mounted within the cavity means; and

(c) filtering means located forward of the backlighting means (12) for transmitting filtered light at specified frequencies and reflecting out of band light rather than absorbing it, wherein the filtering means comprises a reflecting polarizing means (136) for transmitting a light having a first polarization and reflecting a light having a second polarization.

13. The display apparatus of claim 12 wherein the filtering means further comprises a plurality of dichroic filters (24) aligned with the plurality of absorbing color filters.

14. The display apparatus of claim 13 wherein the filtering means further includes a reflective aperture mask positioned around the plurality of dichroic filters (24).

15. The display apparatus of claim 4 wherein the transmissive color filter means (132) comprise red, green and blue light filters arranged in a matrix format suitable for a color display.

16. The display apparatus of claim 14 wherein the transmissive color filter means (132) further comprises a dichroic filter (24) and the display apparatus further includes display electronics connected to control the display wherein the plurality of dichroic filters (24) are arranged in a matrix format and are selected to transmit red, green and blue light so as to produce a color display in response to signals from the display electronics.

17. The display apparatus of claim 16 wherein the filtering means further includes a polarization filtering means for transmitting the red, green and blue light having a first polarization and absorbing the red, green and blue light having a second polarization wherein the filtering means is aligned with the reflecting polarizing means (136).

18. The display apparatus of claim 17 wherein the reflecting polarizing means (136) comprises a wire grid polarizer.

19. A color liquid crystal display comprising:

(a) a front glass (16) having a front glass first surface and a front glass second surface;

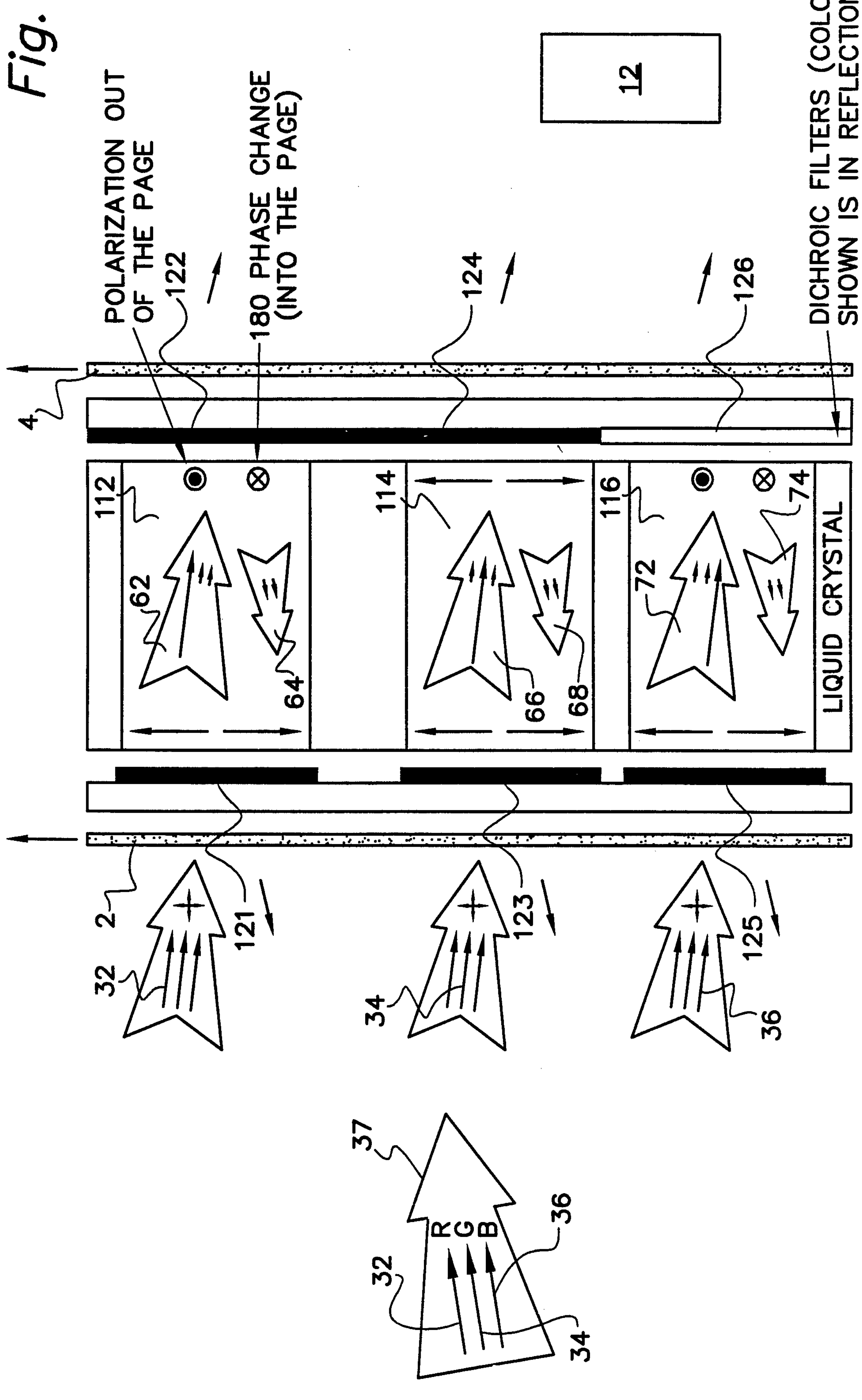
(b) an absorptive filter having a first absorptive filter surface in contact with the front glass second surface and a second absorptive filter surface;

(c) a thin film transistor liquid crystal display having a liquid crystal display first surface in contact with the absorptive filter second surface, and wherein the thin film transistor liquid crystal display has a liquid crystal display second surface; and

(d) a dichroic filter means (24) having a dichroic filter means first surface in contact with the liquid crystal display second surface and the dichroic filter means (24) having a dichroic filter means second surface.

20. The liquid crystal display apparatus of claim 19 further including an array and addressing means wherein the array and addressing means includes speculative reflective means for reflecting light.

Fig. 1


POLARIZATION OUT OF THE PAGE
180 PHASE CHANGE (INTO THE PAGE)
DICHROIC FILTERS (COLOR SHOWN IS IN REFLECTION)
LIQUID CRYSTAL
12
122
124
126
112
114
116
62
64
66
68
72
74
4
2
121
123
125
32
34
36
37
R
G
B

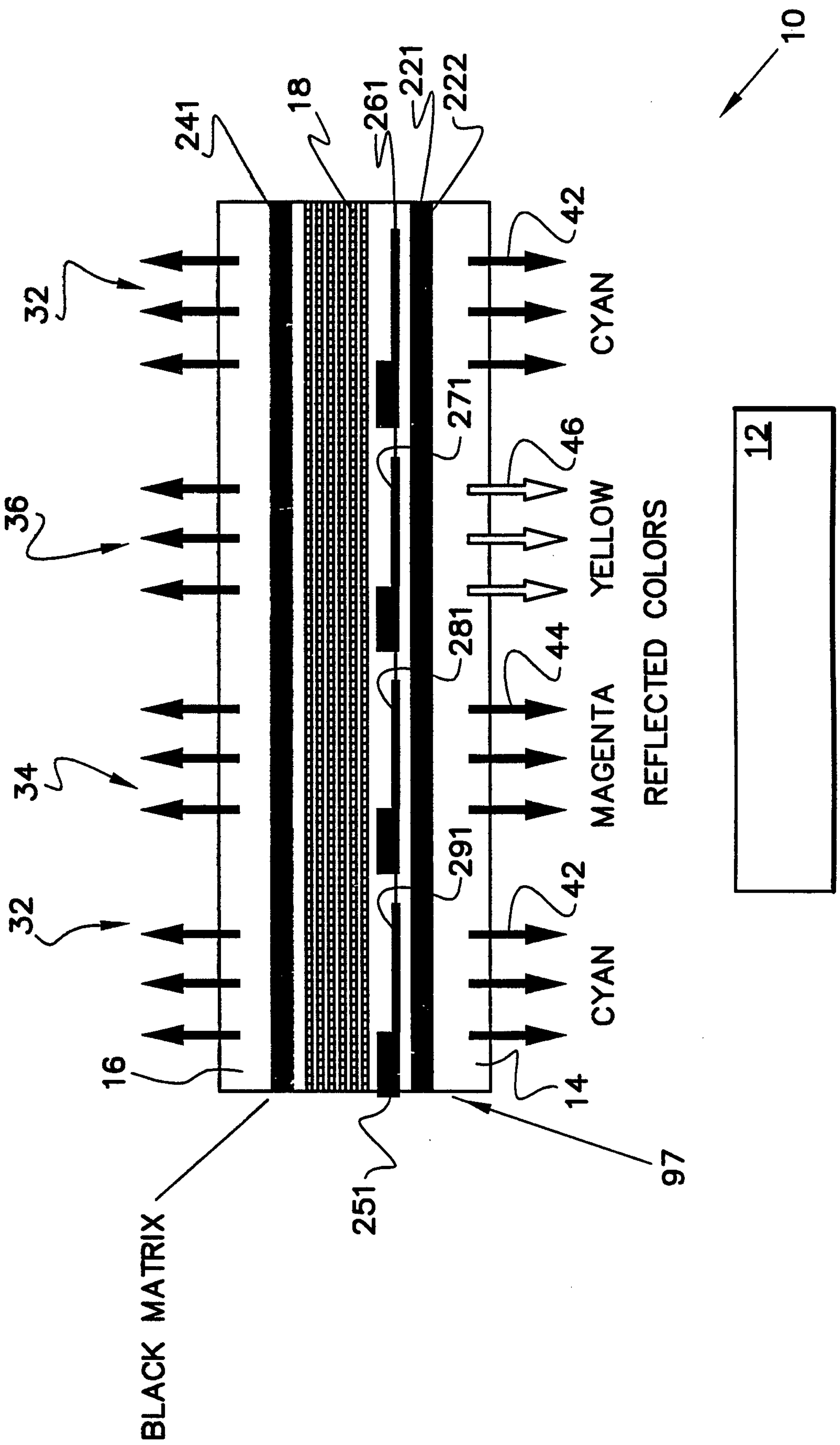

10
241
18
261
221
222
42
32
CYAN
271
46
36
YELLOW
12
281
44
REFLECTED COLORS
MAGENTA
34
291
42
32
CYAN
16
14
251
97
BLACK MATRIX

Fig. 2

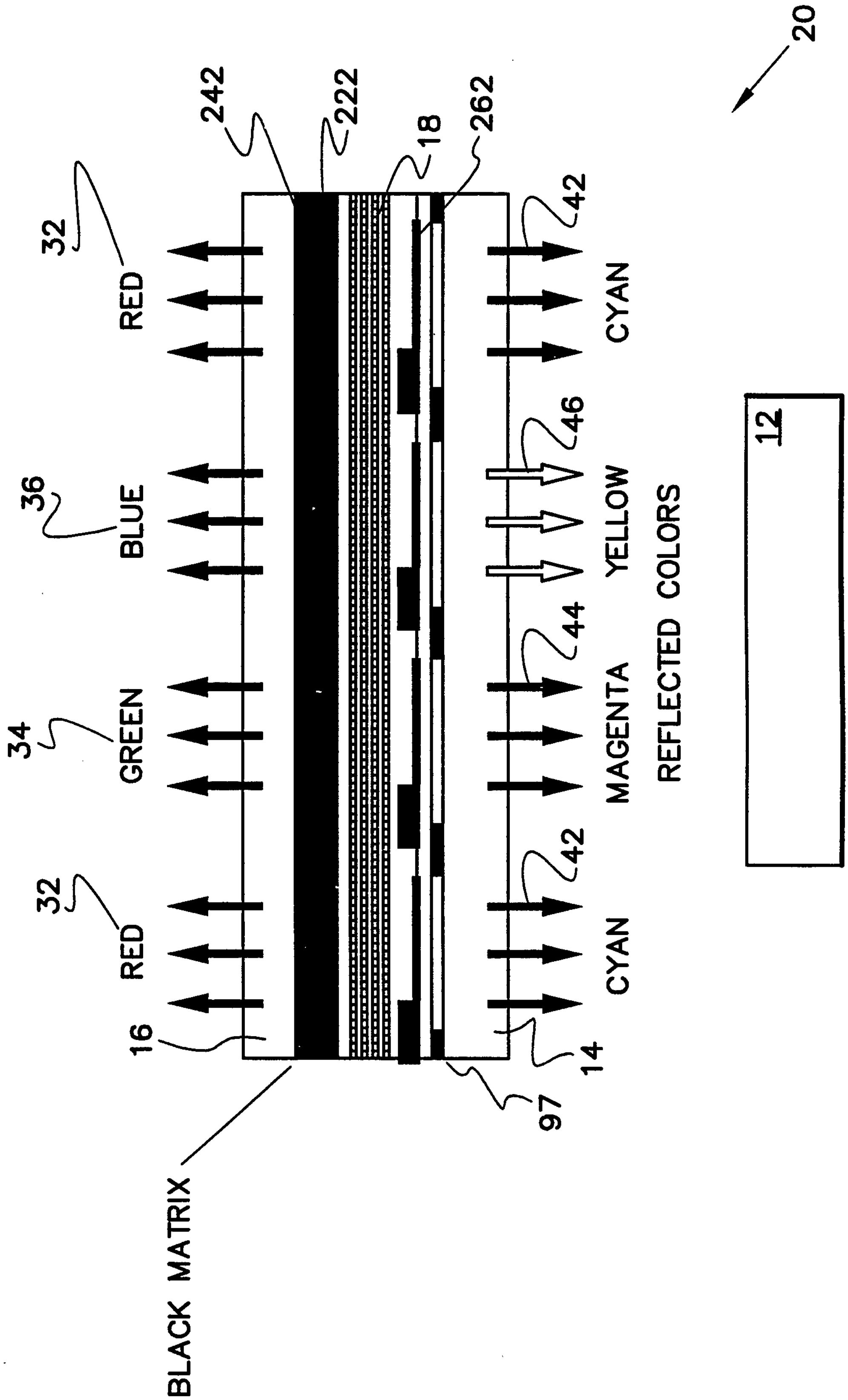

20
242
222
18
262
32
RED
42
CYAN
36
BLUE
46
YELLOW
12
34
GREEN
44
MAGENTA
REFLECTED COLORS
32
RED
42
CYAN
16
14
97
BLACK MATRIX

Fig. 3

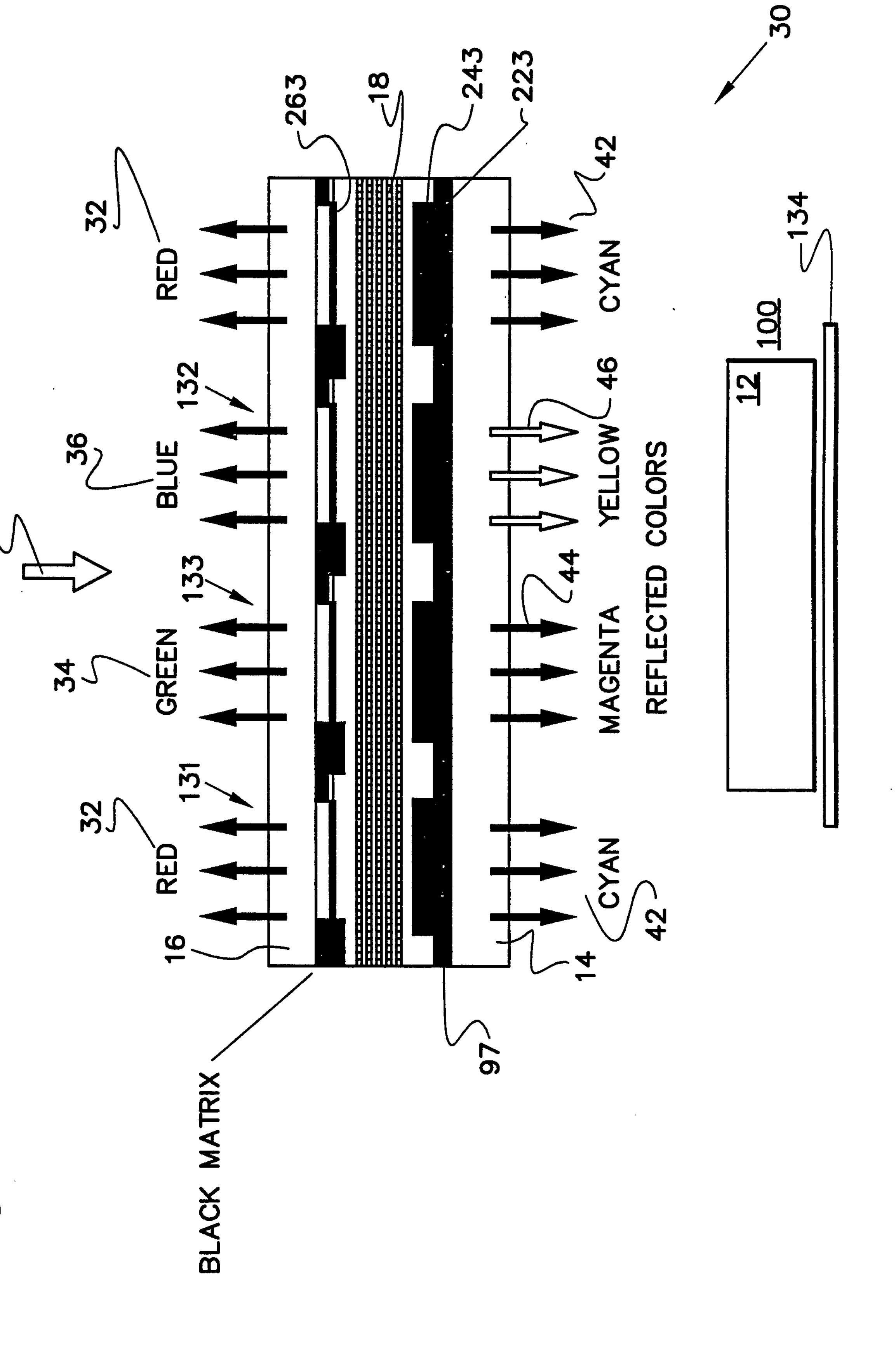

30
32
RED
263
18
243
223
42
CYAN
134
100
12
132
BLUE
36
46
YELLOW
REFLECTED COLORS
39
133
GREEN
34
44
MAGENTA
131
32
RED
CYAN
42
16
14
97
BLACK MATRIX

Fig. 4A

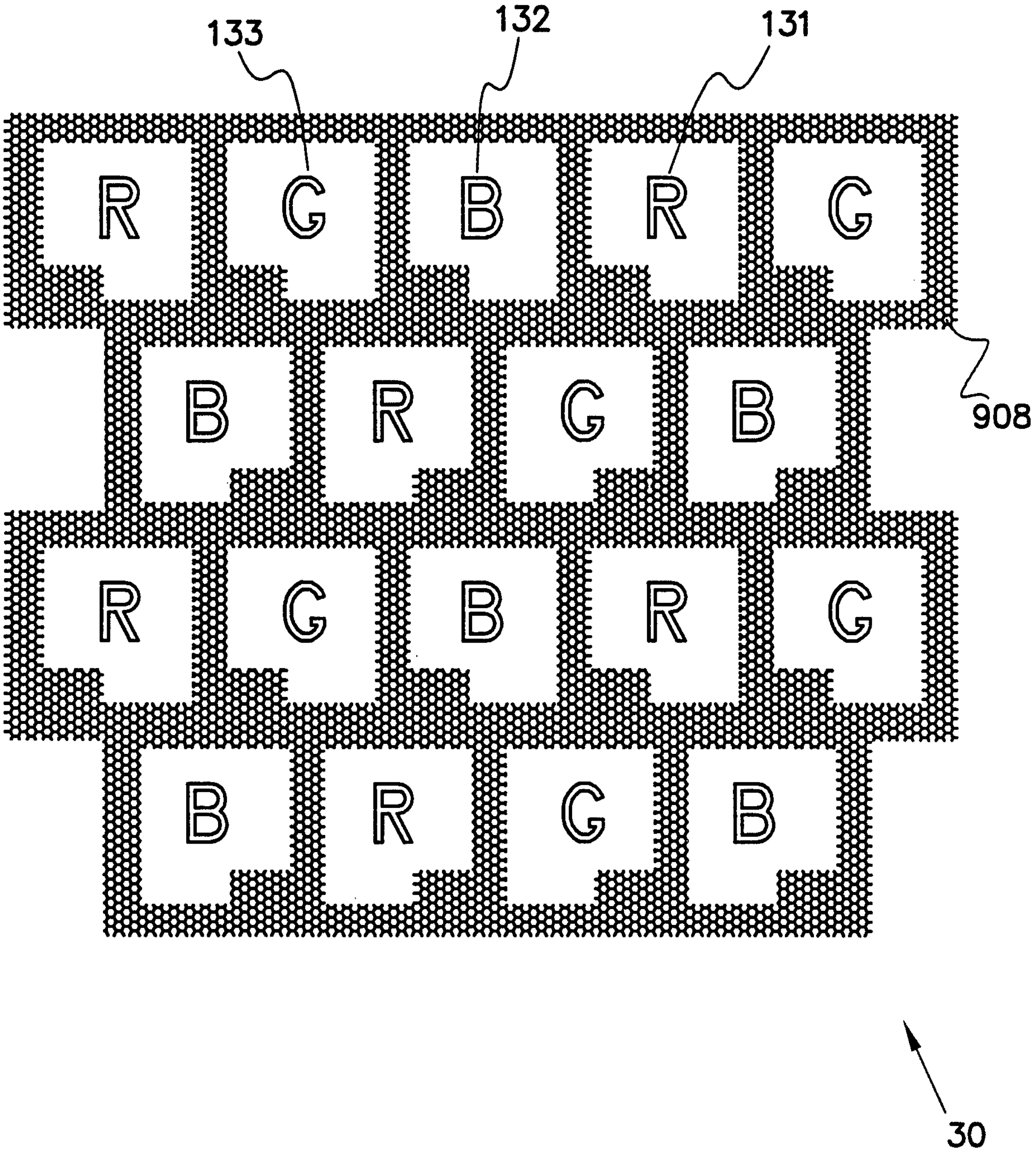


Fig. 4B

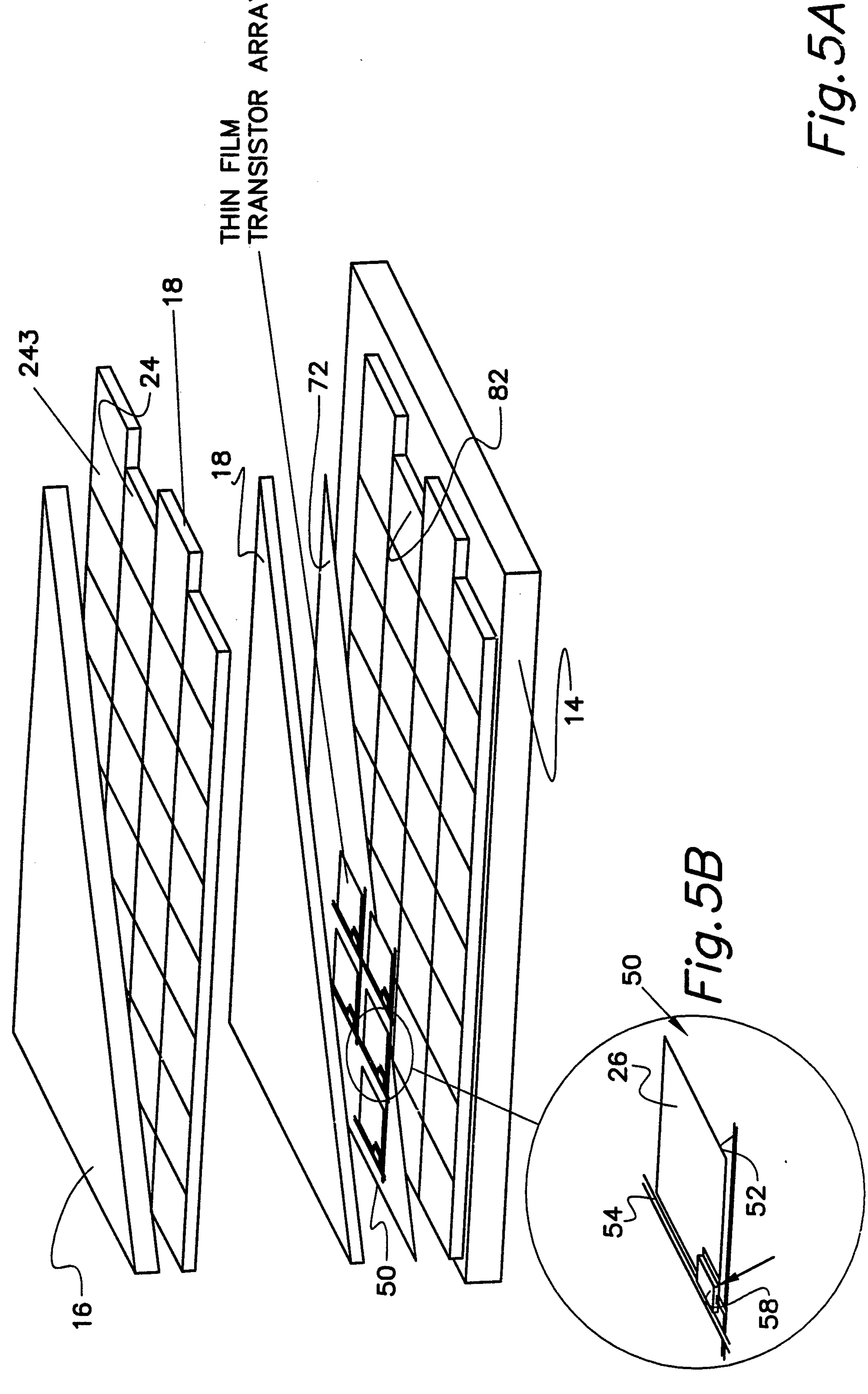
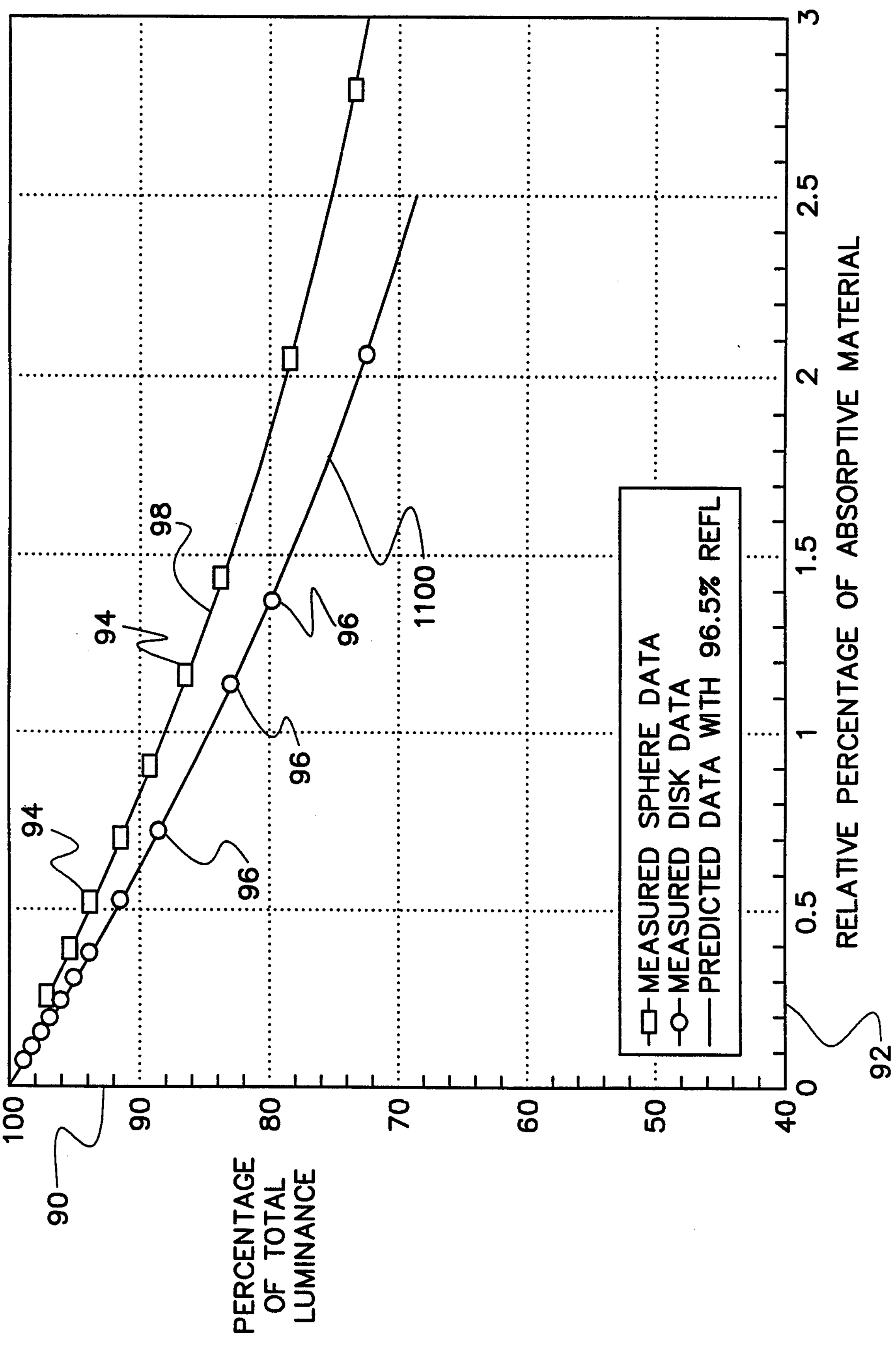

THIN FILM
TRANSISTOR ARRAY
243
24
18
18
72
82
14
16
50
50
26
52
54
58

Fig.5A

Fig.5B

Fig.6


PERCENTAGE OF TOTAL LUMINANCE
100
90
80
70
60
50
40
0
0.5
1
1.5
2
2.5
3
RELATIVE PERCENTAGE OF ABSORPTIVE MATERIAL
MEASURED SPHERE DATA
MEASURED DISK DATA
PREDICTED DATA WITH 96.5% REFL
90
92
94
94
96
96
96
98
1100

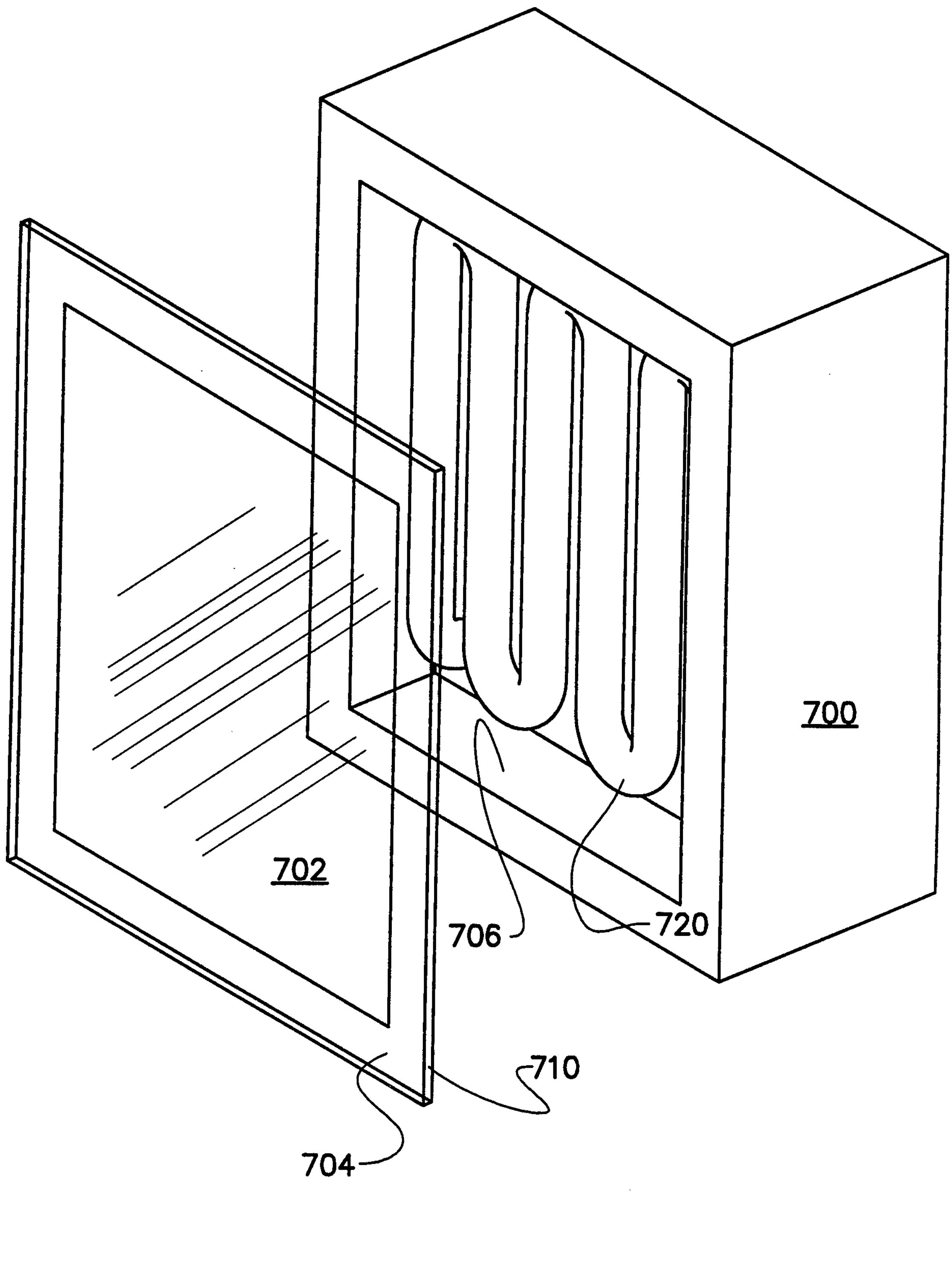


Fig. 7

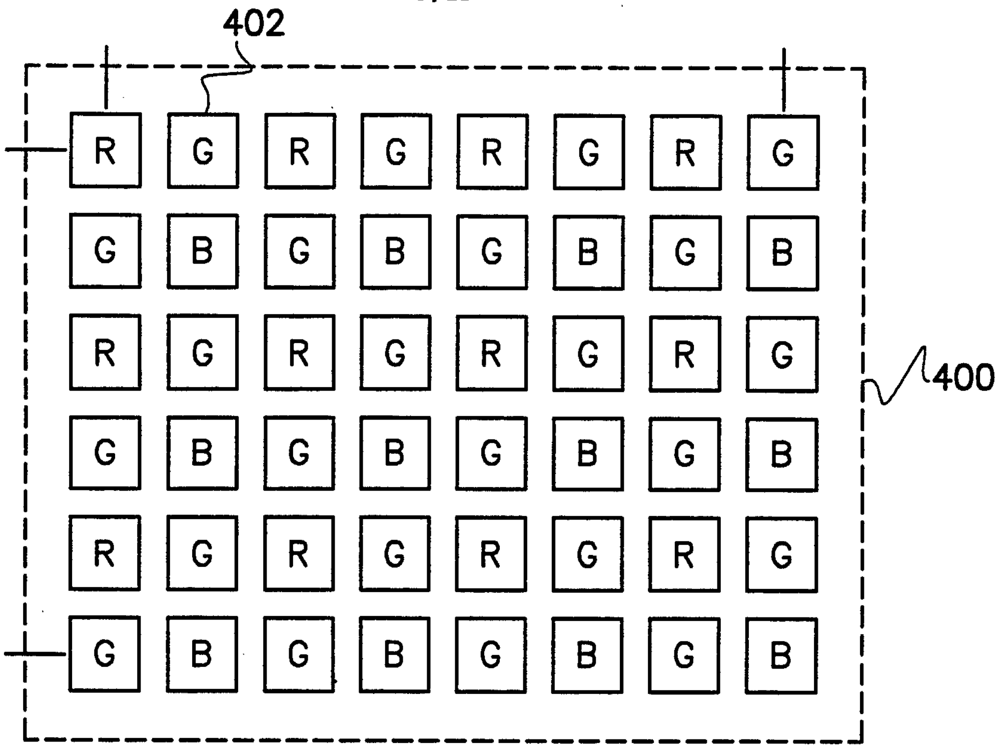

402
400
R G R G R G R G
G B G B G B G B
R G R G R G R G
G B G B G B G B
R G R G R G R G
G B G B G B G B

Fig.8

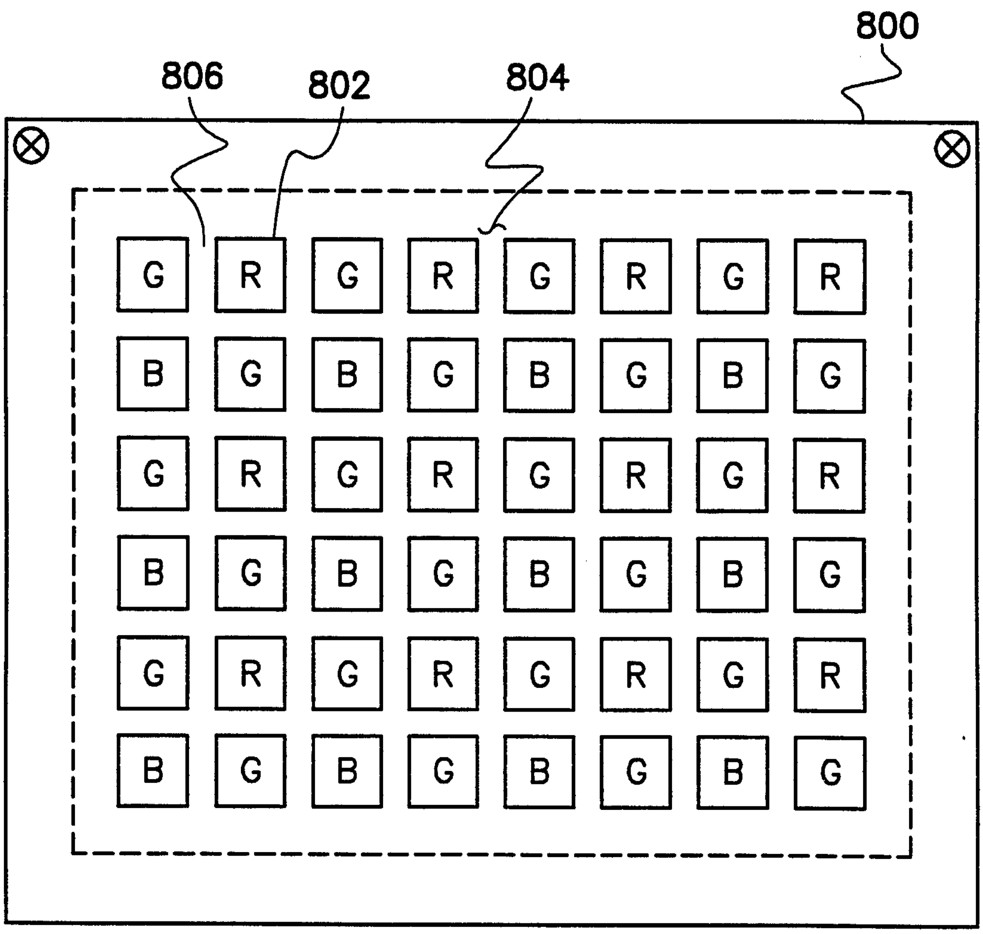

800
806
802
804
G R G R G R G R
B G B G B G B G
G R G R G R G R
B G B G B G B G
G R G R G R G R
B G B G B G B G

Fig.9

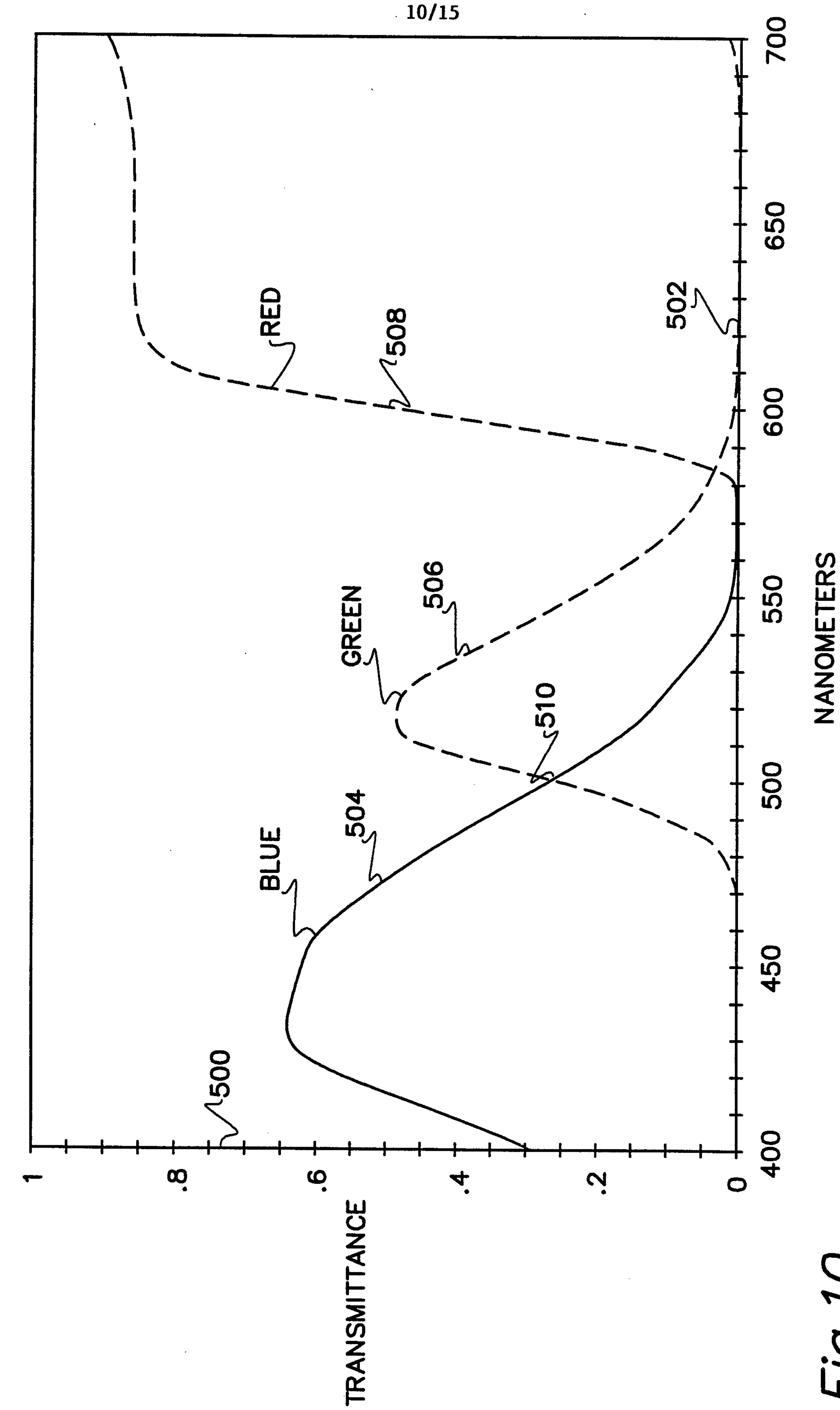

TRANSMITTANCE
NANOMETERS
1
.8
.6
.4
.2
0
400
450
500
550
600
650
700
BLUE
GREEN
RED
500
502
504
506
508
510

Fig. 10

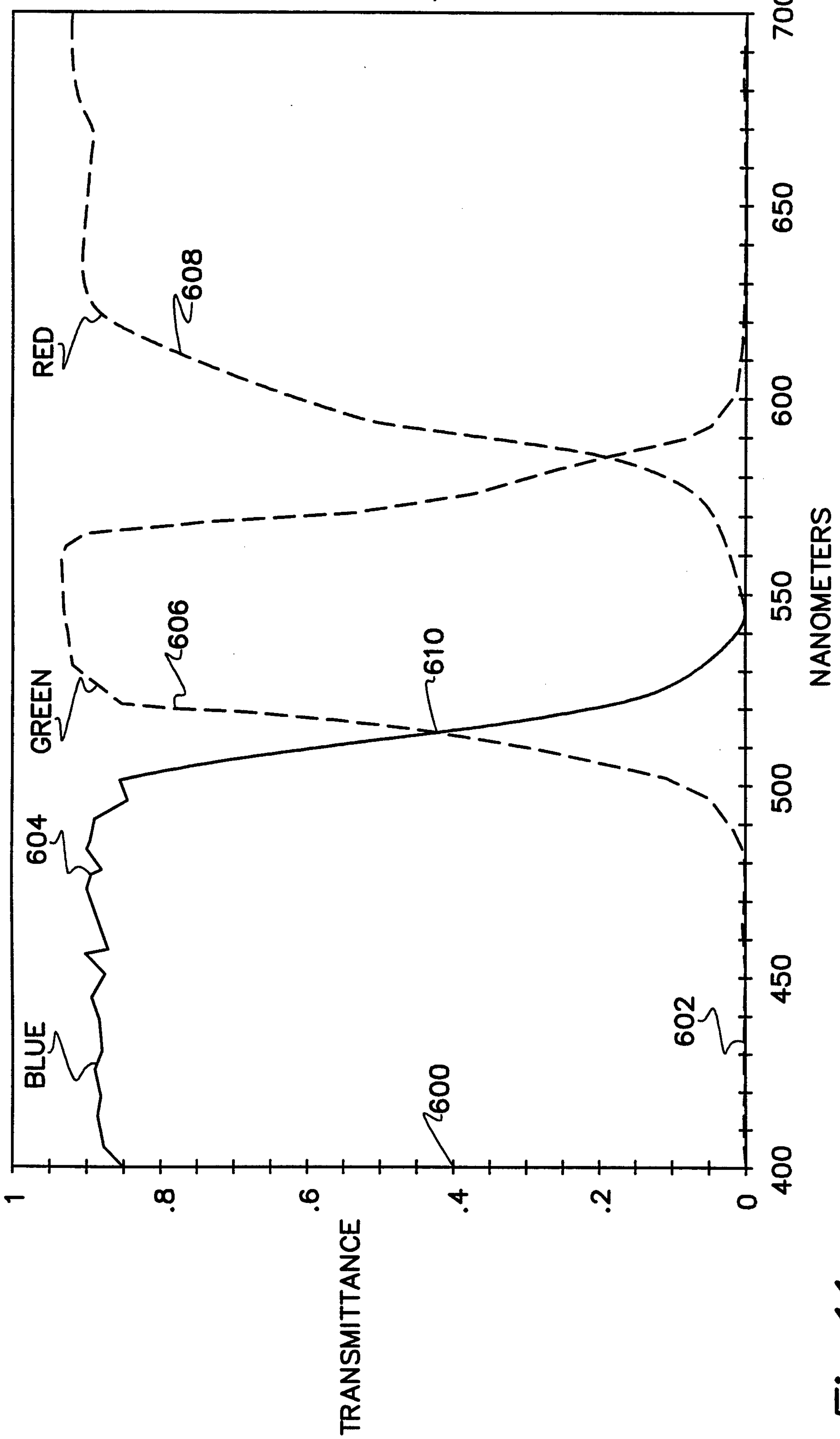

TRANSMITTANCE
NANOMETERS
1
.8
.6
.4
.2
0
400
450
500
550
600
650
700
BLUE
GREEN
RED
600
602
604
606
608
610

Fig.11

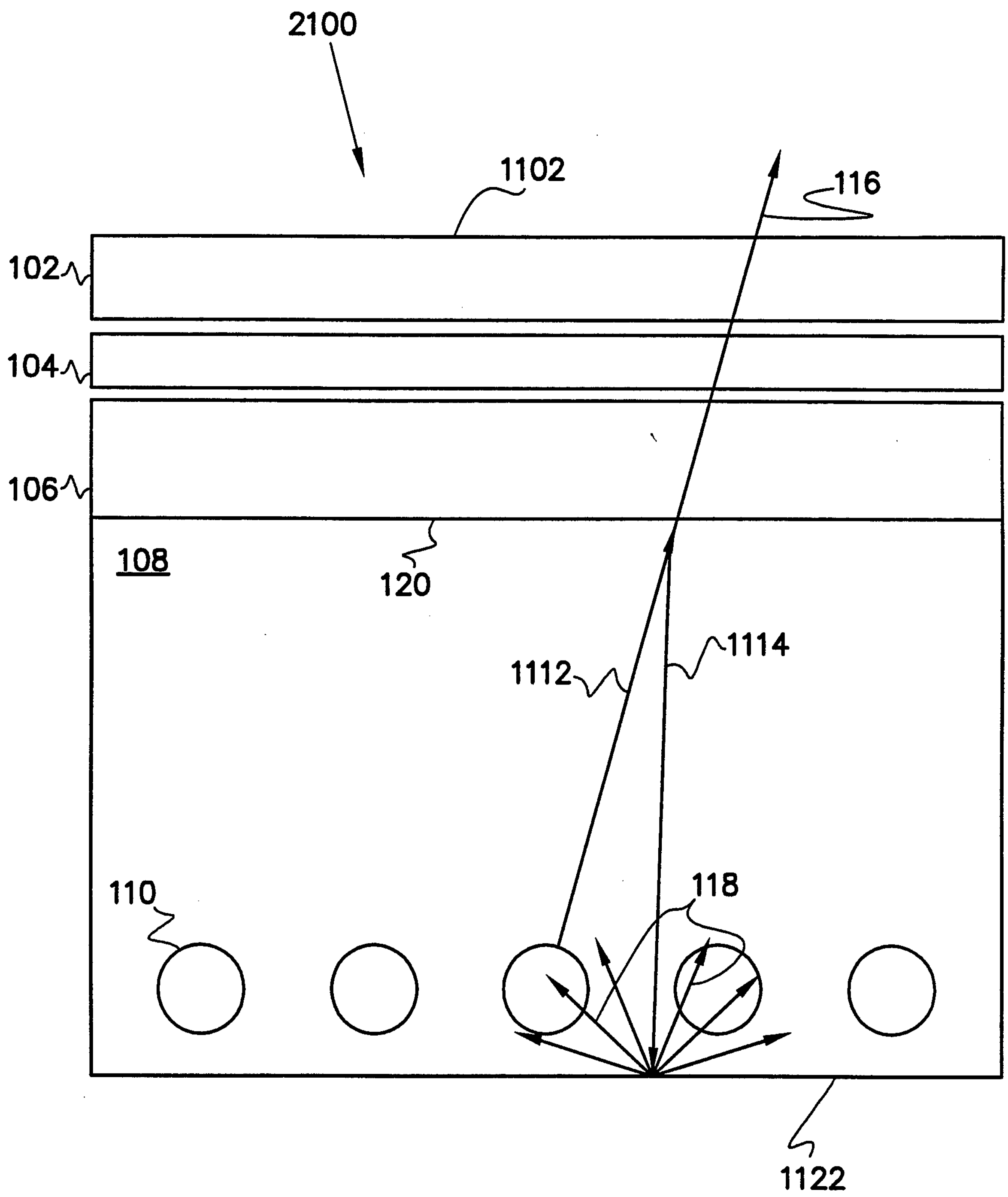


Fig.12

Fig. 13

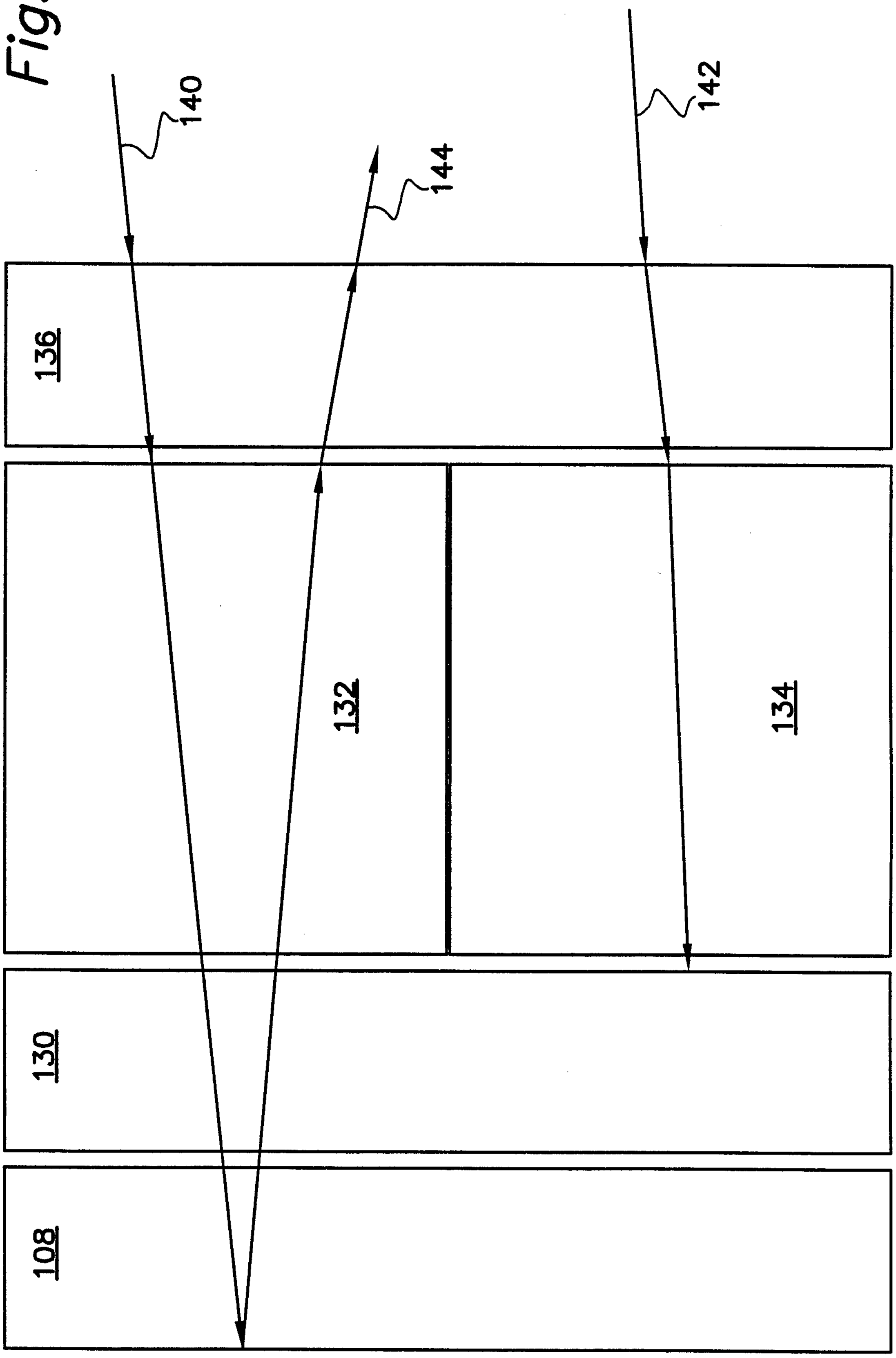
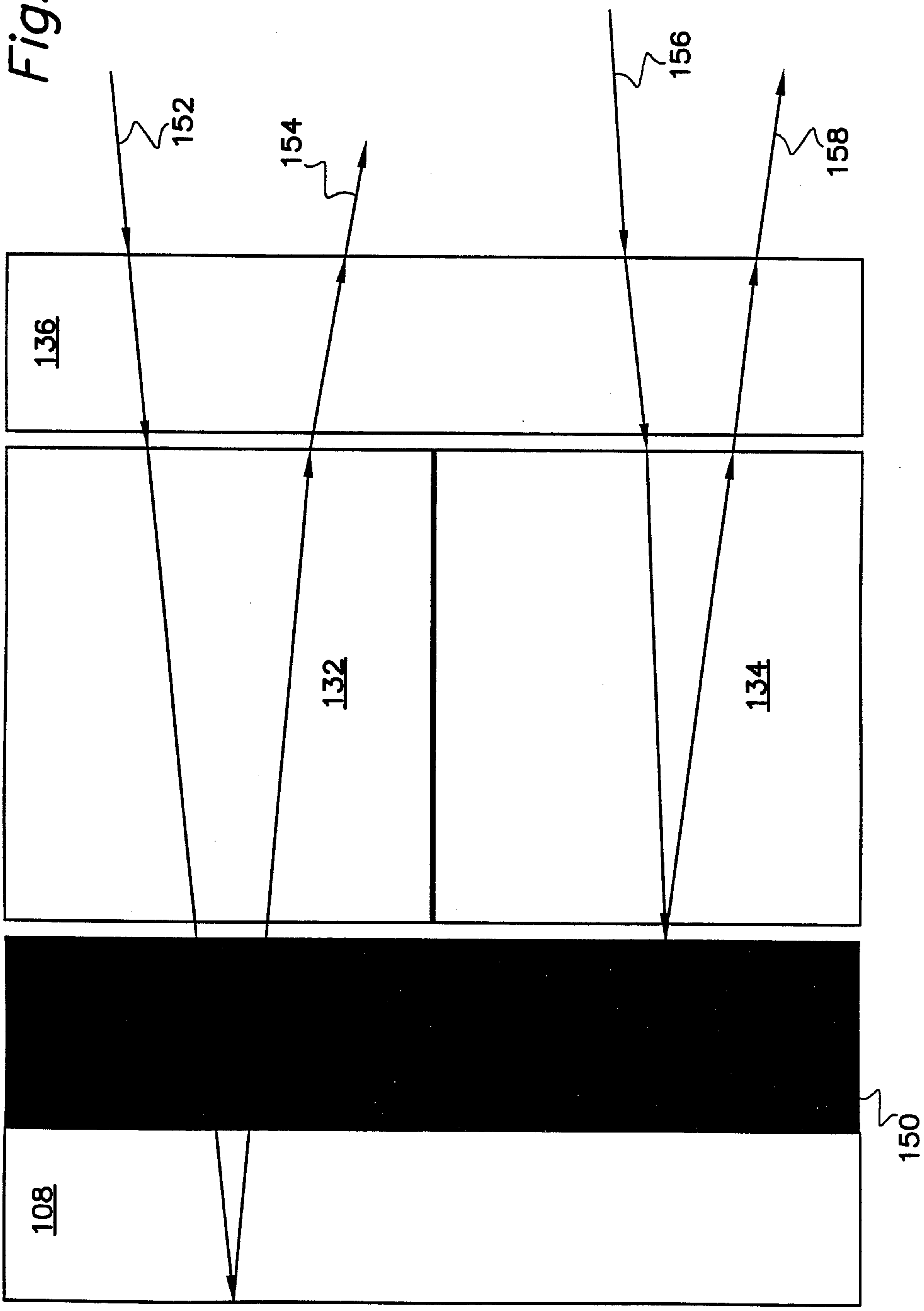


Fig.14



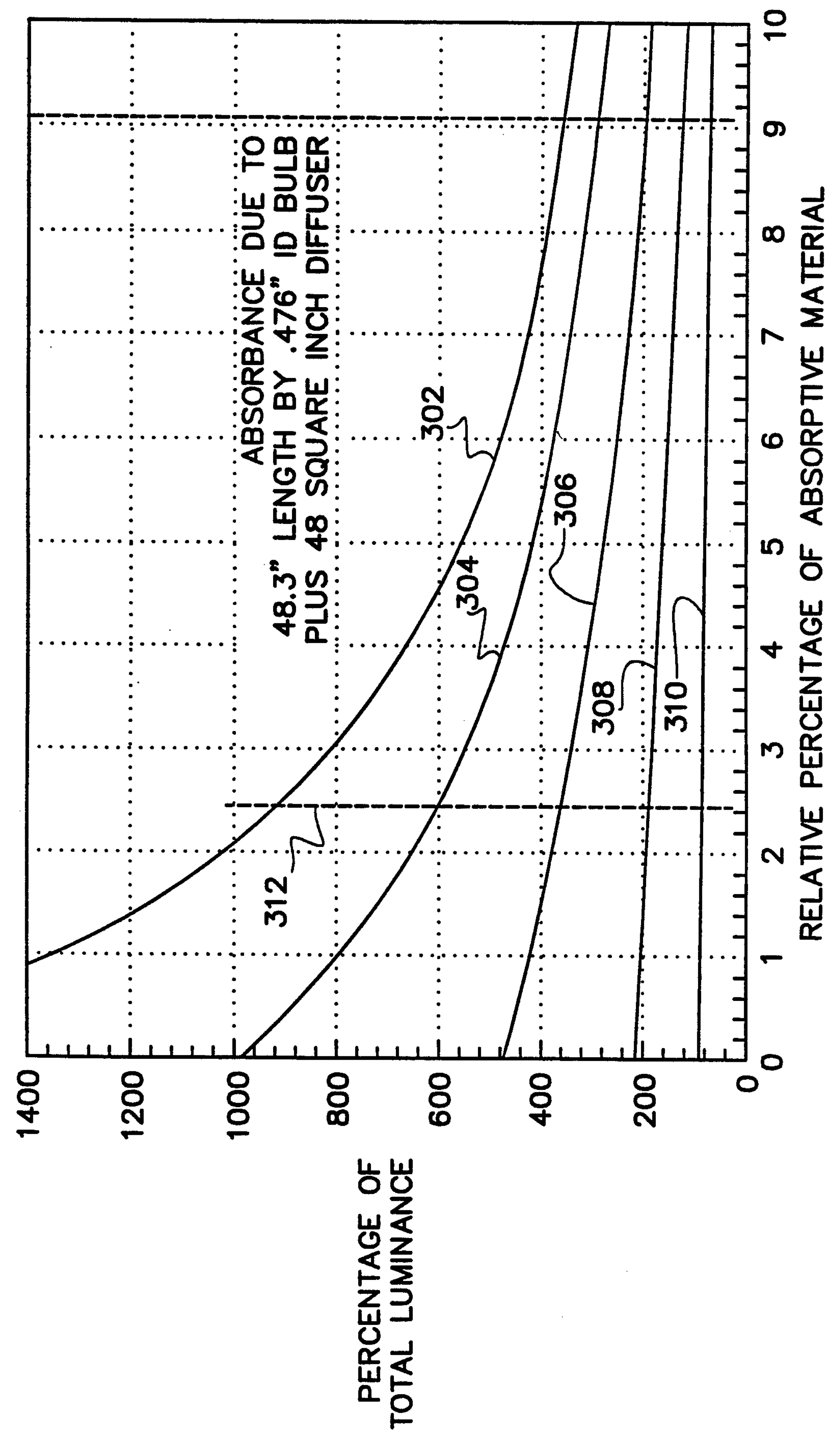

ABSORBANCE DUE TO
48.3" LENGTH BY .476" ID BULB
PLUS 48 SQUARE INCH DIFFUSER
302
304
306
308
310
312
0
200
400
600
800
1000
1200
1400
PERCENTAGE OF
TOTAL LUMINANCE
0
1
2
3
4
5
6
7
8
9
10
RELATIVE PERCENTAGE OF ABSORPTIVE MATERIAL

Fig.15

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 94/02668

A. CLASSIFICATION OF SUBJECT MATTER
IPC 5 G02F1/1335 G02B5/20

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 5 G02F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP,A,0 337 555 (PHILIPS NV) 18 October 1989 see abstract see column 1, line 52 - column 4, line 29 see column 5, line 13 - line 41 see claims 1-6,10,11; figures 1,3	1-11,15, 19,20
A	idem	12,13,16
A	PATENT ABSTRACTS OF JAPAN vol. 012, no. 439 (P-788) 18 November 1988 & JP,A,63 168 626 (CITIZEN WATCH CO LTD) 12 July 1988 see abstract	12,17,18

-/--

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

2

Date of the actual completion of the international search	Date of mailing of the international search report
21 June 1994	22 JUIL. 1994

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Iasevoli, R

INTERNATIONAL SEARCH REPORT

Intern al Application No
PCT/US 94/02668

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
E	WO,A,94 11776 (HONEYWELL INC) 26 May 1994 see abstract see page 9, line 9 - line 30 see page 12, line 1 - line 14 see claims 1-13; figures 10-12 -----	3-5,8-18

2

INTERNATIONAL SEARCH REPORT

...ormation on patent family members

International Application No
PCT/US 94/02668

Patent document cited in search report	Publication date	Patent family member(s)		Publication date
EP-A-0337555	18-10-89	NL-A-	8800951	01-11-89
		JP-A-	2012124	17-01-90
		US-A-	5029986	09-07-91
WO-A-9411776	26-05-94	NONE		