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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : G03B 33/12, G02F 1/03

A1

(11) International Publication Number: **WO 00/02087**

(43) International Publication Date: 13 January 2000 (13.01.00)

(21) International Application Number: PCT/IB99/01224

(22) International Filing Date: 30 June 1999 (30.06.99)

(30) Priority Data:
98202225.3 2 July 1998 (02.07.98) EP

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(81) Designated States: JP, US, European patent (AT, BE, CH, CY, DE, DK, ES, FI, 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: IMAGE PROJECTION SYSTEM

(57) Abstract

The present invention relates to an image projection system (1) comprising an illumination system (3) and a modulation system comprising three image display panels (11, 13 and 15) of the reflective type. The light beam coming from the illumination system (3) is color–separated and, after modulation by the image display panels, color–recombined by a color–separating and color–recombining element (17). At least between the element (17) and the display panels (11, 13 and 15) is arranged a polarization–compensating element (31, 33, 35).

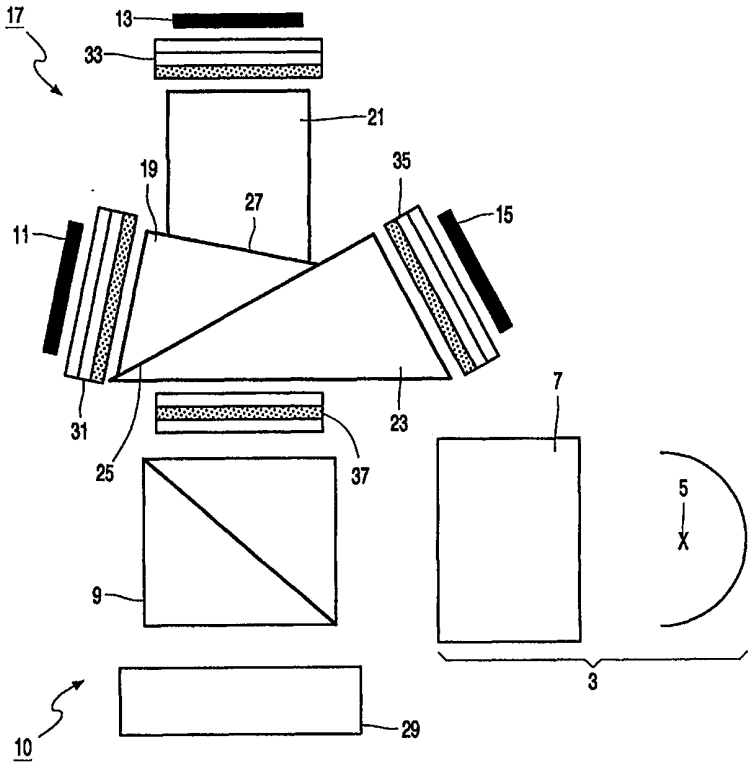

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Image projection system.

The present invention relates to an image projection system comprising an illumination system, a modulation system having at least two reflecting image display panels of the non-diffusing type for modulating light generated by the illumination system in conformity with image information to be projected, and a projection lens system, the image projection system comprising an element having a color-separating as well as a color-recombining effect, and a polarizing beam splitter which is situated between the illumination system and the element and between the element and the projection lens system.

A reflective image display panel of the non-diffusing type is understood to mean a reflective liquid crystalline image display panel of the non-diffusing type or a DMD or the like.

An image projection system comprising two or three reflective image display panels may be given a very compact construction if the color separation and the color recombination are effected by one and the same optical system. The optical system may comprise, for example, a polarizing beam splitter. Since the other optical elements of such an optical system are situated between the reflective display panels and the polarizing beam splitter, it is undesirable that a change of polarization would be effected by the color-separating and color-recombining element. However, this is the case in practice, so that the ultimate image has a too low contrast and strong color deviations for all luminance levels between white and black. This is caused by the polarization-dependent transmission of the color-separating faces of the color-separating element and the geometrical decomposition of the polarization vector on all oblique faces due to non-perpendicular incidence. Each color channel causes a specific change of polarization as a function of the wavelength and the direction of propagation through the color-separating element. In addition to polarization changes of the light, light having a given direction of polarization may be reflected in an unwanted direction. In addition to strong color shifts in a color channel, this also causes unwanted optical crosstalk when light having a certain wavelength reaches a reflective display panel which is meant to modulate light of another wavelength.

The cause of the above-mentioned polarization effects is found in the relatively large angle of incidence on the color-separating faces of the color-separating

element. Dependent on the element used, this angle of incidence may be between 10-20° and 45°. For a large angle of incidence, it is difficult to have an equal transmission characteristic of a color-separating coating for both s-polarized and p-polarized light. The smaller the angle of incidence, the smaller the above-mentioned problem will be. For small angles of incidence, the difference of transmission between p and s-polarized light can be minimized more easily. But also in this case, for example for a plumbicon prism, there is still a change of polarization.

It is an object of the present invention to provide an image projection system in which the above-mentioned drawbacks are obviated.

To that end, the image projection system according to the present invention is characterized in that at least one polarization-compensating element is situated between the element and the image display panels.

After minimizing the differences between the transmission for s and p-polarized light in the desired wavelength range and for the desired viewing angles, by making use of a color-separating element suitable for this purpose, the remaining rotation of polarization induced by the color-separating element is reduced by means of polarization-compensating elements.

A preferred embodiment of the image projection system according to the present invention is characterized in that at least one polarization-compensating element is situated between the polarizing beam splitter and the element.

The solution to the above-mentioned problem is thus found in the addition of polarization-compensating elements. Said elements may be provided to the entrance face of the color-separating element and/or to one or more of the three exit faces of the element. "To the entrance face" is understood to be between the polarizing beam splitter and the color-separating element and "to the exit faces" is understood to be between the color-separating element and the display panels. Direct optical contact is not required.

A further embodiment of the image projection system according to the present invention is characterized in that the polarization-compensating element is a birefringent element.

A very suitable compensating element may comprise a birefringent element or a combination of birefringent elements. A birefringent element or a combination of birefringent elements ensures that a change of polarization by the color-separating element is substantially eliminated within the wavelength range for a plurality of propagation

directions.

A further embodiment of the image projection system according to the present invention is characterized in that the birefringent element has a biaxial symmetry.

When the color-separating element has a viewing angle-dependent behavior which is different for the horizontal viewing directions with respect to the vertical viewing directions, the polarization-compensating element is preferably a birefringent element having a biaxial symmetry.

A further embodiment of the image projection system according to the present invention is characterized in that the birefringent element has a tilted optical axis.

If there is a difference between the positive and negative viewing directions, an element having a tilted optical axis is advantageous.

These and other aspects of the invention are apparent from and will be elucidated with reference to the embodiments described hereinafter.

In the drawings,

Fig. 1 shows an image projection system comprising a polarizing beam splitter and one combined color-separating and color-recombining element, according to the prior art;

Fig. 2 illustrates the difference in transmission for p-polarized and s-polarized light; and

Fig. 3 shows an image projection system comprising a polarizing beam splitter and one combined color-separating and color-recombining element, according to the present invention.

Figure 1 shows an image projection system 1 comprising an illumination system 3 having a light source 5 and illumination optics 7. The illumination optics 7 may comprise, for example, a condensor lens and an integrator system (not shown).

In case that unpolarized light coming from the illumination system 3 is incident on a polarizing beam splitter 9, approximately half of said light is sent to the modulation system comprising, in this Figure, three reflective light valves 11, 13 and 15, one for each primary color. The other half of the light beam coming from the illumination system 3 will be lost.

In case that the illumination opics 7 comprise a polarization converting system (PCS), the light beam from the light source will have been converted into a light beam having substantially the same polarization direction. In that case, the polarizing beam splitter acts as a folding element. The more perfect the PCS has converted the unpolarized light into polarized light, the less light will be lost at the polarizing beam splitter.

Consequently, the light beam bent by the polarizing beam splitter is incident on a color-separating element 17. Said element 17, of which the shown embodiment is also called in plumbicon prism, comprises three prisms 19, 21 and 23. At a first interface 25, the white light beam b_w from the illumination system is split up is a blue sub-beam b_b and a red-green sub-beam b_{r+g}. At a second interface 27, the red-green sub-beam b_{r+g} is split up in a red sub-beam b_r and a green sub-beam b_g. Each of the sub-beams b_r, b_b and b_g is incident on a respective reflective light valve 11, 13, 15 which is suited to modulate the light incident thereon.

After modulation by the light valves 11, 13 and 15, the modulated sub-beams are recombined by the element 17. Said element 17 now performs the function of a color-recombining element. In case the light valves are polarization modulating light valves, the parts of the combined modulated beams which have to result in bright parts in the image are subsequently transmitted to the projection lens system 29. The polarizing beam splitter then acts as an analyzing polarizer.

One of the problems in an image projection system as described above is, that due to an oblique incidence of the beams to be color-separated or color-recombined on the interfaces of the element 17, the polarization directions will change because the transmission of the color-separating and recombining surfaces is polarization dependent. This difference and variation in transmission results in a low contrast and color deviations in the image.

Figure 2 illustrates, for a color-separating or color-recombining interface, the transmission as a function of wavelength for s-polarized and p-polarized light. In a certain wavelength range, the difference in transmission is relatively small ($\Delta T1$), while at the edges of said range the difference becomes much larger ($\Delta T2$).

The present invention overcomes said drawbacks by providing at least one polarization-compensating element 31, 33, 35 between the element 17 and the light valves 11, 13, 15.

Figure 3 shows an embodiment of an image projection system 10 according to the present invention.

Contrast and color balance of the image can be further improved by providing a polarization-compensating element 37 between the color-recombining element 17 and the polarizing beam splitter 9.

A preferred embodiment of such polarization-compensating elements 31, 33, 35 and 37 is a birefringent element or a combination of birefringent elements.

The sensitivity of the color-separating and recombining element with respect to the viewing angle may vary for the vertical and the horizontal viewing direction. In that case, the birefringent element preferably has a biaxial symmetry. If there is moreover a difference between the positive and the negative viewing directions, the birefringent element preferably has a tilted optical axis.

Birefringent elements as mentioned above are commercially available from a.o. Nitto Denko and Fuji Film.

CLAIMS:

1. An image projection system comprising an illumination system, a modulation system having at least two reflecting image display panels of the non-diffusing type for modulating light generated by the illumination system in conformity with image information to be projected, and a projection lens system, the image projection system comprising an element having a color-separating as well as a color-recombining effect, and a polarizing beam splitter which is situated between the illumination system and the element and between the element and the projection lens system, characterized in that at least one polarization-compensating element is situated between the element and the image display panels.

2. An image projection system as claimed in claim 1, characterized in that at least one polarization-compensating element is situated between the polarizing beam splitter and the element.

3. An image projection system as claimed in claim 1 or 2, characterized in that the polarization-compensating element is a birefringent element.

4. An image projection system as claimed in claim 3, characterized in that the birefringent element has a biaxial symmetry.

5. An image projection system as claimed in claim 3, characterized in that the birefringent element has a tilted optical axis.

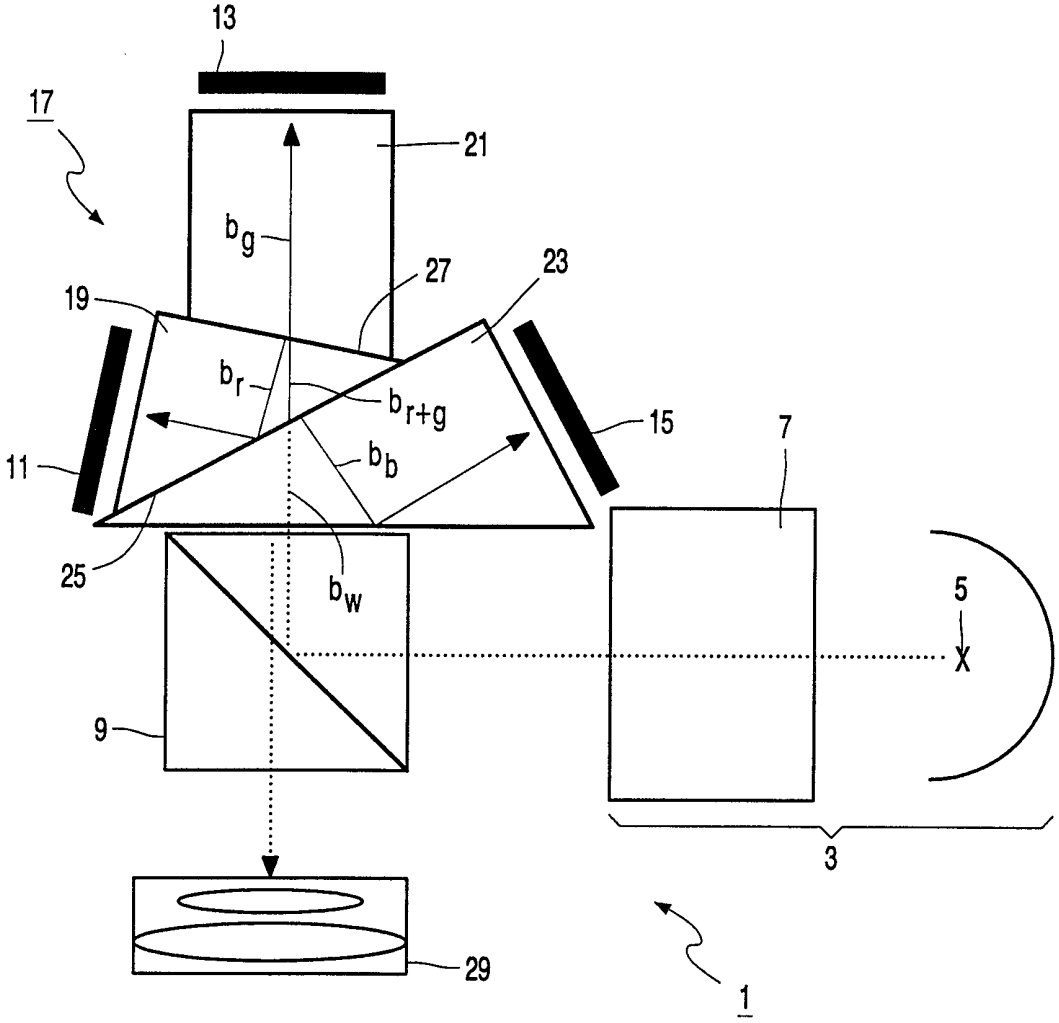

FIG. 1

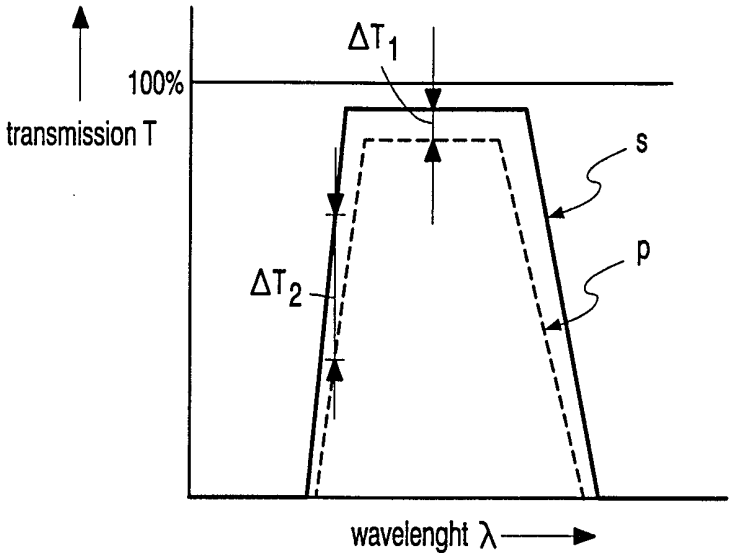
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FIG. 2

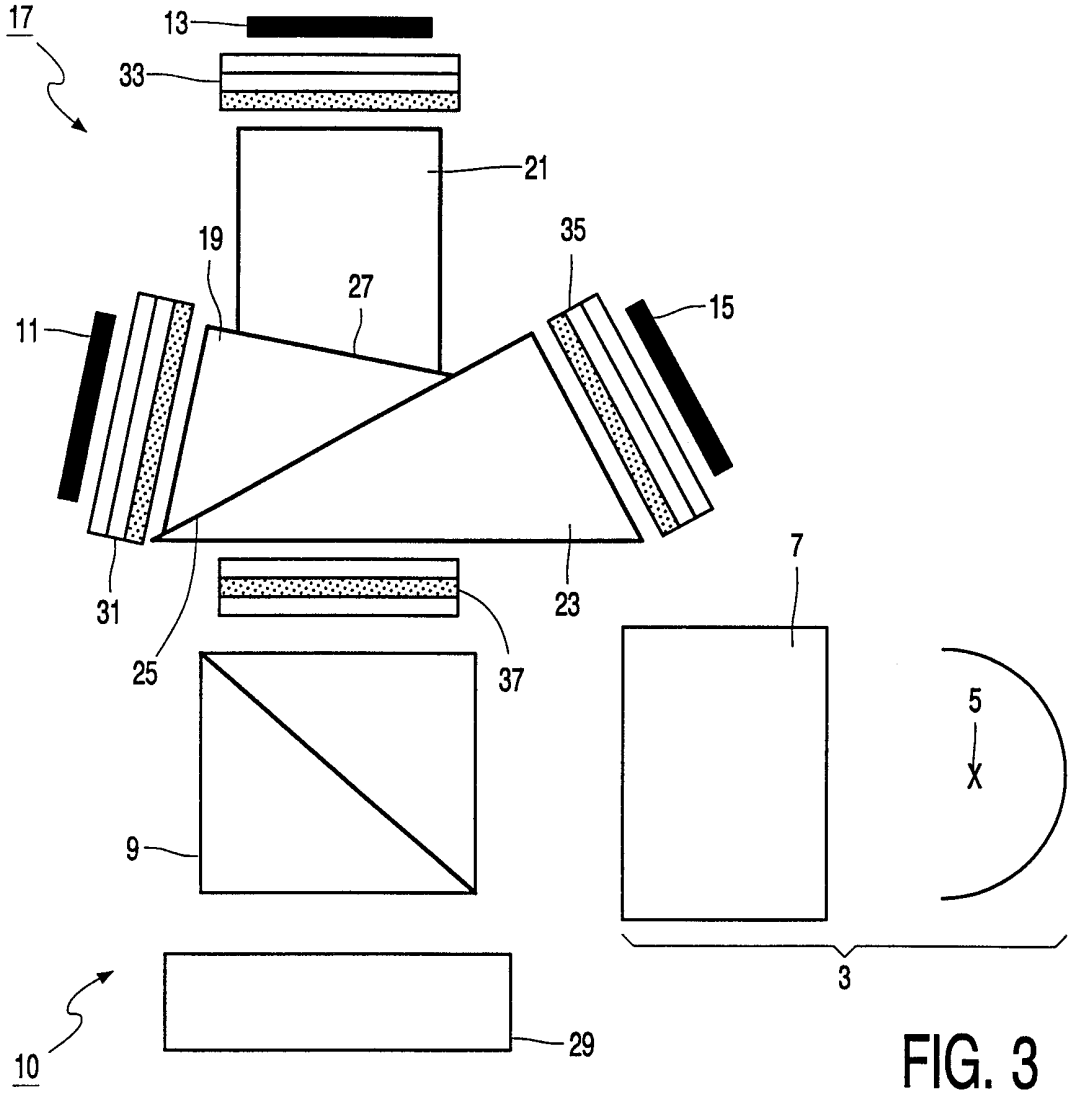
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FIG. 3

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IB 99/01224

A. CLASSIFICATION OF SUBJECT MATTER

IPC6: G03B 33/12, G02F 1/03
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)

IPC6: G03B, G02B, G02F

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

SE,DK,FI,NO classes as above

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

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C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP 0436924 A2 (HONEYWELL INC.), 17 July 1991 (17.07.91) --	1-5
A	EP 0734183 A2 (INTERNATIONAL BUSINESS MACHINES CORPORATION), 25 Sept 1996 (25.09.96) --	1-5
A	EP 0295137 A1 (SHARP KABUSHIKI KAISHA), 14 December 1988 (14.12.88) --	1-5

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Information on patent family members

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International application No.
PCT/IB 99/01224

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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