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Burstyn

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[54] **PENTAPRISM COMBINER/SPLITTER**

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[51] **Int. Cl.**[6] **G02B 27/14**; G02B 5/04

[52] **U.S. Cl.** **359/634**; 359/636; 359/834

[58] **Field of Search** 359/634, 636, 359/831, 834

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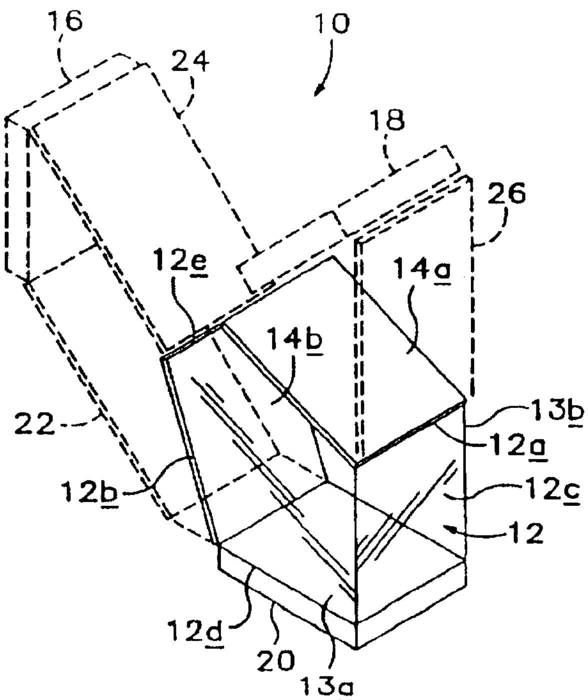
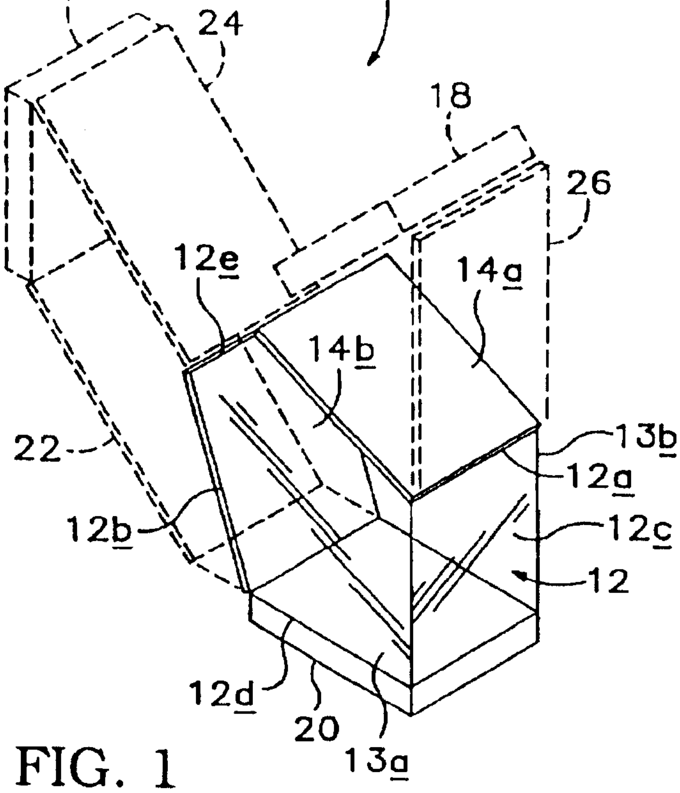
[57] **ABSTRACT**

An optical engine for combining or splitting color light beams, compatible with modern high-speed projection systems, is described. The invention utilizes a unique pentaprism core element, partially bounded by five faces, two each on either side of a plane of bilateral symmetry and one opposite, bisected by the plane of bilateral symmetry. Two of the faces of the pentaprism are coated with dichroic films. Functioning as a light combiner, the pentaprism uses these dichroic surfaces and its geometry to interact with incoming tri-color light beams which, after first passing through appropriately modulated light valves, are selectively transmitted and reflected such that all beams exit, axially aligned, from one side of the pentaprism. Functioning as a light splitter, the pentaprism uses the dichroic surfaces and its geometry to split a white light beam into its component primary colors and pass these colors out of the pentaprism. Turning mirrors are used to direct the tri-color beams into or out of the pentaprism region at the necessary angles for proper operation. The turning mirrors are configured to increase compactness of the optical engine while maintaining nearly equal path lengths for all of the tri-color beams.

27 Claims, 2 Drawing Sheets




16
10
24
18
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12e
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13b
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12c
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12d
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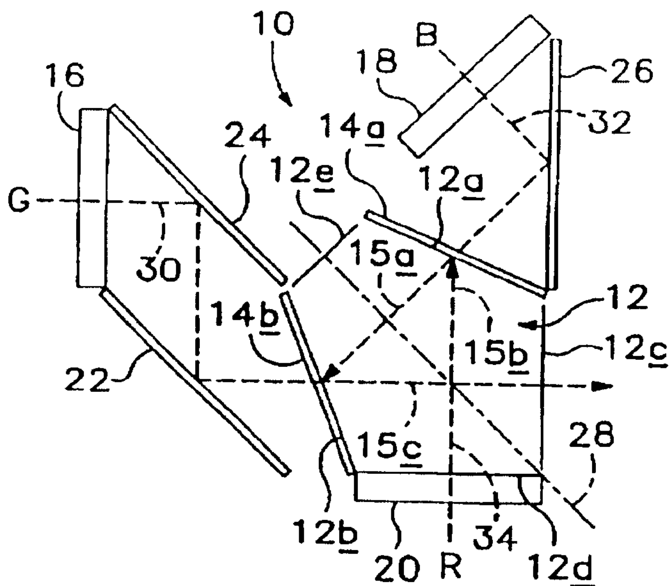
13a

FIG. 1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R
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FIG. 2

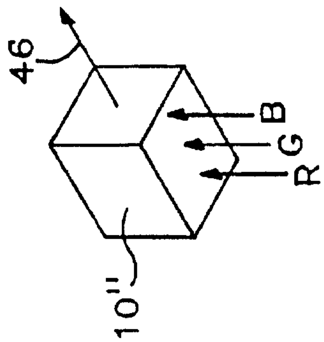

FIG. 5

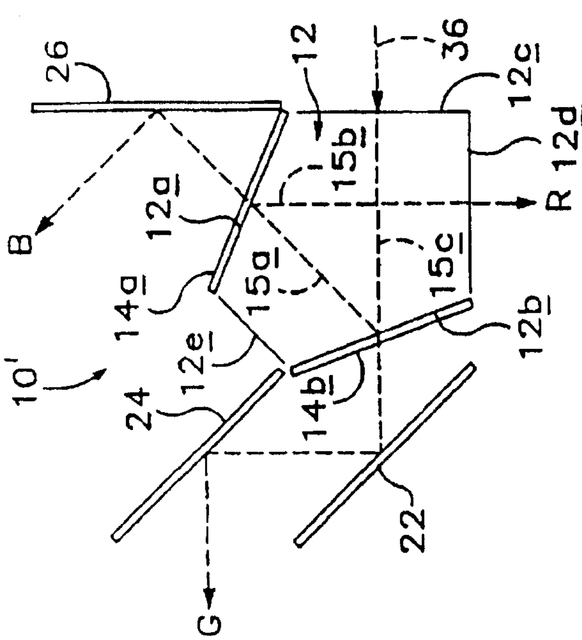

FIG. 3

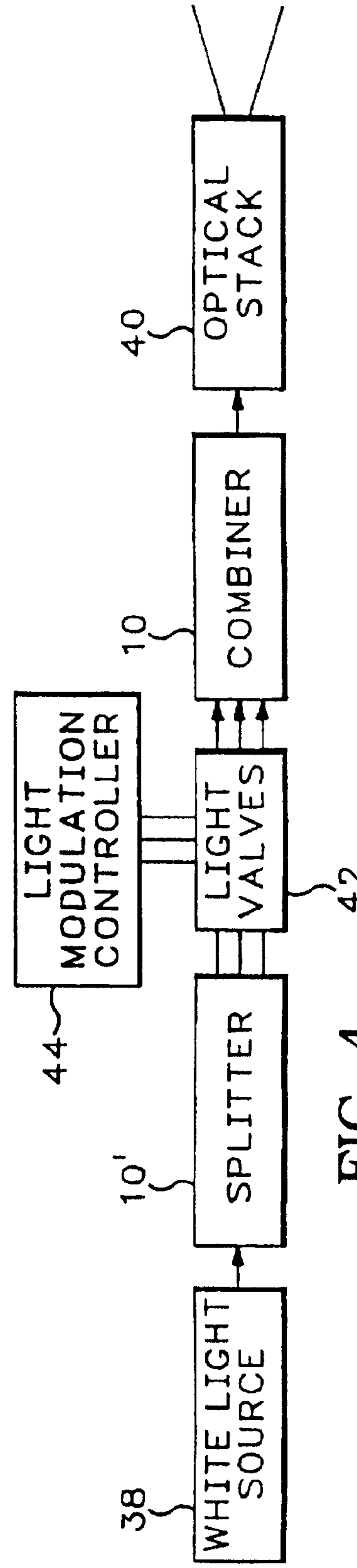

FIG. 4

PENTAPRISM COMBINER/SPLITTER

BACKGROUND AND SUMMARY OF THE INVENTION

This invention pertains to what can be thought of as a dual-operating-mode optical engine that is capable of functioning bidirectionally both as an optical combiner and as an optical splitter respecting the relationship between so-called white light and the primary components thereof—red, green and blue light. In particular, the invention relates to a unique, compact, single-piece pentaprism element which forms the core optical component of the engine and which functionally is compatible with the high speed of modern projection systems without requiring the use of problematic high-index glass.

Conventional color combiners, for example, exist primarily in one of two forms—the ladder configuration and the so-called Phillips prism configuration. The standard ladder configuration uses dichroic elements oriented at 45-degrees to incoming light beams to achieve color combination. If the dichroic elements are implemented as dichroic films coated on plates, aberrations such as astigmatism and coma may become a problem. Also, the typical high angle of incidence between such dichroic films and impinging light beams decreases both transmission and reflection efficiency, and as a result, the combiner becomes incompatible with the brightness requirement typically specified for a high-speed projector system. Similarly, a Phillips prism system, if configured without the use of an appropriate high-index glass, is incompatible with high-speed projection systems utilizing field lenses to achieve compactness due to total internal reflection ("TIR") failure. This can be overcome through the use of high-index glass prisms, but such prisms suffer several inherent problems, such as a tendency to chip, poor transparency in the blue range, and unwanted dispersion which characterizes the performance of high-index glass.

A general object of the present invention, accordingly, is to offer a unique, compact, high-efficiency optical engine which avoids the kinds of drawbacks and difficulties just suggested above, and which offers all of the advantages that are sought in relation to sophisticated high-speed projection systems.

According to a preferred embodiment of the present invention, the engine proposed thereby employs, as its core element, a unique low-index glass pentaprism, on a pair of faces in which are coated dichroic films, combined with other optical elements that are arranged in a selected geometrical configuration which can achieve color separation/combination without the use of TIR, and its attendant problems thereto. The body of the pentaprism element, in its interior, defines what is referred to herein as a light-modification region, alternatively called a light-integration and light-separation region, and in this region, where light beams impinge upon the two faces in the pentaprism which are dichroically coated, the angle of incidence on both sides of the faces is much lower than the typical 45°. In the embodiment specifically described and illustrated herein the angle of incidence is more in the nature of about 22½°.

The novel pentaprism element proposed according to the invention is a single-piece element, alternatively called a solid prism assembly, and by virtue of that fact, offers the important is advantage that it contains no internal optical boundaries or discontinuities which require light beam transition and the opportunity for potential problems.

Combined in the overall engine with the dichroically coated pentaprism element are plural light valves, three to be

specific, with one provided for each of the three primary beam colors of red, blue and green. These light valves sit in the appropriate paths for these beams, and are operable, for example under computer control, to respond to appropriate image-containing data streams that are relevant to each of these three colors.

In addition to the several important features and advantages just mentioned above, the engine proposed by this invention, cored as it is by the unique pentaprism mentioned, affords the opportunity for selective construction of an engine with different possible configurations, each of which promotes compact, efficient, and relatively low-cost construction.

Further, the use of the core, single-piece pentaprism effectively reduces to zero the requirement for tedious and painstaking optical alignments of the type which attend the set-up and use of many prior art systems.

These and other objects and advantages that are attained by the invention will become more clearly understood and apparent from a consideration of the accompanying drawings when viewed in light of the text material which now follows.

DESCRIPTION OF THE DRAWINGS

FIG. **1** is a simplified isometric view illustrating a preferred embodiment of the system in which, at the upper and left sides of this view, certain components present in the system are shown in dashed lines to afford a clearer view than might otherwise exist of what has been referred to above as the central optical pentaprism element in the system.

FIG. **2** is a view, on a slightly smaller scale than FIG. **1**, taken generally from the lower left side of FIG. **1**, with all of the main structural components in the system/engine shown in solid lines. FIG. **2** illustrates the system/engine of the invention being employed as a combiner of red, blue and green light beams.

FIG. **3**, which is drawn on substantially the same scale as FIG. **2**, pictures the system/engine being employed as a splitter of white light into red, blue and green components.

FIG. **4** is a block/schematic diagram illustrating a projector which utilizes two engines constructed in accordance with the present invention—with one functioning as a light splitter and the other functioning as a light combiner.

FIG. **5** is a very simplified and schematic isometric view illustrating generally a configuration of the engine/system performing as a light combiner, wherein incoming red, blue and green light beams approach the engine from the same direction along parallel axes (which might be thought of as being contained generally in one plane), with emergent, combined white light exiting orthogonally in the same plane.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENT OF THE INVENTION

Turning now to the drawings, and referring initially to FIGS. **1**, **2** and **3** collectively, indicated generally at **10** and **10'** are two versions (reverse-directionally related) of an optical system, also referred to herein as an optical engine, each of which is constructed in accordance with a preferred embodiment of the present invention. In quick summary, engines **10**, **10'** include, as what is referred to herein as a central element, a unique low-index glass pentaprism **12**, on faces **12*a*** and **12*b*** in which are provided dichroic coatings **14*a***, **14*b***, respectively. These coatings are alternatively called dichroic surfaces and dichroic films, and as can be seen they are disposed at acute angles relative to one other. The dichroic surfaces function in a manner that will be described shortly.

Engine **10** further includes first, second, and third conventionally available light valves **20**, **18**, **16**, respectfully, alternatively called optical elements, light-modulation structures and pixelating light-valve structure. No such light valves are present in engine **10'**. Included in both engines **10**, **10'** are three conventional turning mirrors, **22**, **24**, **26**, alternatively called reflective surfaces and reflective coatings, whose functions also will shortly be described.

Engines **10**, **10'** further include and define a first optical path segment **15*a*** extending between faces **12*a*** and **12*b*** and normal to a plane of bilateral symmetry (that will be described shortly below) and second and third optical path segments **15*b*** **15*c***, respectively, disposed at oblique angles to that same plane of bilateral symmetry. Segment **15*b*** extends as shown between face **12*a*** and the plane of bilateral symmetry and segment **15*c*** extends between face **12*b*** and the plane of bilateral symmetry. The geometrical composite of optical path segments **15*a***, **15*b***, **15*c*** takes the form of a right triangle.

Focusing attention on FIG. **2** among these three figures, indicated by dash-dot line **28** is what has been referred to herein above as a plane of bilateral symmetry which characterizes a geometric feature of pentaprism **12**. As can be seen in FIG. **2**, on one side of this plane are a first and second face **12*a***, **12*c***, respectively, and on the other side are a third and fourth face **12*b*** **12*d***, respectively. A fifth face **12*e*** in the pentaprism is bisected by normally intersecting plane **28**.

Another way of looking at the central pentaprism of the invention is to envision an optical plane through which the red, blue, and green light beams transmit, best thought of as the plane of FIG. **2**. Then, as can be envisioned from FIG. **1**, this plane would be in-between, and parallel to, spaced-apart end surfaces **13*a*** and **13*b***, with faces **12*a***, **12*b***, **12*c***, **12*d***, and **12*e*** being transverse to the optical plane. If the optical engine were being used as a combiner, for example, light would enter through three of the faces, be combined within the pentaprism, and exit a fourth face, thereby leaving a fifth face optically inoperative.

Continuing with attention focused principally on FIG. **2**, let us now consider how engine **10** performs as a light combiner. Through any suitable means and organization which is not relevant to the core of the present invention, green, blue and red incoming light beams are presented, and these are shown by dashed lines **30**, **32**, **34**, respectively. As pictured in FIG. **2**, these three beams are generally coplanar and lie within the plane of FIG. **2**. Green beam **30**, labeled G, enters from the left side of FIG. **2**, passes (when permitted) through light valve **16**, is reflected 90° by mirror **24**, is reflected again 90° by mirror **22** into a path which parallels its incoming path, passes through face **12*b*** and coating **14*b*** (at a low angle of incidence-about 22½°), and then passes directly, and straight through, the pentaprism as illustrated. In connection with this remark about passing straight through the pentaprism, one will recognize that, with the engine of the invention being used as a combiner, what emerges from the pentaprism is a combined beam, axially aligned, that includes elements drawn from all three of the incoming beams. It is noted that the green, blue and red beams traverse an isosceles triangular path within the interior region of the pentaprism. The length of a shorter side of this triangle is of length X, as indicated in FIG. **2**, and represents the length of the traverse on the isosceles triangle of the green light beam.

Further with respect to the path followed by the beam of green light, measured from where the beam emerges from what can be thought of as the exit face of valve **16** (the right side of thereof is, FIG. **2**) to the point along that path where it exits the pentaprism at face **12*c*** this overall length is called the green-beam path length. An interesting feature of the present invention is that the path lengths, so defined, for all three beams, including each of the other two beams (blue and red), are substantially identical.

The beam of blue light **32**, labeled B, enters angularly from the upper side of FIG. **2**, passes (as permitted) through light valve **18**, is reflected 90° by mirror **26**, passes through coating **14*a*** and prism face **12*a*** (at substantially the same low angle of incidence mentioned above), is reflected and turned (at the same low angle of incidence) by dichroic coating **14*b***, and emerges from the side **12*c*** of the pentaprism as a portion of the combined output beam, and along the same final portion of the path followed by the green beam. The beam of blue light may be seen to traverse two sides of the triangle described above, over a length thereon of approximately 2.4X. Reinforcing the notion that path lengths are equal, the overall blue-beam path length is measured from the point at which the beam emerges from the downstream side of valve **18** (the underside thereof in FIG. **2**) to the point where the beam emerges from face **12*c*** in FIG. **2**.

Completing a description of the "combining" performance now being described in relation to FIG. **2**, red beam **34**, labeled R, enters from the bottom side of the figure, passes (as permitted) through light valve **20** to enter the underside of prism **12** in FIG. **2**, is reflected and turned (at substantially the same low angle of incidence mentioned repeatedly above) by dichroic coating **14*a***, is reflected and turned again, and at the same low angle of incidence, by dichroic coating **14*b***, and then passes through prism face **12*c*** to exit along the same final portions of the paths followed by the previously described green and blue beams -- thus to form the final, combined, constituent in the output combined beam. The beam of red light may be seen to traverse all three sides of the triangle described above, over a length thereon of approximately 3.4X. The overall path length followed by the red beam is defined as that length between the point at which the beam exits or emerges from the downstream side of valve **20** (its upper side in FIG. **2**) to the point where it exits face **12*c*** of prism **12**.

Having thus described how engine **10** performs as an optical combiner, let us turn attention now to FIG. **3** which shows the other, reverse mode of operation where engine **10** functions as a light splitter. When engine **10'** is employed in this mode, no light valves are required, and accordingly, FIG. **3** omits a showing of these valves. It does, however, contain the turning mirrors previously described. Those skilled in the art will recognize that no fresh, elaborate discussion is required to explain what really is occurring in the splitting activity pictured in FIG. **3**. The white-light beam to be split enters as indicated by arrowhead **36** at face **12*c*** of prism **12**, experiences internal low-angle of incidence reflection from coating **14*b*** (with respect to the red and blue components) while **15** passing the green component through and out of the system via turning mirrors **22**, **24**. The blue component passes through coating **14*a*** to exit the system after striking turning mirror **26**, and the red component exits downwardly in FIG. **3** through the prism after low-angle of incidence reflection from coating **14*a***. The exiting, separated light beams are alternatively called substantially monochromatic light beams.

With attention now directed to FIG. **4**, and as was mentioned above in the description of the drawings, here

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