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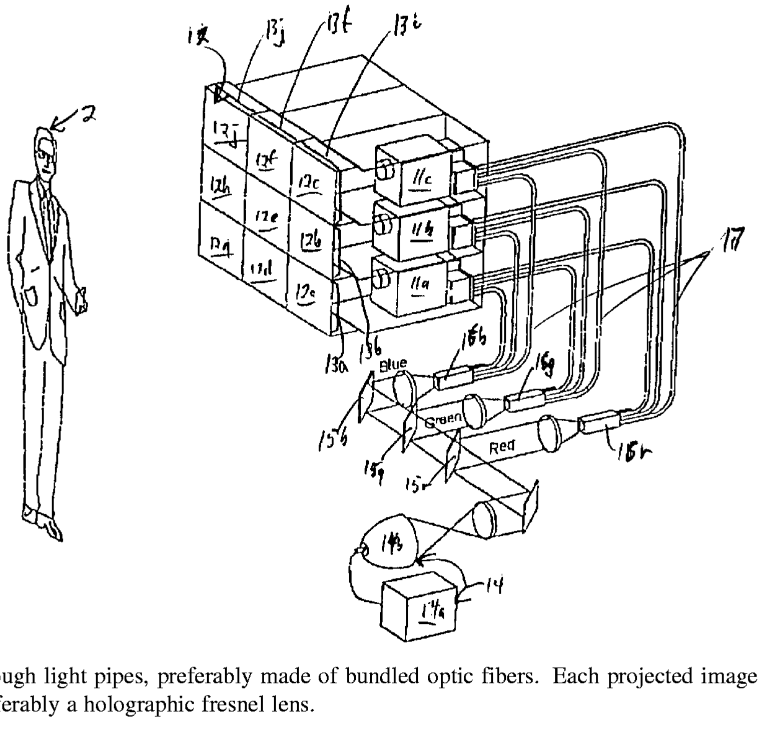
(54) Title: VERY-LARGE-SCALE VERY-HIGH-RESOLUTION MULTIPLE-PROJECTOR TILED DISPLAY WITH UNIFORM INTENSITY, COLOR TEMPERATURE AND COLOR BALANCE THROUGHOUT BY USE OF A SINGLE LIGHT SOURCE FOR EACH COLOR; INTENSITY AND SPECTRAL MANAGEMENT IN ALL LIGHT PATHS; AND OPTIONAL FRESNEL LENSES BEHIND EACH DISPLAY TILE



(57) Abstract: Multiple projectors, each preferably of a .9 inch (or larger) 1365 x 1024 pixel (or greater) active matrix liquid crystal type located in an array, serve to project a common light: typically asingle 1.6 kW xenon arc, incandescent High Intensity Discharge (HID) or laser light as may optionally pass through dichroic filters; to produce from multiple tiled segments: each typically twenty-one inches (21") in the diagonal; a high-resolution; normally 75 dpi or greater; seamless ultra-bright large or very large image, normally some meters or greater in diagonal measurement. Use of the single light source accords uniform and stable: (i) illumination intensity; (ii) color temperature; and (iii) color balance between and throughout all image segments, giving a high quality composite image suitable for scientific research, control rooms or electronic cinema. The light is preferably conducted to the multiple projectors through light pipes, preferably made of bundled optic fibers. Each projected image tile preferably passes through a fresnel lens, preferably a holographic fresnel lens.

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VERY-LARGE-SCALE VERY-HIGH-RESOLUTION MULTIPLE-PROJECTOR TILED DISPLAY WITH UNIFORM INTENSITY, COLOR TEMPERATURE AND COLOR BALANCE THROUGHOUT BY USE OF A SINGLE LIGHT SOURCE FOR EACH COLOR; INTENSITY AND SPECTRAL MANAGEMENT IN ALL LIGHT PATHS; AND OPTIONAL FRESNEL LENSES BEHIND EACH DISPLAY TILE

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RELATION TO A PROVISIONAL PATENT APPLICATION

The present patent application is descended from, and claims benefit of priority of, U.S. provisional patent application Serial No. 60/227,935 filed August 25, 2000, for LARGE-SCALE HIGH-RESOLUTION UNIFORM-INTENSITY COMPUTER DISPLAY USING ONE LIGHT SOURCE to inventors including the inventors of the present invention.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention generally concerns computer-driven multiple-projector tiled displays.

The present invention particularly concerns large-scale and very-large-scale multiple-projector computer-driven tiled displays where the image tiles arise from multiple projectors using reflective-mode active matrix liquid crystals, commonly referred to in the industry as "LCOS (liquid crystal on single crystal silicon) displays".

The present invention still more particularly concerns both (i) the origin, and (ii) the management, of colored light beams that are both used by, and, in combined form, projected from, multiple projectors, all to the end that the image tiles of a displayed composite image should be devoid of visually perceptible and objectionable artifacts.

The present invention still further concerns the use of fresnel lens in the optical paths of a multi-projector tiled display.

2. Background of the Invention

2.1 General State of the Art in Large Scale Computer Displays

Computer and network technologies have enjoyed a rapid expansion for the last few decades. Computer chip speeds and network and data archive capacities have advanced geometrically, with an aggregate improvement of roughly 10^6 over the past twenty-five 25 years. In contrast, computer display technology has improved more gradually until recently (i.e., until a few years before present year 2001).

Desktop displays have only recently shown modest improvements beyond one megapixel (1 Mpixel) capacity. At the same time microelectronic manufacturing developments have led to widespread availability of thin-film Liquid Crystal Display (LCD) panels at reasonable costs. Thus, LCD display elements are now used in digital video and data projectors with resultant improvements in performance, flexibility and cost.

Meanwhile, the scale of experimental data and of numerical output from supercomputer simulations has grown substantially. There is a present need for computer displays with capacities above 10 Mpixels so that the data outputs of advanced computing systems can be balanced with their user interfaces.

There is, for example, a need to analyze and visualize large scale scientific data, such as that associated with planetary scale oceanographic simulations. See Wunsch, K. and Stammer, D. on the World Wide Web at: <http://www.npaci.edu/enVision/v14.3/wunsch.html>.

Alternatively, consider the display of 8.5 Mpixels images recently created for the new Hayden Planetarium space show, "Passport to the Universe". See Hayden Planetarium on the World Wide Web at <http://www.amnh,org/ROSE> (January, 2000).

Oceanographic visualizations have a natural "landscape" aspect ratio and are well suited to a 3000 x 1000 pixel, or larger, display. Otherwise it is impossible to view simultaneously the localized turbulent zones within the larger oceans on a standard monitor.

Other immediate uses for large scale displays include medical and geographic imaging.

One way to increase the screen capacity (commonly called "resolution") of a computer display is to "tile" several image projectors, yielding a larger composite image. Examples include the so-called PowerWalls and "Visionariums" capable of 3 - 12 Mpixels. See Woodward P., et al. on the World Wide Web at: <http://www.msi.umn.edu/Projects/woodward/powerwall/powerwall.html> (1994). See also Van Dam A., et al. IEEE Computer Graphics & Applications, 20(6), p. 26-52 (November 2000).

These displays often require purpose-build installations; typically a 2-story room with a 10 meter diagonal screen costing up to US $3M (circa 2001). Over the past decade these higher capacity computer displays have become available -- but only in limited-access such as the US DOE labs, NASA's JPL and some U.S. national supercomputer centers. See Woodward P., supra, and also Schikore D.R., Fischer, R. A., Frank R., Gaunt, R., Hobson, J. & Whitlock, B., IEEE Computer Graphics & Applications 20(4), p. 38-44 (July, 2000).

Experimental, lower cost systems are now (circa 2001) being developed at Princeton. See Funkhouser T. and Li K., (guest editors) IEEE Computer Graphics & 20(4), p 20-76 (July, 2000). See also Li K.; <http//www.cs.princeton.edu/omnimedia>.

Experimental systems are also being developed at Stanford. See Humphreys G., Hanrahan P., Proceedings of IEEE

Visualization'99, p 215-223 (1999). See also Hanrahan, P.; <http://;www.graphics.stanford.edu/projects/multigraphics/>.

Finally, an experimental system is also being developed at the Argonne National Lab. See Hereld M., Judson I., Stevens R., IEEE Computer Graphics & Applications 20(4), p. 22-28 (July, 2000)

All these systems have limited image quality and uniformity. Existing display systems use tiled projectors each incorporating an associated, independent, light source. However, two projectors are not alike when displaying the same image due to (i) variability of manufactured components and (ii) differential aging rates of each projector's lamp. This leads to differences in both intensity and color, due to factors such as differences between the dichroic filters or the light sources of the projectors.

Multi-projector display systems of existing construction require laborious and repeated balancing of illumination, color temperature and color balance between projectors, and between the image tiles produced by the projectors. Limitations in the accuracy, and the maintainability, of these adjustments degrades the overall image uniformity and quality, as is especially visible at the borders between the tiles. The overall fidelity of a computer-generated large-scale tiled image currently (circa 2001) lags the fidelity of, by way of example, a motion picture film as might be projected in a theater.

The present invention will be seen to address, and to solve, issues of variation in illumination and color uniformity within and between the multiple tiles of a computer-generated tiled large-scale (and very-large-scale) display. Nonetheless to dramatic improvements in the uniformity of illumination, color temperature and color balance, display systems in accordance with the present invention retain the desktop/workbench size (fitting in a normal room) of, and are not appreciably more costly than, the more advanced predecessor systems.

2.2 D-ILA Projector Technology

The present invention will be seen to use a number of high-resolution large screen projection computer displays tiled so as to produce in combination a very large display. The displays are preferably reflective-mode active matrix liquid crystal displays -- commonly referred to as LCOS (liquid crystal on single crystal silicon) in the industry -- and are more preferably D-ILA™ LCOS displays from JVC (D-ILA is the trademark of JVC for its proprietary reflective-mode active matrix liquid crystal display technology). Such D-ILA projectors are commercially available in year 2001 from JVC; for example as JVC G15 and M4000 Models.

For the sake of completeness of this disclosure, D-ILA this technology is explained hereafter as drawn from the paper "D-ILA Projector Technology: The Path to High Resolution Projection Displays" written by W. P. Bleha of JVC. For the purposes of the present invention it is sufficient only to know that displays using this technology each have a single light source, for example a xenon arc lamp, as, indeed, do other display technologies suitable for use with the present invention.

The D-ILA technology of JVC is used in high-resolution large screen projection displays as, according to JVC, promise to revolutionize the high-resolution projection display market both in virtual personal displays and in personal and group projection displays. This prediction is asserted to be based on at least five inherent advantages of LCOS display design and manufacture over competing technologies.

First, there exists wide spread capability in semiconductor foundries to fabricate the single crystal silicon back plane for LCOS displays. Design rules for such displays are not typically at the state of the art; thus well-established foundries with largely amortized capital costs are well capable of economically making the back plane. The investment for BEOL "(back-end of the line)" LC processing is minimized by the use of processes and equipment developed for the high volume flat panel LCD market. This leads to lower cost/pixel in display production than any other emerging technology.

Second, the unique high performance and small dimensions of single crystal silicon back plane circuitry allows a high level of integration of driver and processing circuitry. This is coupled with the high electro-optic efficiency and reliability of liquid crystal materials.

Third, LC technology, in contrast to micromirror technology, offers adaptability and scalability in pixel size and aspect ratio can be readily adjusted to meet optical system requirements. In fact, designs have been fabricated that change pixel size and shape on a single device over the area of the device to correct for optical system aberrations.

Fourth, high performance reflective-mode displays fill the display surface with closely spaced pixel elements, thus minimizing the pixel border "screen door" look of transmissive LCD displays. The close spacing of the pixels and the ability to block light from the circuitry also permits high luminous output, sufficient to cover a gamut of applications.

Fifth, thermal stability of the silicon back plane can be controlled across the entire aperture for stability and reliability in operation. Ultra-bright systems are possible. The JVC D-ILA device, or display modulator, typically has a display aperture of only 0.9 inches. This technology, called the "Direct Drive Image Light Amplifier", is a reflective liquid-crystal design where electronic signals are directly addressed to the device. The light valves use active matrix addressing of the liquid crystal to achieve the spatial modulation. The active matrix consists of (i) an array of electrical switches in the form of MOS transistors, and (ii) addressing electronics. The sources and drains of the transistors are connected to the columns and pixel electrodes. The gates of the transistors are connected to the row electrode. The electrical image signal is sampled successively into a sample-and-hold circuit (S/H) in the columns. Eight contiguous columns are sampled by one S/H register. When a full line of data has been sampled, a row electrode is enabled, opening the channels of all the transistors on this selected row. The charges on the S/Hs are transferred to the capacitance of the corresponding pixel. The gate pulse is then removed, isolating the charge. The process is repeated for successive rows. The image information is updated at the vertical refresh rate. Since the nematic liquid crystal responds to voltage level directly, the gray scale is determined by the value of voltage set on each pixel. This reduces the data rates required to address the multi-gray levels sequentially as in the case of bi-stable devices such as the DMD, and thus reduces the required data rates and thus driver complexity.

The JVC D-ILA X-Y matrix of pixels is configured on a C-MOS substrate using the planar process standard in IC technology. Each pixel is covered, except for a small border, with an aluminum reflective pixel electrode. The driving transistor is connected to this reflective pixel electrode. The homeotropic (vertically aligned) liquid crystal is sandwiched between the reflective pixel electrode and continuous transparent ITO electrode. The thickness of the liquid crystal layer is ~3 micrometers. The liquid crystal material has a negative dielectric constant necessary for homeotropic alignment and low viscosity for video-rate response. The voltage applied to the selected pixel of the matrix makes the liquid crystal above the pixel change birefringence and thus modify the polarization state of the projection light in the D-ILA. See the discussion in the section on D-ILA projector technology, following. Ordinary transmissive active matrix LCD panels block projection light because of driving transistors, gate lines and signal lines that reside in the light path. The blocked light is converted to heat, thus raising the temperature of the device. There is no effective way of removing this heat load except through increasing the size of the panel. Overall light output is further constrained by the fact that the sheet polarized filters used by the systems also absorb light and cause further generation of heat.

A typical display area of the JVC D-ILA device is 0.907" diagonal with a 1365 (H) x 1024 (V) pixel array. The JVC D-ILA device can reproduce true SXGA images on a large screen with high brightness, high contrast and fast response time. A lightly doped drain structure is used in each pixel MOS transistor to improve the break down voltage. In operation the voltage applied to the liquid crystal at maximum transmission is 3.6 V. Three metal layers are formed on the silicon chip: the first metal layer for the driving circuit, the second for the light blocking layer, and the third for reflective pixel electrode. The 1365 x 1024 pixel electrodes of the array are 13.0 x 13.0 micrometers each in size, separated by 0.5 micrometers.

The D-ILA device can be driven with high speed image signals resulting from the high carrier mobility of the crystalline silicon. The reflectivity and light blocking structure of the silicon chip substrate are important factors in achieving a projected image of 4000 lumens. The pixel electrodes of the D-ILA device have a 93% aperture ratio, and have high intrinsic reflectivity. The insulating layers formed between each metal layer are made flat and smooth by chemo-mechanical polishing techniques. The final aluminum pixel mirror approaches a reflectivity of 91%. The light blocking layer is formed under the mirror electrode in order to prevent light leakage to the transistor located on the first metal layer in the silicon chip. Light leakage would activate the transistor. Each metal layer also has anti-reflective layers on both sides. A light-induced voltage drop in the pixel electrode could cause decreased projection light output due to decreasing liquid crystal modulation. With anti-reflection layers, JVC reports that no voltage drop was observed with over 4000 lumens light output in the projection system. JVC claims that it is possible to produce individual projectors with greater than 10,000 lumens using D-ILA devices.

Homeotropic alignment of the liquid crystal allows a high device contrast ratio in the visible light spectrum range since, in a tunable birefringence mode, the birefringence of the liquid crystal is near zero at the threshold off-state voltage. This allows the theoretically highest contrast ratio for any liquid crystal device. The liquid crystal molecules are aligned almost perpendicular to the surface with a small pre-tilt angle at off state. A low pre-tilt angle is the most important factor in achieving high contrast ratios and good quality in the projected image. In the homeotropic liquid crystal alignment there is a range of pre-tilt angles best suited for producing a high contrast ratio and a good uniform image without disclination. This is about a 1° pre-tilt. With this pre-tilt the intrinsic device contrast ratio for an f/4.8 optical system is greater than 2000.

This high device contrast ratio is ultimately limited by the optical system of the projector, in particular the polarizing beam splitters. In order to achieve a much higher contrast ratio, the use of a quarter wave plate "super contrast mode" can be used to eliminate a geometric cause of contrast ratio degradation in the polarizing beam splitters. This is discussed in the previous D-ILA projector technology section. D-ILA devices hare reported by JVC to have achieved greater than 1000:1 sequential contrast ratio in an optimized optical system using the super contrast mode.

The D-ILA device has a true video-rate response time (the rise time plus fall time equals less than 16 milliseconds). In general, the response time of liquid crystal layers is strongly related to the layer thickness. Reflective mode permits a thinner liquid crystal cell gap compared to transmissive mode LCD's because in this mode the light passes through the liquid crystal twice-effectively doubling the modulation. In addition the pre-tilt angle of liquid crystal is a determining factor for response time. The pre-tilt angle is set at a high enough value to avoid potential liquid crystal artifacts that can occur at very low tilt angles while maintaining video-rate response.

The thermal stability of the device is good. How the voltage versus transmission curve changes with various temperatures of T over a wide range of temperatures is a measure of how the light transmitted by the liquid crystal varies as a function of voltage driving each pixel. There is almost no change in the front slope of the V-T curves with temperature. This thermal stability of the device is required in high brightness projection systems so that ambient temperature variations do not change the image characteristics.

The D-ILA device has achieved true SXGA resolution, high brightness projection capability of 4000 lumens, a video-rate response time and a high 1000:1 (non-system) sequential contrast ratio.

In use of D-ILA devices in projectors, the driving IC controls the voltage across the liquid crystal layer between reflective pixel electrode and transparent electrode based on image signal level. This signal level determines the intermediate levels, or gray scale, of the image. Polarized light from the light source (Xenon lamp) passes through the activated liquid crystal and is reflected by reflective pixel electrode for each selected pixel.

The liquid crystal molecules change birefringence according to the signal voltage, changing the polarization direction of the illumination light. The optical system for a single device is the same as for RGB D-ILAs is the same. The light from the arc lamp is separated into two linear polarization states before it reaches the D-ILA. One state is reflected in the PBS and reaches the D-ILA device. In the JVC G15 and M4000 Models, a polarization combiner is used before the PBS to partially convert the second state into the first and increase the efficiency of the illumination by ~50%. Then the polarized light is reflected by pixel electrode and modulated by the liquid crystal again.

For pixels that have image information (highlight and gray level), the polarized light is rotated through 90° for highlight and partially rotated for gray level. The rotated light is transmitted through the PBS to the projection lens to be finally imaged on the projection screen. For the pixels that have no image information (black), the polarized light remains unchanged after leaving the D-ILA and then reflected back to the lamp by the PBS. The G Series D-ILA projectors from JVC have 3 devices for R (Red), G (Green), and B (Blue). Each device has its own PBS. The modulated output projection light from the 3 D-ILAs is combined by a crossed dichroic prism, which transmits the full color image to the projection lens for imaging on the projection screen.

In September 1999 JVC announced what they describe as a major breakthrough in the development of D-ILA technology. This is the SD-ILA (single D-ILA) for full color projection displays. The SD-ILA incorporates for the first time in a projection display a RGB color separating holographic filter that efficiently focuses the RGB components of full white spectrum of the projection light source on the RGB sub-pixels of each pixel. Previous single panel transmissive mode AMLCD projectors have used standard absorptive color dye filters where over 2/3 of the white light transmitted through each sub-pixel is absorbed to create the correct color of each sub-pixel. This inefficiency severely limits the advantages of the single panel configuration. The SD-ILA uses the same CMOS single crystal silicon reflective AMLCD technology as the D-ILA, including the homeotropic LC alignment. Thus a compact high resolution modulator with high performance is achieved.

The SD-ILA has 1028 (V) x 1280 (H) pixels or 1.3 M pixels (3. 9 M RGB sub-pixels) in a 1.22 inch modulator diagonal with a 16:9 aspect ratio. This is an impressive 6 times increase of the pixel density over a high-density conventional transmissive LCD projection panel. The first JVC product incorporating the SD-ILA is a 16:9 50-inch diagonal rear projection television. The use of a very wide-angle projection lens allows the rear projection unit depth to be 45 cm, which is less than a typical 21" CRT television monitor. The projection light source is a 200 W UHP lamp mounted in a vertical configuration to extend lifetime.

Advanced processing features include the following: Digital HD formats are reproduced. Ten-bit digital gamma correction achieves high quality image. High picture definition is realized with a newly developed (circa 2000) flat panel DPC-LSI, which converts NTSC images to a quality level equivalent to HD standards. Incorporating a newly developed interpolation technology, the flat panel DPC-LSI converts natural progressive 480p up to HD standards. The projection unit is equipped with 3-dimensional natural progressive scan. This processing doubles the density of scanning lines and plays back a smooth image without flicker or vertical line interference. It plays back any kind of scene naturally and clearly as it distinguishes among still images, slow moving images, and normal moving images and enhances each of them appropriately using JVC's exclusive motion adaptive 3-dimensional process that samples 3.3 million pixels. A feature called "Digital Super Detail" (DSD) calibrates contours according to the type of scene, and thus plays back an extremely sharp image.

Natural cinema function faithfully plays back film image sources. Through JVC's newly developed (circa 2000) projection technology, the image quality of telecine converted movie software is restored to original film quality, for clear reproduction of details. As the state-of-the-art SD-ILA technology graphically illustrates, multi-mega pixel modulators are possible with very compact D-ILA modulators. Thus it will be possible in the future to reach projection display resolutions, while maintaining highest picture quality, equivalent to 70 mm film. These remarkable developments will bring electronic projection technology into many new areas of image display. And, by using the latest developments of IC and LC technology, D-ILA systems will be produced with the highest performance and yields and the lowest cost pixel of any technology.

The D-ILA device specifications are, circa 2000, an effective Display area 18.468 mm (H), 13.878 mm (V); resolution 1365 (H) x 1024 (V) Pixel pitch 13.5 micrometer x 13.5 micrometer; sequential Contrast Ratio >1000:1 Aperture Ratio 93%; response time rise plus fall <16 msec.

Additional articles on active matrix liquid crystal displays include: 1. Atsushi Nakano, Akira Honma, Shintaro Nakagaki and Keiichiro Doi, "Reflective active matrix LCD: D-ILA." SPIE Proceedings 1998, Vol 3296, p. 100; 2. H. Kurogane, K. Doi, T. Nishihata, A. Honma, M. Furuya, S. Nakagaki, I. Takanashi, "Reflective AMLCD for Projection Displays: D-ILA", Society for Information Display International Symposium Digest of Technical Papers, Vol. XXIX, 1998, p. 33; 3. A. M. Lackner, J. D. Margerum, L. J. Miller, "Photostable Tilted-Perpendicular Alignment of Liquid Crystals for Light Valves," Society for Information Display International Symposium Digest of Technical Papers, Vol. XXI, 1990, p. 98; 4. R. D. Sterling, W. P. Bleha, "ILA Projectors for Advanced Applications" Proceedings of the International Display Workshops, 1997, p. 809; and 5. F. Tatsumi, S. Moriya, Y. Ishizaka, "Optical System Using 3 Pieces of D-ILA Panel Module," Proceedings of the International Display Workshops 1998, p. 753.

2.3 <u>Present Limits on the Size of any LCOS Projector Technology</u>

The well-established approach to making very large, and very, very large displays, on the order of meters and tens of meters diagonal dimension, has been to tile the images of a number of separate displays concurrently controlled to produce a composite image. Although each individual display of the array -- commonly 2x2 or 3x3 or even 4x4 in size -- may function quite well, the composite image may, and usually does, suffer from disconcerting artifacts.

Each of (i) illumination intensity, (ii) color temperature, and (iii) color balance over the area of the composite image may vary in accordance with the minor differences in manufacture, adjustment and age of the separate projectors. The human eye is very sensitive to these differences, and can typically readily discern the boundaries of each separate projector within the composite tiled image even if the mechanical registration of the separate pixelated images is perfect. If the mechanical registration is not perfect, than image artifacts serve to highlight such mis-registration as exists, making differences in the separate tiled images even more disconcerting, and objectionable.

2.4 <u>Use of a Fresnel Lens with an Image Projector</u>

It is known to use a fresnel lens, typically glass, in the optical path of an image projector for purposes of bending light that is within the light cone of a projected image so as to make light rays at the peripheral regions of this projected image will be more substantially co-parallel with light rays at central regions of the image; all light rays normally being adjusted so as to be orthogonal to a screen upon which the image is projected. The co-parallel light rays help to make that all regions of the image appear to be "painted" with equal intensity light and that, particularly, the peripheral regions of the image do not appear to be less intense, and darker, because of the divergence of light rays in these regions from the visual axis of the eye of a viewer located to the center fore of the image.

The present invention will be seen to use a fresnel lens, preferably of the holographic type, in the light paths of each of a number of image tiles projected by a corresponding number of projectors in a manner that is not known by the inventors to have previously occurred. The purpose of the normalization of intensity over the area of a single image tile is still served by each fresnel lens, but an additional purpose of preventing the light rays from a number of image tiles to intersect and overlap will also be seen to be served.

SUMMARY OF THE INVENTION

The present invention generally contemplates a uniform illumination high-resolution, multiple-projector-based tiled computer display. All projectors are illuminated by (1) a single, common light source for each color. The light that will be used for display by all projectors in all tiles starts as the same light, with the same intensity and color temperature.

Furthermore, the optical path of the light of each color as is distributed in parallel to all projectors incorporates (1a) a fiber optic beam splitting system, and (1b) a single, associated one of a set of red, green and blue dichroic filters. By these structures uniformity of each of (i) the intensity, (ii) the color temperature, and (iii) the color balance, of the colored lights is preserved to, and through, all projectors.

Still further, the present invention contemplates (3) use of a rectilinear fresnel lens behind each rectilinear tile of, and in, a multi-tile multi-projector computer display system. The fresnel lens serves to make that a conical light beam illuminating the rear of each display tile is passed through, and emitted to the front, each display tile in a direction substantially uniformly orthogonal to the plane of the tile. Viewers located to the front of each and all display tiles see co-parallel light rays of equal intensity from all regions of each display tile, and from all display tiles.

A multiple-tile computer display so constructed provides to and between all the arrayed projectors colored lights that are (1) each of uniform illumination intensity, (2) each of a single color temperature and a single color spectrum, and, for all the colored lights, (3) of equal color balance. Further, the light emission from the areas of each, and of all, tiles, is in the same direction. This equal illumination uniformly directed serves to produce a tiled image display with unprecedented image uniformity both between, and within, the tiles.

1. <u>Theory of the Invention</u>

The present invention more particularly contemplates (1) use of but one single source of light for each color in a multi-projector display system where a number of projectors selectively gate light so as to, in conjunction with other display projectors, form a composite, tiled, image; and (2) careful optical management of the colored lights each arising from but a single source. In accordance with the present invention, colored lights are each (1) from an associated single source, with distribution of the light of each and all colors in each and all light paths being (2) carefully handled so that no differences in intensity nor color temperature nor color balance arise.

The light emissions each from (1) an associated single colored light source are preferably narrowband, with a sharp and well defined spectral peak. The (2) careful handling first serves to multiplex light of each color from all spatial regions of its source to each and all of the projectors, and along an optical path of equal attenuation, making that each projector receives light of equal intensity. The spatial multiplexing of the light is done with optic fibers, as is the transmission along paths of equal length. The (2) careful handling also passes the light of each color through but one single dichroic filter (of a set of such filters) prior to transmitting the colored to each projector in parallel, with a recombination of the light of all colors occurring in a polarizing beamsplitter/recombiner in each projector. In accordance with the present invention, the passband of each dichroic filter is narrower than is the passband of the projectors' polarizing beamsplitter/recombiner. This makes that variations in the spectral passbands of the polarizing beamsplitters/recombiners of the projectors are inconsequential; all the narrowband colored light reaching each projector is therein recombined the same.

This (1) same light, (2) carefully handled so as to induce no variations, makes that when the colored lights are recombined in each of the projectors, and are used to produce the tiled image, then this image will bear no visually distinguishable, nor undesirable, artifacts in, or between, any of its tiles arising from variations in any of (i) illumination intensity (visible as image brightness), (ii) color temperature and stability (visible as image hue and chroma), or (iii) color balance.

Still further, the (3) rectilinear fresnel lens contemplated by the present invention serves, in its position behind each rectilinear tile of, and in, a multi-tile multi-projector computer display system, to make that a projected conical light beam illuminating the rear of each display tile is passed through, and emitted to the front, each display tile in a direction substantially uniformly orthogonal to the plane of the tile. Viewer to the front of each and all display tiles see co-parallel light rays of equal intensity from all regions of each display tile, and from all display tiles.

Consider now that the sole remaining challenge to production of a "perfect" composite image -- image registration between the tiled image segments -- (i) is not the subject of the present invention, (ii) is a problem previously solved, and that (iii) suitable advanced image registration techniques are employed in the preferred large-scale high-resolution uniform-intensity computer display in accordance with the present invention.

Accordingly, the net effect of the present invention in producing at great scale a composite, tiled, image having uniform intensity, color temperature and color balance throughout is to render a computer-generated image that is devoid of visually perceptible, and objectionable, artifacts. Although this is the image quality that motion pictures have enjoyed for decades, it is not known to the inventors that any large scale computer, and computer video, display has heretofore achieved this level of performance.

It will further be understood by a practitioner of the computer imaging arts that each image projector is commonly controlled by a dedicated computer and computer display card so that the computer generated image may be both (i) of high resolution rapidly refreshed, and (ii) economically so. Resolution across a span of yards (meters) in the preferred embodiment of a projection computer tiled display system in accordance with the present invention is of the order of 105 dots per inch (40 dots per centimeter), with still higher resolutions possible.

2. A Multi-projector Display System

Accordingly, in one of its aspects the present invention is embodied in A multi-projector display system where (i) a number of display projectors each selectively gating light so as to, in conjunction with other ones of the plurality of display projectors, form a composite image; while (ii) one or more light sources, less in number than are the number of display projectors, supply all the display projectors with that light which each display projector serves to project.

The display projectors are preferably color projectors; and the one or more light sources preferably consist of one only light source supplying light in each of three primary colors.

The preferably one light source may preferably be any of (1) an incandescent illumination source, including (1a) an arc illumination source, including (1b) a xenon arc illumination source; or (2) a laser.

When the one single light source provides the three different primary colors then light of all three primary colors -- typically red and green and blue -- is supplied to each of the display projectors. The colored light is preferably derived from (i) a white light source. preferably an incandescent source, producing white light, and (ii) one set only of three color filters for filtering the white light from the white light source into three different primary colors, with the three filtered primary colors being supplied to each of the color projectors.

As a subsidiary aspect of the present invention, each of the color projectors normally includes a recombiner of received light of three primary colors. In accordance with the present invention this recombiner has three relatively wide frequency pass bands respectively for each of the three colors. Meanwhile each of the preferably three only dichroic color filters has a relatively narrow frequency pass band. Thus the pass bands of the dichroic color filters for each of the colors is less than, and entirely within, the pass bands of the recombiner. By this relationship the finite pass bands of the recombiner for each of the color projectors is without effect on color balance of the three colored lights as recombined because each of the three colored lights is, by action of an associated one of the three dichroic filters, already of a frequency pass band that is completely within the associated frequency pass band the recombiner.

In numerical terms, a multi-projector display system in accordance with the present invention typically has 3p light conduits where p is the number of color projectors. Each light conduit serves to transmit a light of one of the three primary colors from an associated one of three color filters to one of the p display projectors. Meanwhile three light multiplexors each receive colored light from an associated one the three color filters and channel this colored light into p light conduits.

In accordance with the present invention, these light multiplexors so multiplex the light in a spatially distributed manner: some light from each and all regions of the associated color filter goes into and via a light conduit to each and all of the color display projectors. By this spatially distributed distribution of colored light from each of the three color filters, the colored lights as delivered by the p light conduits to each and to all of the p projectors are of substantially equal intensity.

In details of construction, each of 3p light conduits preferably consists of a multi-stranded optic fiber cable, with each of the three light multiplexors (that performs spatially distributed distribution of a colored light) consisting of a fiber optic junction box receiving colored light from an associated one of the three filters so as to communicate this colored light into the multiple fibers of each of p multi-stranded optic fiber cables. Thus the multiple optic fibers that are within each cable are physically spatially distributed within each junction box so as to collect light arriving at the junction box from multiple different regions of the associated color filter. By this preferred construction the intensity of color light in each of optic fibers need not be -- dependent upon where from the associated color filter it was received -- the same, but, because of the spatial distribution, the colored light transmitted within and each of the p optic fiber cables to each of the p projectors will be of the same overall intensity.

Still further in accordance with the present invention a multi-projector display system having a screen upon which each of the plurality of projectors projects, via a light beam of frustaconical shape, an image tile further includes fresnel lenses, located between each of the projectors and the screen, for bending light rays of a projector beam of frustaconical shape until, until all light rays of each projector beam impinge upon the screen in a direction substantially orthogonal to a plane of the screen. By this optical construction an observer of the image tiles that are upon the screen will not detect differences in image intensity due to regional convergence or divergence of any projected light beam at any image tile upon the screen, of which regional convergence or divergence there is none.

The fresnel lens is preferably a hologram.

3. <u>A Method of Projecting a Tiled Image</u>

In another of its aspects the present invention is embodied in a method of projecting a tiled image. In the method a number of display projectors are supplied with light from a single light source. Each of the projectors selectively gates light received from the single light source so as to project an image tile that, in conjunction with image tiles projected by other ones of the display projectors, forms a composite tiled image. My this method both light, and the image tile, from each display projector is, to the limits of un-augmented normal human vision, of (i) uniform illumination intensity, and (ii) uniform color temperature, to light and to image tiles from all others of the display projectors because each display projector is supplied with light from the single common source of light.

The display projectors are preferably each supplied with colored lights from sources of colored lights. In this case each of the display projectors serves to selectively gate colored light received from the sources of colored lights so as to project a colored image tile that, in conjunction with image tiles projected by other ones of the plurality of display projectors, forms a composite tiled color image. By this method a color balance in each image tile projected from each one of the plurality of display projectors is imperceptibly different from the color balance in each image tile projected from all other one or ones of the plurality of display projectors because all the plurality of display projectors are gating colored lights from the same sources.

The supply of each of the display projectors with colored lights light preferably proceeds by (i) filtering with color filters white light from a source of white light into different primary colors, and (ii) supplying each of the filtered primary colors to each of the plurality of display projectors by an associated light conduits.

More preferably, the supplying of each of the filtered primary colors to each of the display projectors by an associated light conduits proceeds by coupling in a manner spatially distributed across the area of the filter filtered colored light from each of the filters into an associated plurality of the light conduits. By this spatially distributed coupling intensity of light of single color within each conduit transmitting light of that color is visually indistinguishably different in intensity and in color temperature from light that is transmitted in all other ones of the conduits transmitting light of that color.

Further preferably, the supplying of each of the filtered primary colors to each of the plurality of display projectors is by associated light conduits of equal length, and equal attenuation.

Also in accordance with the method of the present invention for projecting a tiled image, primary colors are preferably produced by filtering with color filters white light from a source of white light into different primary colors; the produced colored lights each being of a predetermined, relatively narrow, bandwidth. The subsequent selective gating of colored lights at each of the display projectors (so as to project an image tile) includes recombining the colored lights of the different primary colors in a color recombiner having, for each of the different primary colors, a pass band that is relatively wider than is a corresponding relatively narrower pass band of an associated color filter. This inequality of pass bands makes that the substantially equal color balance between the projectors already existing because of the shared usage of the same colored lights is not changed by any differences in the pass bands of the recombiners.

Also in accordance with the present invention, the projection of an image tile at, and by, each projector preferably includes a bending with a fresnel lens of the projected light. This bending makes that the light at each, and all, image tiles is co-parallel, and orthogonal to any screen on which the image tiles are projected. Such light will produce a composite image that is devoid of objectionable apparent variations in illumination intensity due to what is, in fact, a variation in the angle of the perceived light rays from various portions, and tiles, and/or tile images, of the composite image.

4. <u>A Multi-Projector System With Fresnel Lenses</u>

In yet another of its aspects the present invention is embodied in a multi-projector display system where a number of display projectors each selectively project light onto a screen to form an associated image tile so as to, in conjunction with other ones of the display projectors, form a composite image. In accordance with the present invention a fresnel lens is located in each located in each path of light projected from each projector to the screen in order to produce the corresponding image tile. $Each fresnel lens serves to bend the light that is projected from the associated projector so that all the projected lights impinging upon the screen as the collective image tiles, and for each image tile, will be both (i) substantially co-parallel, and (ii) substantially orthogonal to the screen.

The preferred fresnel lens is a hologram, and is more preferably a computer generated hologram.

As with other aspects of the invention, all the projectors are preferably supplied with light from a single source.

5. Summary Results

Because the intensity, color temperature and color balance of each projector is the same, and is known, the tiled images produced may suitably be overlapped and blended by action of computer processing in a manner that was not only futile, but actually counterproductive in the prior art (serving only to make a marginal situation worse). In the present invention such preferred computer blending serving to control the edge pixels of an image, most particularly including at the extreme borders of each image tile that is projected by each of the arrayed display projectors, serves to make a composite image that -- although of high resolution (to 8M and more pixels per image tile, at 105 dpi and higher resolution) and huge scale (multiple meters in total size) -- is visually perfect and seamless, and without detectable imperfection(s) to the unaided eye. Such an image devoid of artifacts is not only aesthetically pleasing, it is required in some applications such as medical imaging applications where a physician is looking for contrast changes.

These and other aspects and attributes of the present invention will become increasingly clear upon reference to the following drawings and accompanying specification.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a diagrammatic perspective view of a first, white light, embodiment of a light projection system in accordance with the present invention.

Figure 2 is a diagrammatic perspective view of a second, R-G-B color, embodiment of a light projection system in accordance with the present invention.

Figure 3 is a simplified optical schematic of the prior art JVC D-ILA projector, showing that a light from a light source is selectively gated.

Figure 4 is a detail optical schematic of the prior art JVC G1000 optical projector, again showing that a light from a light source is selectively gated.

Figure 5 is an optical schematic diagram of the second, R-G-B color, embodiment of a light projection system in accordance with the present invention previously seen in perspective view in Figure 2.

Figure 6 is a first perspective view of the connection of an external light source via fiber optics into the base of a prior art JVC G1000 D-ILA optical projector in accordance with the present invention.

Figure 7, consisting of Figures 7a-7c, are respective top, front and side views of the connection of an external light source via fiber optics into the base of a prior art JVC G-1000 D-ILA optical projector in accordance with the present invention previously seen in Figure 5.

Figure 8, consisting of Figures 8a-8c, are front views illustrating alignment and compactness considerations in the connection of an external light source via fiber optics into the base of a prior art JVC G-1000 D-ILA optical projector in accordance with the present invention as was previously seen in Figures 5 and 6, and a side view of which connection will be shown in Figure 10.

Figure 9 is a perspective view of a single light projector in the light projection system of the present invention.

Figure 10 is a side view of the mounting of the optical fiber light pipes from the external light source to the optical core of the prior art JVC G-1000 D-ILA optical projector in the light projection system of the present invention.

Figure 11 is a detail view of a white light source, a dichroic filter, and a preferred coupler for coupling colored light into a fiber optic bundle for use in the light projection system in accordance with the present invention.

Figure 12, consisting of Figures 12a and 12b, are respectively perspective, and side plan, views of the receipt via an optic fiber bundle of colored light into a projector, and a preferred aggregator and collimator for coupling the received color light into the optical paths of the projector, within the light projection system in accordance with the present invention.

Figure 13, consisting of Figures 13a through 13d, are graphs showing the photometry measurement for red, green, blue and composite white lights, respectively, projected in formation of each image tile in a light projection system, nominally a 3 x 1 projector horizontal array, in accordance with the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

The present invention teaches that judicious use of a single light source obviates problems with variation in any of (i) illumination intensity, (ii) color temperature, and/or (iii) color balance over the area of a composite tiled image -- as routinely occur when multiple light sources are used -- generated from multiple image projectors. The use of the single light source accords uniform and stable (i) illumination, (ii) color temperature, and (iii) color balance through all image segments, giving a high quality composite image suitable for scientific research, control rooms or electronic cinema.

1. <u>A Large-Scale Computer Display</u>

The preferred computer display in accordance with the present invention is scalable, compact, low-cost, and possessed of an image that is uniform in each of intensity, color temperature and color balance. A first, white light, embodiment of a light projection system in accordance with the present invention is shown in diagrammatic perspective view in Figure 1. A second, red-green-blue (R-G-B) color, embodiment 1b of a light projection system in accordance with the present invention is shown in diagrammatic perspective view in Figure 1. The composite image may be generated, by way of example, from a 3 x 3 projector array 11 (of which arrayed nine projectors 11a-11j a vertically arrayed three projectors 11a-11c only are shown in Figures 1 and 2). Each image tile 12a-12j is optionally, preferably, backed by a rectilinear fresnel lens 13a-13j (of which selected one are shown). Each fresnel lens is located at the image plane of its associated projector.

Each projector 11a-11i produces through its associated fresnel lens 13a-13j an associated image tile image 12a-12j of, nominally, 1280 x 1024 pixels. The final, composite screen image 12 is thus typically and preferably about 3840 x 3072 pixels with physical dimensions of, most typically, 128 cm x 96 cm.

The composite tiled image 12 may be comfortably viewed by a human viewer 2 (not part of the present invention) at a distance of up to several tens of meters.

The path of the white light from a light source 14 consisting of a power supply 14a and, preferably, a reflectorized zenon arc light 14b, is, in the white light embodiment of Figure 1, through a single fiber optic junction box 16 (a part of which closest to the optic conduits 17 is shown at expanded scale in Figure 10). In the color embodiment of Figure 2, the white light from the light source 14 is turned into light of normally three primary, normally red and green and blue, colors in, preferably, color, dichroic, filters 15r, 15g and 15g prior to each color be collected by an associated fiber optic junction box 16r, 16g and 16b before being distributed to each of the projectors 11a-11j via associated ones of the light conduits 17.

The light conduits 17 are not required to maintain spatial registration of any transmitted image, but only to transmit light. The may accordingly be made as liquid filled light pipes or, more preferably, as non-coherent fiber optic bundles of, most typically, some thousands of individual stands within about 1 centimeter diameter.

The preferred projectors 11 are type D-ILA 61000 from JVC. These projectors have a native resolution of 1350 x 1024 pixels. See Sterling R., Bleha W. P., "ILA projectors for advanced imaging applications", Proc. Society for Information Display Workshop, p. 809, (1997).

A simplified optical schematic of a general prior art JVC D-ILA projector, showing that a light from a contained light source is selectively gated, is shown in Figure 3. Light from a lamp, normally a reflectorized incandescent lamp, 110 is directed by condensing lens 111a to a polarizing beam splitter 111 where some of this light is reflected to, and then again by, an ILA assembly 112. This ILA assembly 112 may have been patterned, among other possibilities, by light from a cathode ray tube 113 passed through a relay lens 114 to the ILA 112. Reflected, patterned, light from the ILA 112 is again passed through the polarizing beam splitter 111 and then through a projection lens 115 to a screen (not shown, such as the screen 12 of Figures 1 and 2).

More precisely, in special cases -- such as for tiled color displays of greater than one meter (1 m) dimension, or monochrome tiled displays of greater than one meter (1 m) dimension -- more than one source of light can be used, but the number of these light sources is always less in number than is the number of display projectors; each light source supplying several, and preferably all, of the display projectors with the light that the display projector serve to gate.

To produce the preferred embodiment display system of the present invention use: (i) quantity one (1) JVC Model 360 ILA arc lamp assembly, plus (ii) a cold mirror, plus (iii) a dichroic deck, plus (iv) a base plate, plus (v) an arc lamp power supply/igniter. Use also (vi) quantity nine (9) fiber light pipes for RGB connection between illumination and projectors, and (viii) quantity three (3) Model G1000 (2-3:1 zoom lens) D-ILA projectors.

Momentarily leaping ahead in order that an overview may be gained, each projector is modified by removing its existing lamp, modifying the projector housing as shown in Figures 7 and 8, and by installing fiber optic receptacles (three for each projector) shown in Figure 10. A rigid base and dust cover for each projector is preferably also made and installed.

The main power supply for each projector is tethered, and a special base so supporting is used. Remote lamp turn-on and ignition is preferably provided.

Still further, an illumination system for RGB fiber illumination is made as shown in Figures 2 and 5. A mounting/enclosure is provided for the arc lamp, illumination system and power supply. A remote lamp turn-on and ignite switch (not an RS 232 interface) is preferably provided. The projection lens is preferably selected for nominal 21 inch diagonal image size (per projector, 63 inch overall diagonal composite image size). If the projectors are provided -- as is standard -- with an RS 232 interface for image generation, then this interface is controlled by standard, pre-existing, software.

2. Details of Construction of A Large-Scale Computer multiple-Projector Tiled Display in Accordance with the Present Invention

A detail optical schematic of the particular preferred prior art JVC 61000 optical projector, again showing that a light from a light source is selectively gated, is shown in Figure 4. Light from, in this case, a preferred arc lamp 110a, is directed to a polarizing beam splitter 112 where some of the light is reflected through quarter wave plate 116 to D-ILA assembly 117. Light patterned, and reflected, by D-ILA assembly 117 is again passed through the polarizing beam splitter 111 and then through a projection lens 115 to the screen 12.

Recent availability of QXGA (2048 x 1536) and 4000 x 2000 pixel chips (8M total pixels per D-ILA projector), although at a higher cost, means that the number of pixels of the final image can be increased by using such projectors. A short throw (0.8:1) lens was fitted on each projector in order to achieve a 21" diagonal for each projected image tile, consistent with standard desktop monitors. Tests show that the diagonal can be reduced down to 15" without distortion thus increasing the pixel density from 75 dpi to 105 dpi. A Jenmar black screen 12 was used in rear projection mode. See Jenmar: <http:www.jenmarvs.com/>. Three projectors were tiled horizontally and the images were edge-abutted with pixel-level precision.

An optical schematic diagram of the second, R-G-B color, embodiment 1b of a light projection system in accordance with the present invention -- previously seen in a mechanical perspective view in Figure 2 -- is shown in Figure 5. Colored light from a remote light source such as one of the dichroic filters 15r, 15g, 15b and the associated optic fiber junction box 16r, 16g, 16b (shown in Figure 2) is passes through one of the optical conduits 17 (also shown in Figure 2 to be received at an aggregator and collimator 1150 (further shown in Figure 12) consisting of a combination of two regular, and two rectilinear fish eye, lenses. The shaped and dispersed (colored) light (i) is passed through color-splitting dichroic beamsplitters 1151, pre-polarizers 1152, and polarizers 1153, and (ii) is then modulated (i.e., patterned) by D-ILA assemblies 1154 (one for each color) until, in a color combining X-cube 1155, a single (multi-colored) output projection beam is emitted through projection lens 1156.

Image edge alignment, at pixel level, is achieved by physical alignment of each projector using an in-house 6-axis positioner, upon which the projector opto-electronic cores are mounted. These can be seen in Figures 6-8. In the perspective view of Figure 6 the connection of an external light source -- for example the exemplary red light source 15r, 16r shown in Figures 2 and 5 -- via three fiber optic bundles 17r, 17g 17b into the base 1160 of a prior art JVC G1000 D-ILA optical projector is shown. Aggregators and collimators 120r, 120g, 120b contain the integrating and condensing lenses 1150 just seen in Figure 5: more detail will later be seen in Figure 12. Various stanchions are for support of other assemblies above the base plate 1160: for example, stanchion 1161 supports a circuit board while stanchions 1162 support various optics and electronic assemblies. The main teaching of Figure 6 is simply that light of three colors is delivered into each projector 11.

Figures 7a-7c respectively show top, front and side views of the connection of an external light source via fiber optics into the base 1160 of a prior art JVC G-1000 D-ILA optical projector. Dimension A-E are typically respectively 12.6, 16.8, 21, 11.1 and 7.2 inches.

Figures 8a-8c are all front views illustrating alignment and compactness considerations in the connection of an external light source via fiber optics into the base 1160 (previously seen in Figures 6 and 7) of a prior art JVC G-1000 D-ILA optical projector (in accordance with the present invention) as was previously seen in Figures 5 and 6). A side view of an exemplary one of the same connections is shown in Figure 9. In all cases adjustments center around the projection lens 1156 (also shown in Figure 5). The teaching of Figure 8 is that there are many ways to realize mountings, and adjustments, but that some are easier than others. The mounting and alignments of Figures 8a, 8b and 8c range from the most to the least preferable.

As shown in Figure 9, a rectangular-physical mask 1157 in front of each projector 11 further delineates the image tile and eliminates stray light. Also diagrammatically shown in Figure 9 is an a.c. power connection 1158, and, at the screen 120, optional infrared sensors 121 as may be used for sensing in an automated, remote, ambient light sensing and display intensity control circuit -- as is well known in the display arts.

Figure 10 shows a side view of the mounting of the optical fiber light conduits 17 from the external light source to the optical core of the preferred modified JVC G-1000 D-ILA optical projector 16 in the light projection system 1 of the present invention. The aggregator and collimator assemblies 1150, previously seen in Figures 5-8, and to be shown in detail in Figure 12, are part of the optical path.

Before showing and discussing these aggregator and collimator assemblies 1150, a view of the white light source 14a, and the dichroic filter 15r, 15g or 15b (both previously seen in Figure 2) plus a detail view of the preferred coupler 16r, 16g or 16b for coupling light of a primary color into a fiber optic bundle 17 for use in the colored light projection system 1b in accordance with the present invention is shown in Figure 11. A lens 161 guides light onto a butt end 171 of an optic fiber bundle 17, of which a partial, end, view is shown in Figure 11.

Now in Figure 12, consisting of Figures 12a and 12b, are shown a detail views of the aggregator and collimator assemblies 1150. An optic fiber bundle 17 feeds colored light into an aggregator and collimator assembly 1150 containing, in order, (i) a regular, convex, first condensing lens 11501, (ii) a first rectilinear fish-eye lens 11502, (iii) a second rectilinear fish-eye lens 11503, and (iv) a regular, convex second condensing lens 11504 (best seen in Figure 12b). This preferred aggregator and collimator assembly 1150 couples the received color light into the optical paths of the projector 11 in accordance with the present invention. The light emitted from each aggregator and collimator assembly 1150 is, as collimated, directed onto the color-splitting dichroic filters 1151 (also shown in Figure 5).

Figures 13a through 13d are graphs showing the photometry measurement for red, green, blue and composite white lights, respectively, projected in formation of each image tile in a light projection system 1b in accordance with the present invention. Photometry measurements were performed on each projector using a Photo Research PR-650 spectroradiometer. The Figures 13a-13d generally show that (i) the colored lights are spectrally non-overlapping, and (ii) combine to produce a synthetic white light that is, in accordance with the principles of the invention, or equal intensity, color temperature, and color balance at each of the display tiles.

Accordingly, it has been shown how unified illumination is achieved in a tiled display by using a common light source. Commercially-available projectors or standard form were redesigned, and the light source and associated power supply were removed from each projector. A single 1000 watts xenon arc lamp preferably provides a single, universally common, illumination source. The preferred white light is preferably distributed via three optical fiber splitters and a single set of dichroic filters (RGB) to the respective RGB D-IL,A modulators in each projector. The use of a common light source eliminates illumination and color variability across the screen "tiles", resulting in a seamless and visually uniform image across all projectors and along all axis.

Accordingly, the multiple projector system of the present invention solves the illumination, uniformity and color matching problem previously experienced across the tiles of a tile image by use of a single light source: hence uniform illumination, color temperature and color balance were achieved as shown and taught.

This display of the present invention is conservatively believed to represents an order-of-magnitude improvement over previous large scale multiple tile display systems in each of computer display image quality, size, price and, hence, scalability to still larger and higher capacity displays.

In the near future it is expected to set the capacity of the display of the present invention at 12 Mpixels for use at the San Diego Supercomputer Center of the University of California at San Diego. This is equivalent to a tiled stack of 3 x 3 projectors, using a total of 27 optic fiber bundles for light distribution.

Other types of illumination sources are contemplated such as, mainly, the use of three lasers to provide a common illumination. This will have the advantage of removing the lamp and the dichroic falters, and improving the color gamut. Different types of screens, and different tiling Fresnel lenses, are envisioned as well.

3. Recapitulation

Accordingly, the present invention has been seen to involve, inter alia, Ii) a number of display projectors each selectively gating light so as to, in conjunction with other ones of the plurality of display projectors, form a composite image where (ii) one or more sources of light, less in number than the number of display projectors, supply all the display projectors with that light which the display projectors serve to gate.

The single light source is typically an incandescent illumination source, and more typically an arc illumination source, including arc sources of the xenon arc type, or still other types of light sources known in the art including tungsten halogen, metal halide and mercury-doped xenon. The single light source may alternatively be a laser.

When the composite image is in full color, there may be considered to be three sources supplying colored light to each of the display projectors. Even here, however, the colored lights are preferably derived from a single source by, most commonly, use of three color filters that filter light from this single source into three different primary colors. In this case the preferred illumination source remains an incandescent xenon arc illumination source, and each of the three color filters is preferably a dichroic filter.

The preferred projection system further includes a number of light pipes, equal to or greater in number than the number of display projectors, for communicating light from the one or more sources of light to each of the display projectors. These light pipes are preferably multi-fiber optic light pipe, being bundles of optic fibers. The number of light pipes may equal to the number of the plurality of display projectors, with each light pipe communicating white light to an associated display projector. Alternatively, the number of the light pipes may be three times the number of display projectors, three light pipes being associated with each display projector with each light pipe of the three communicating a different one of three primary colors to the display projector.

The present invention has further been seen to be embodied in a method of projecting a tiled, and most typically a large, image. The method of the invention projects an areal portion of the large image with each of a number of display projectors, each of which display projectors selectively serve to gate light so as to, in conjunction with other ones of the display projectors, form a composite large image.

In accordance with the present invention, all the display projectors are supplied with the light that each serves to gate from but a single common light source. By this method light from each display projector is of uniform (i) illumination intensity, and (ii) color temperature, to light from all others of the display projectors because each display projector uses light from the single common source of light. If the display projectors gate colored lights then these lights also are derived from a single source, at most one source for each of three primary colors, thus making that (iii) color balance is uniform throughout the area of the composite display.

In summary, by use of the present invention each part of a tiled composite display looks, insofar as luminance and color temperature and color balance go, exactly the same as any other part. Minimum proper care to mechanically align adjacent image segments being taken, the eye is easily fooled into thinking that one large image is being observed, even if uneliminatable borders to the image segments give a slight "multi-pane window effect". In fact, with proper image resolution, the net effect is very comparable to looking out a large window, which for certain projector set-ups may appear to be a multi-pane window.

In accordance with the preceding explanation, variations and adaptations of the light projection system in accordance with the present invention will suggest themselves to a practitioner of the computer light projector arts. For example, in very, very large displays comprises of multitudinous image segments the routing of light need not be direct from the single source to each projector, one or more fiber optic light pipes per projector, but may be via intermediary optical "junction boxes".

In accordance with these and other possible variations and adaptations of the present invention, the scope of the invention should be determined in accordance with the following claims, only, and not solely in accordance with that embodiment within which the invention has been taught.

CLAIMS

What is claimed is:

1. A multi-projector display system CHARACTERIZED IN THAT

a plurality of display projectors each selectively gating light so as to, in conjunction with other ones of the plurality of display projectors, form a composite image; while

one or more light sources, less in number than the plurality of display projectors, for supplying all the plurality of display projectors with that light which each display projector serves to project.

2. The multi-projector display system according to claim 1 FURTHER CHARACTERIZED IN THE

the plurality of display projectors are color projectors; and

the one or more light sources supply light in each of three primary colors.

3. The multi-projector display system according to claim 1 FURTHER CHARACTERIZED IN THAT

the one or more light sources consist of one single light source supplying light to all the plurality of display projectors.

4. The multi-projector display system according to claim 3 FURTHER CHARACTERIZED IN THAT the one single light source is an incandescent illumination source.

5. The multi-projector display system according to claim 1 FURTHER CHARACTERIZED IN THAT

the plurality of display projectors are color projectors; while

the one or more sources of light consist of one single light source providing light of three different primary colors, light of all three primary colors being supplied to each of the plurality of display projectors.

6. The multi-projector display system according to claim FURTHER CHARACTERIZED IN THAT

the one single light source consists of a source of white light; and

three filters for filtering the white light from the white light source into three primary colors.

7. The multi-projector display system according to claim 1 FURTHER CHARACTERIZED IN THAT

each of the projectors includes a recombiner of received light of three primary colors, the recombiner having three relatively wide frequency pass bands for each of the three colors; and

where each of the three color filters has a relatively narrow frequency pass band;

wherein the pass bands of the color filters for each of the colors is less than, and entirely within, the pass bands of the recombiner;

wherein the finite pass bands of the recombiner for each of the projectors is without effect on color balance of the three colored lights as recombined because each of the three colored lights is, by action of an associated one of the three color filters, already of a frequency pass band that is completely within the associated frequency pass band the recombiner.

8. The multi-projector display system according to claim 1 FURTHER CHARACTERIZED IN THAT

a plurality of light conduits, equal to or greater in number than the plurality of display projectors, for communicate light from the one or more sources of light to each of the plurality of display projectors.

9. The multi-projector display system according to claim 8 FURTHER CHARACTERIZED IN THAT each of the plurality of light conduits consists of a multi-fiber optic light pipe.

10. The multi-projector display system according to claim 8 FURTHER CHARACTERIZED IN THAT

the number of the plurality of light conduits is equal to the 1p where p is number of the plurality of display projectors, each light conduit communicating light from the one or more sources of light to an associated one of the p display projectors.

11. The multi-projector display system according to claim 1 FURTHER CHARACTERIZED IN THAT

the plurality of display projectors are color projectors;

the one or more light sources supply light in each of three primary colors; and

the number of the plurality of light conduits is equal to 3p where p is the number of the plurality of color display projectors, three light conduits being associated with each color display projector where each light conduit of the three communicates a different one of three primary colors to an associated color display projector.

12. The multi-projector display system according to claim 1 FURTHER CHARACTERIZED INT THAT

each of the plurality of projectors projects, via a light beam of frustaconical shape, an image tile upon a screen; while

a fresnel lens, located between each of the projectors and the screen, bends light rays of the projector beam of frustaconical shape until, until all light rays of each projector beam impinge upon the screen in a direction substantially orthogonal to a plane of the screen;

wherein an observer of the image tiles that are upon the screen will not detect differences in image intensity due to regional convergence or divergence of any projected light beam at any image tile upon the screen, of which regional convergence or divergence there is none.

13. The multi-projector display system according to claim 12 FURTHER CHARACTERIZED IN THAT

the fresnel lens is a hologram.

14. A display system CHARACTERIZED IN THAT

an array of display projectors each selectively project light received from a single source of light via one or more light conduits so as to, in conjunction with other ones of the display projectors, form a composite tiled image that is both of uniform illumination intensity, and uniform color temperature, to all others of the display projectors because each display projector is projecting light received in common from the single source of light.

15. The display system according to claim 14 FURTHER CHARACTERIZED IN THAT

the single source of light consists of a light producing white light; and one set only of three color filters for filtering white light from the light into three different primary colors, which three filtered primary colors are each supplied to each of the display projectors by an associated one of the light conduits.

16. The display system according to claim 15 FURTHER CHARACTERIZED IN THAT

each of the display projectors includes a recombiner of received light of three primary colors, the recombiner having a bandpass of an associated first range of frequencies for each of the colors; and

each of the three only color filters has a bandpass of an associated second range of frequencies for each of the colors;

wherein the second range of frequencies for each of the colors is less than, and entirely within, the first range of frequencies for each of the colors;

wherein the bandpass for each of the colors of the recombiner of each of the projectors is without effect on the three colored lights that it serves to recombine because each of these three colored lights is, by action of an associated one of the three dichroic filters, already of a first frequency range that is completely within the associated second frequency range of the recombiner.

17. The display system according to claim 15 FURTHeR CHARACTERIZED IN THAT

each of the arrayed display projectors contains a liquid crystal light modulator.

18. A method of projecting a tiled image CHARACTERIZED IN THAT

a plurality of display projectors supplied with light from a single light source selectively project light received from the single light source to display an image tile that, in conjunction with image tiles projected by other ones of the plurality of display projectors, forms a composite tiled image; and

wherein both light, and an image tile, from each display projector is, to the limits of un-augmented normal human vision, of uniform illumination intensity, and of uniform color temperature, to light and to image tiles from all others of the display projectors because each display projector is supplied with light from the single common source of light.

19. The method according to claim 18 FURTHER CHARACTERIZED IN THAT

the plurality of display projectors are each supplied with colored lights from sources of colored lights; with

each of the plurality of display projectors selectively gating received colored lights from the sources of colored lights so as to project a colored image tile that, in conjunction with image tiles projected by other ones of the plurality of display projectors, form the composite tiled color image; and

wherein a color balance in each image tile projected from each one of the plurality of display projectors is imperceptibly different from the color balance in each image tile projected from all other one or ones of the plurality of display projectors because all the plurality of display projectors are gating colored lights from the same sources of colored lights.

20. A multi-projector display system CHARACTERIZED IN THAT

a plurality of display projectors each selectively project light onto a screen to form an image tile so as to, in conjunction with other ones of the plurality of display projectors, form a composite image; while

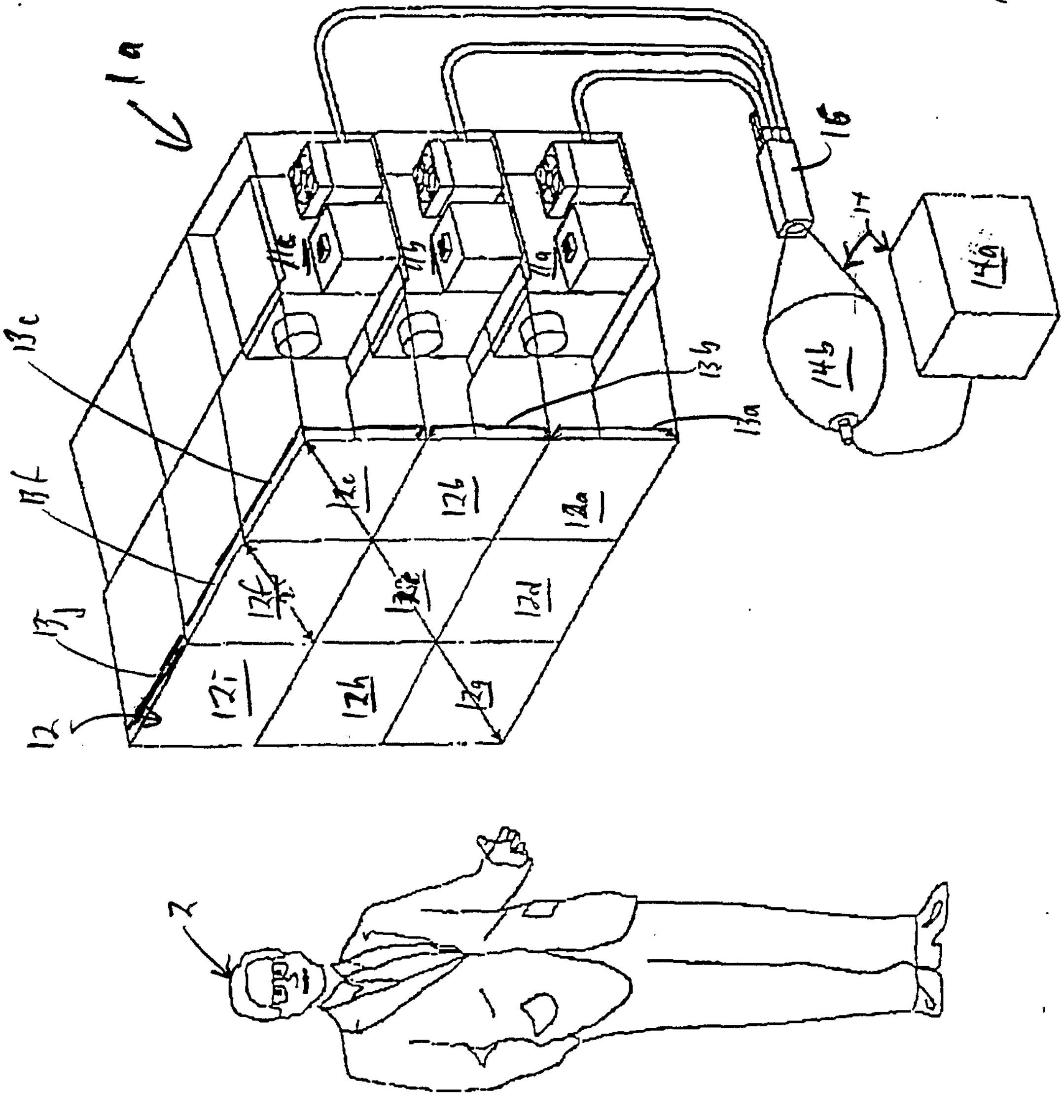
a plurality of fresnel lenses, each located in a path of light projected from one of the plurality of projectors to the screen in order to produce a corresponding image tile, bend the light projected from an associated one of the plurality of projectors so that all projected lights impinging upon the screen as the collective image tiles are both (i) substantially co-parallel, and (ii) orthogonal to the screen.

21. A multi-projector display system according to claim 20 FURTHER CHARACTERIZED IN THAT each of the plurality of fresnel lenses is a hologram.

22. The multi-projector display system according to claim 20 FURTHER CHARACTERIZED INT THAT

one or more light sources, less in number than the plurality of display projectors, supply all the plurality of display projectors with that light which each display projector serves to project.

Fig. 1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11b
11c
12
12a
12b
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12d
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13c
13f
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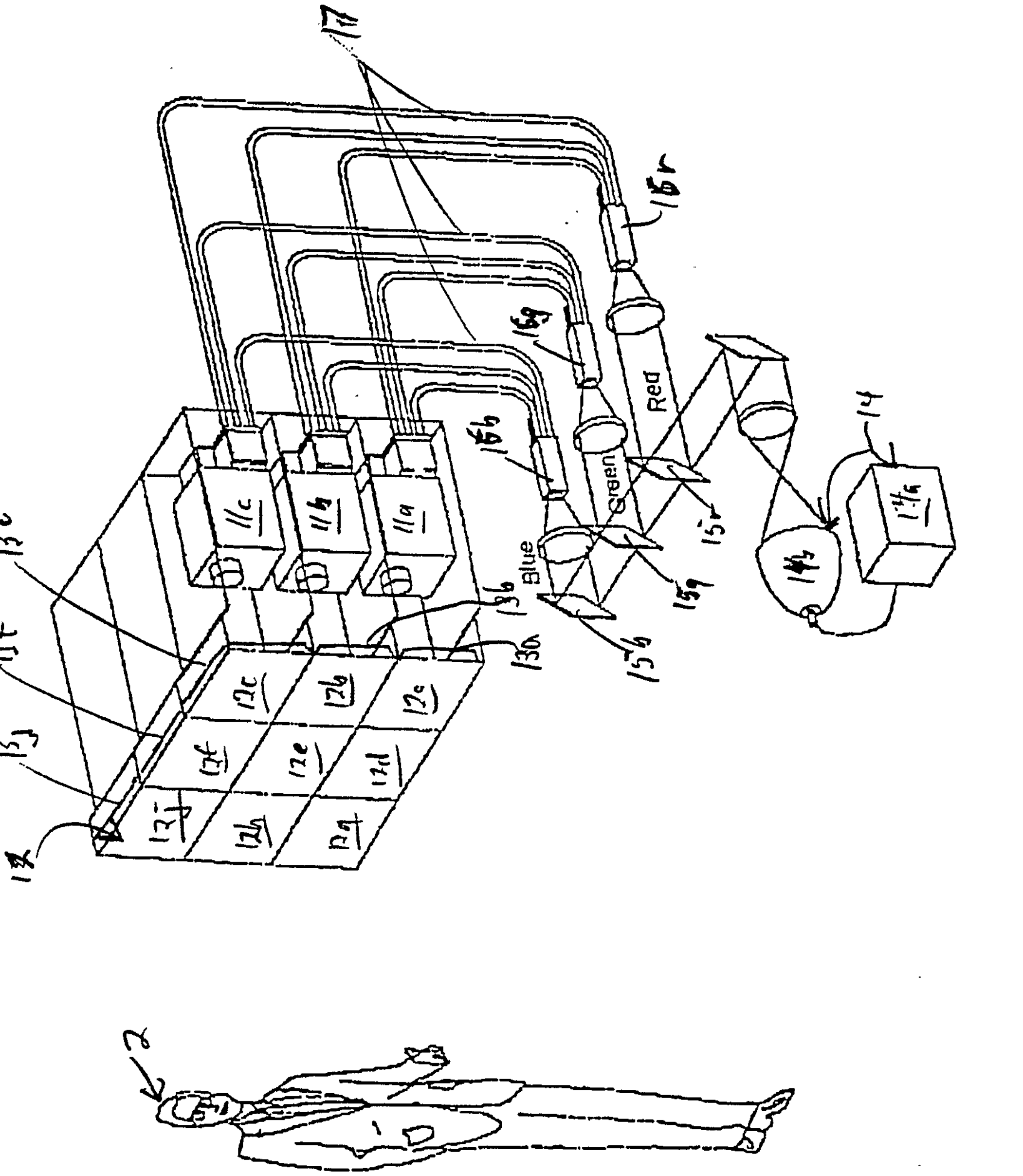
14
14a
14b
16
2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16g
16b
Red
Green
Blue
15r
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14
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12b
12c
12d
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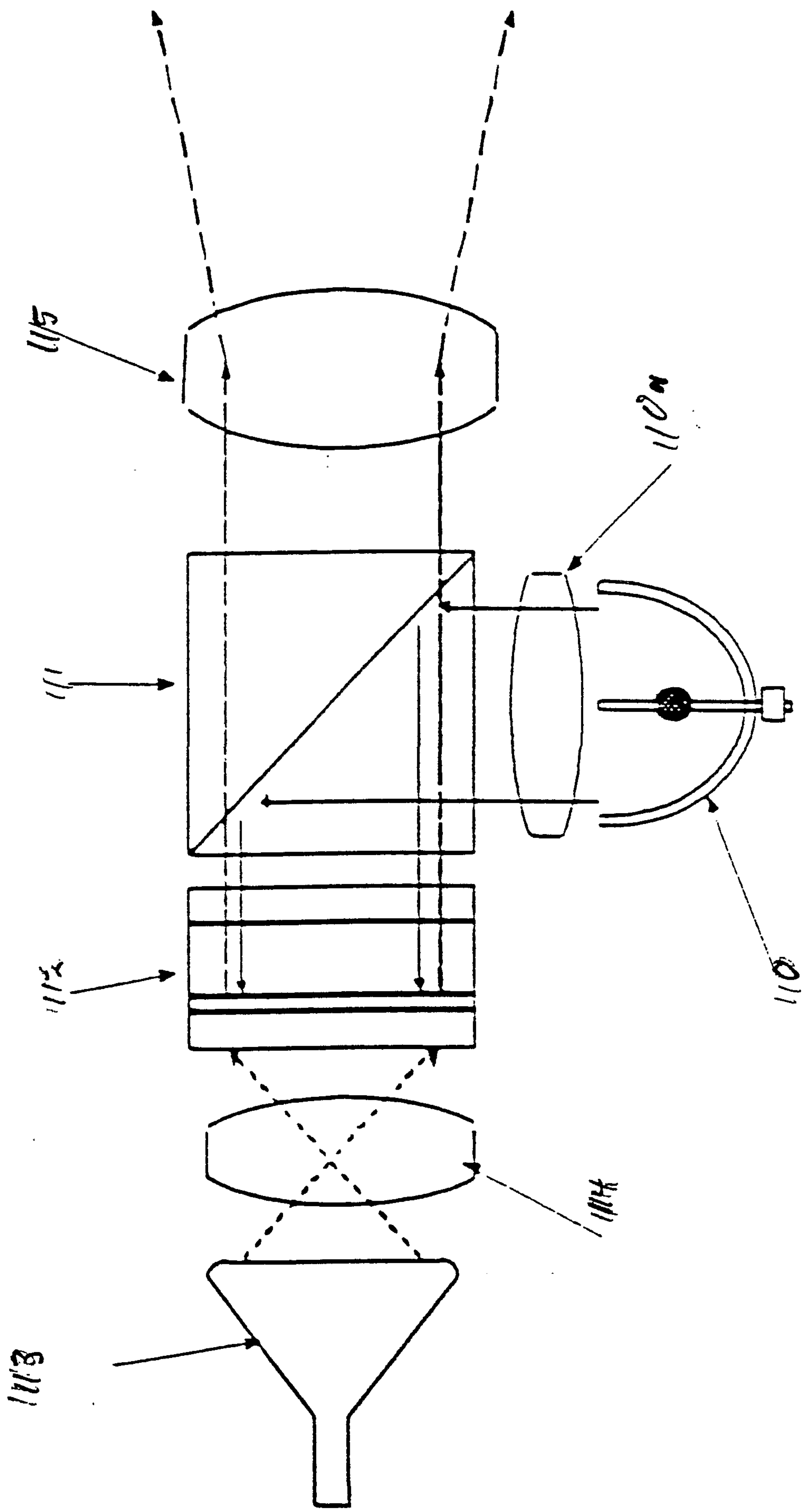
2

Fig. 2

Fig. 3
PRIOR ART



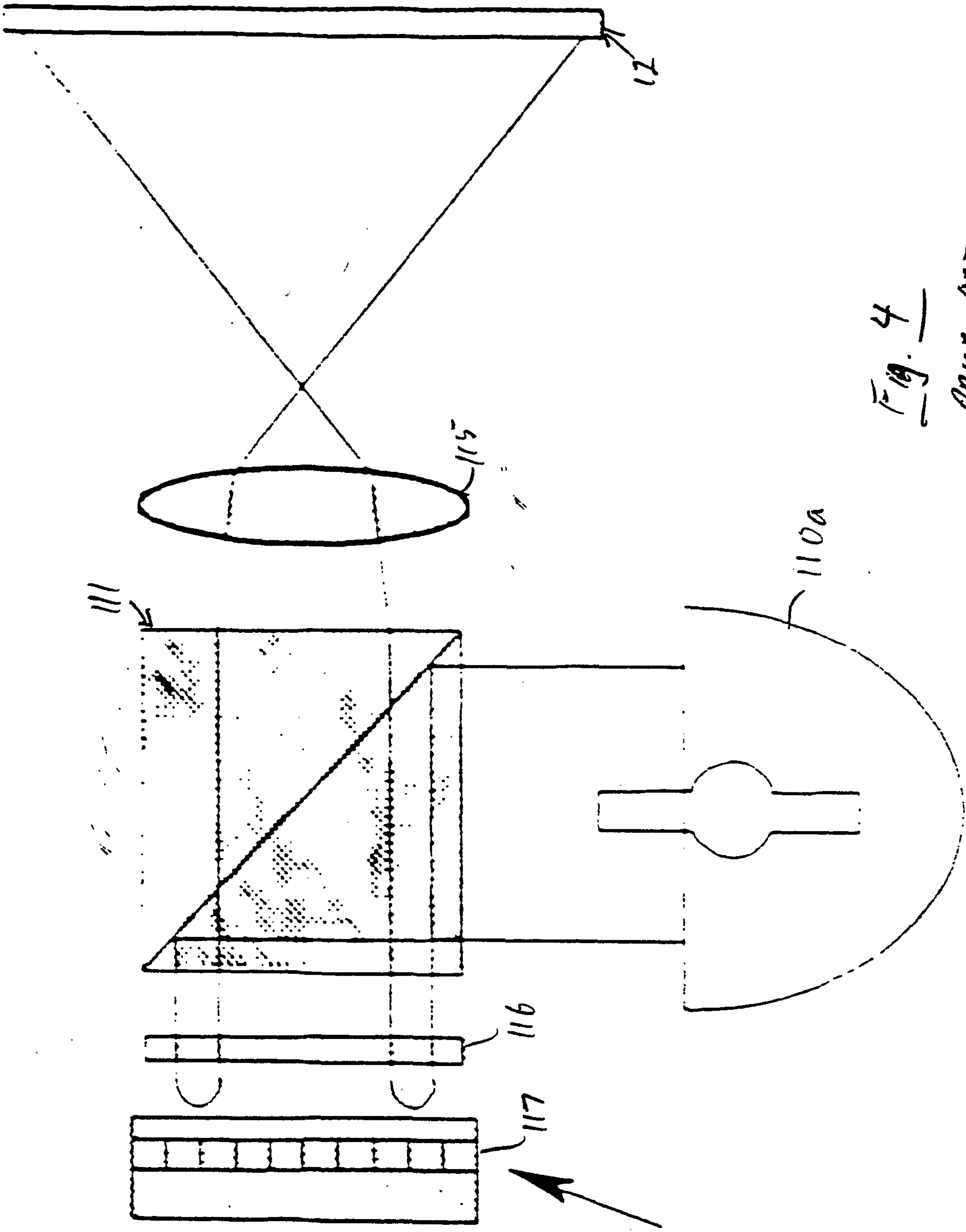


Fig. 4
PRIOR ART

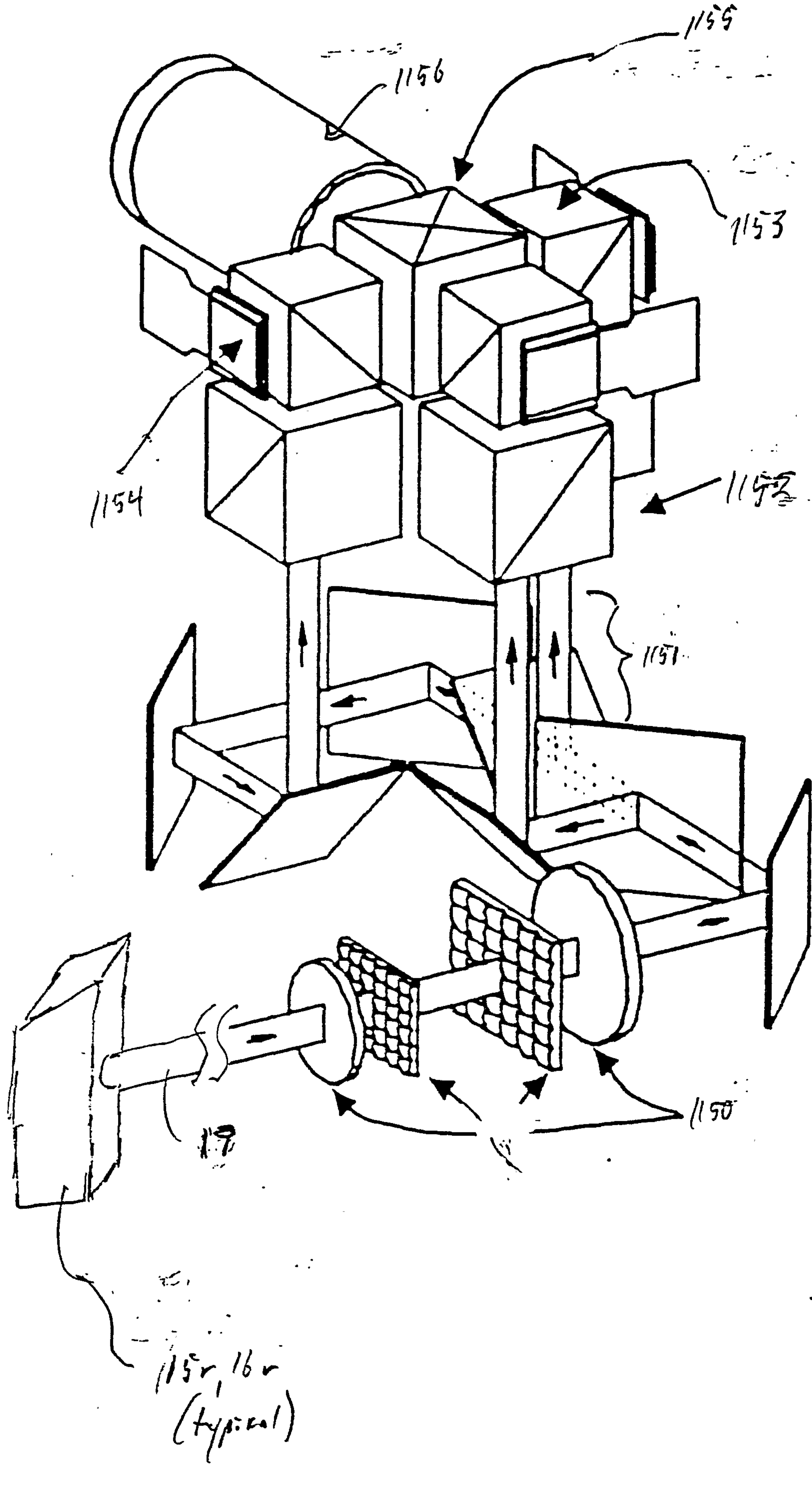


Fig. 5

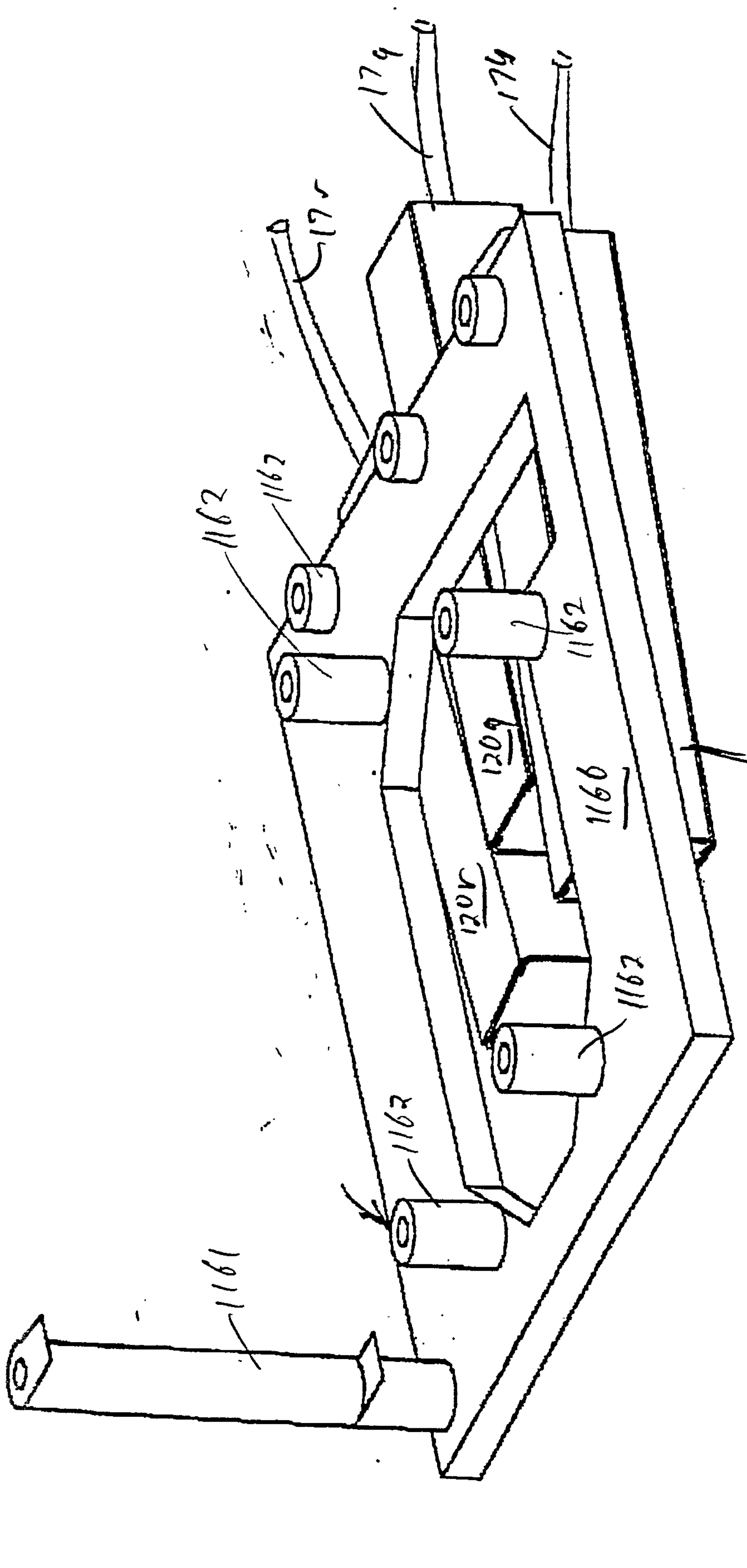


Fig 6

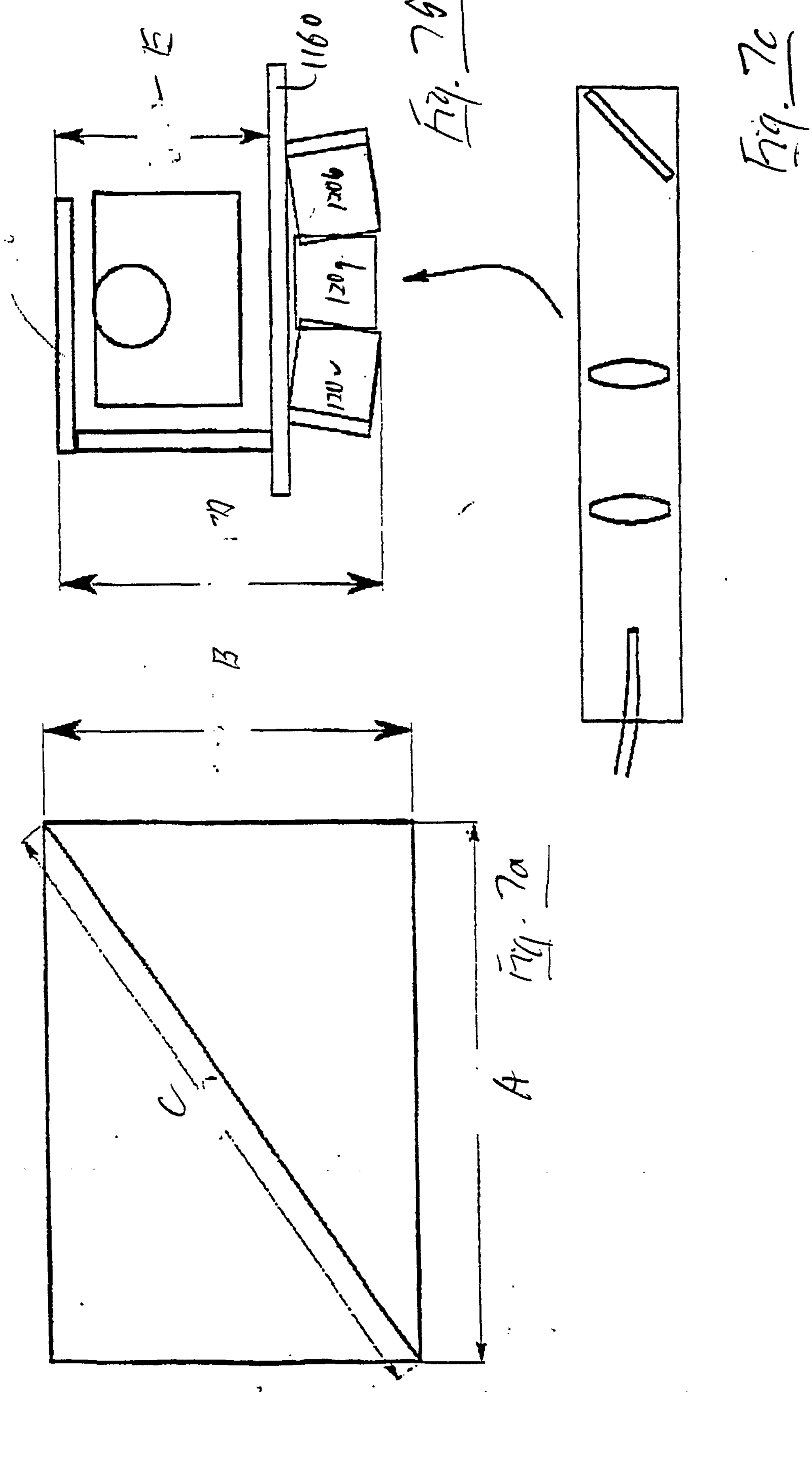


Fig. 7a

Fig. 7b

Fig. 7c

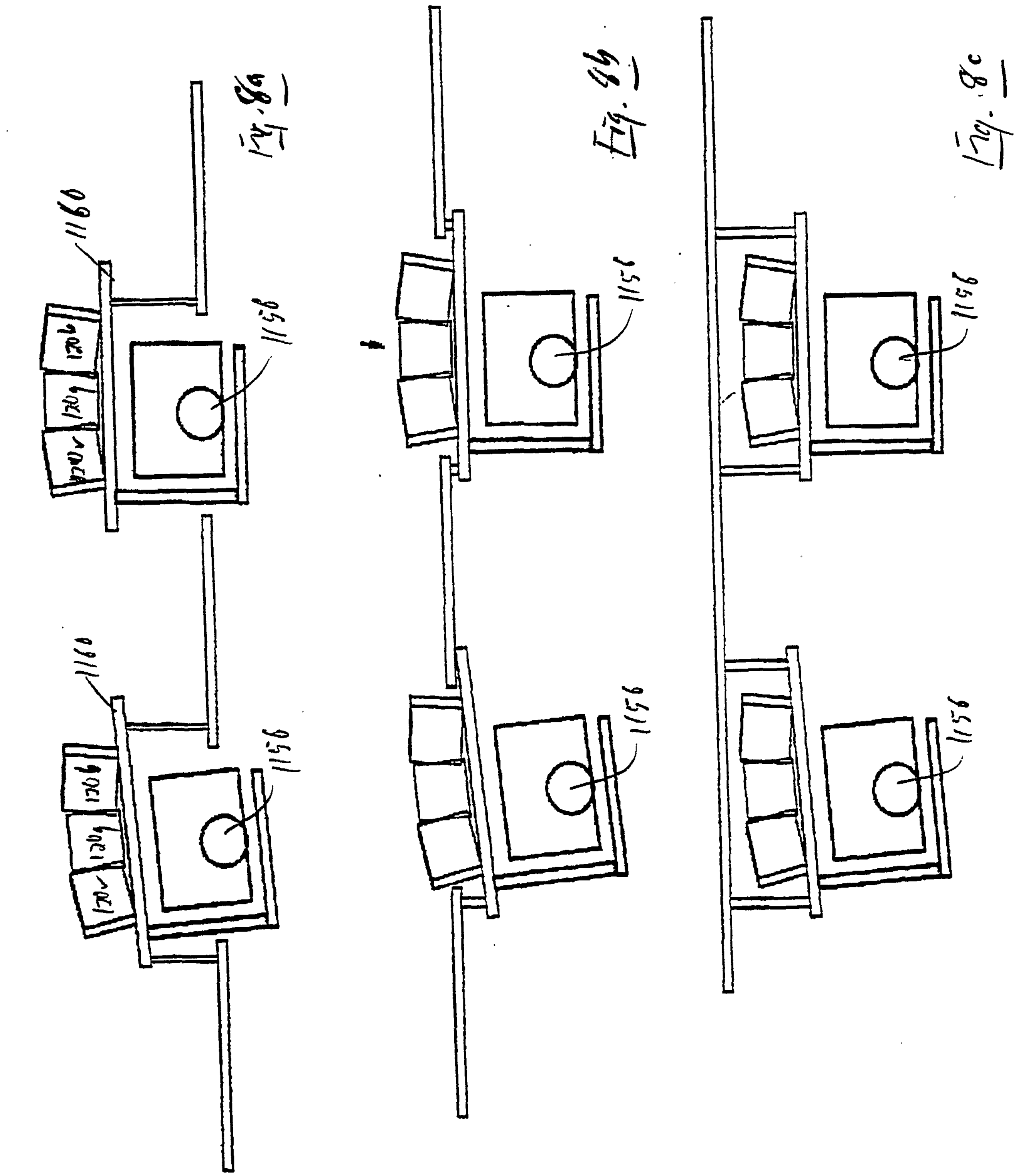


Fig. 8a

Fig. 8b

Fig. 8c

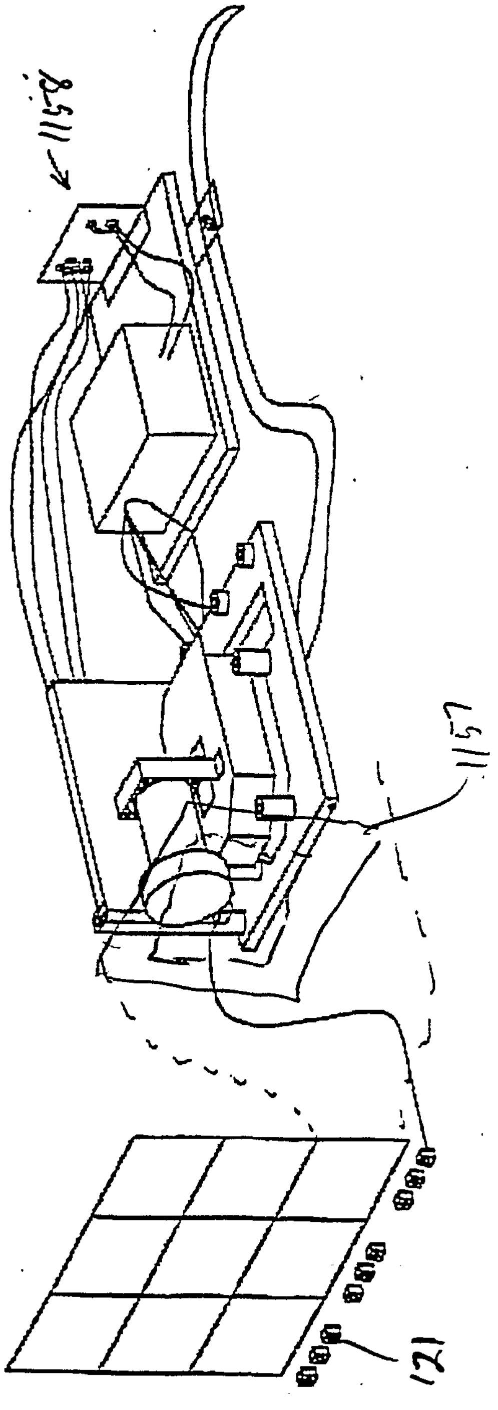


Fig. 9

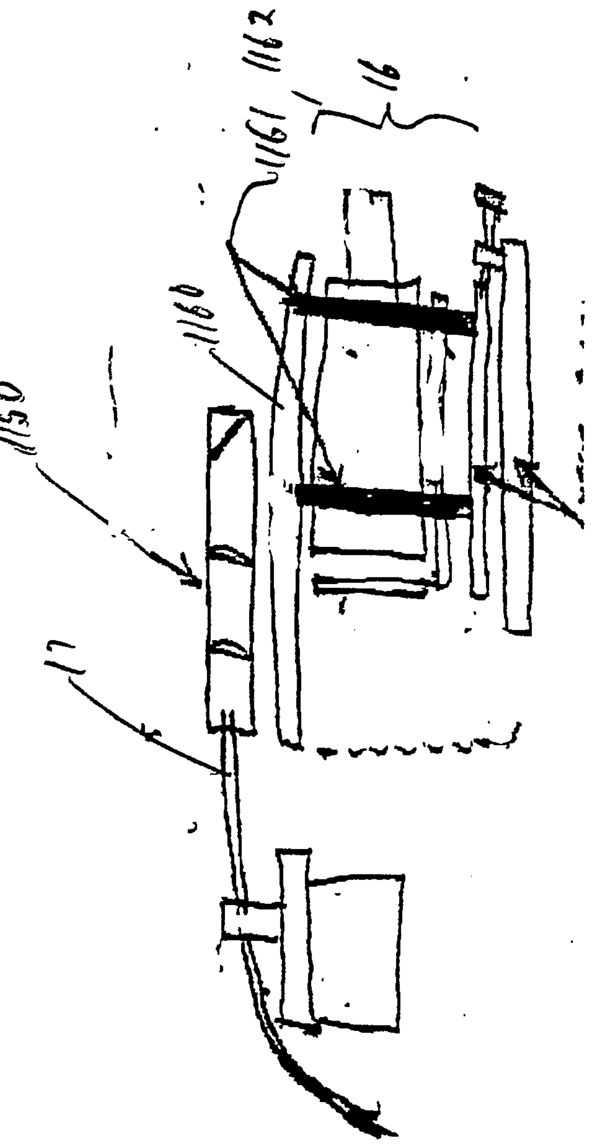


Fig 10.

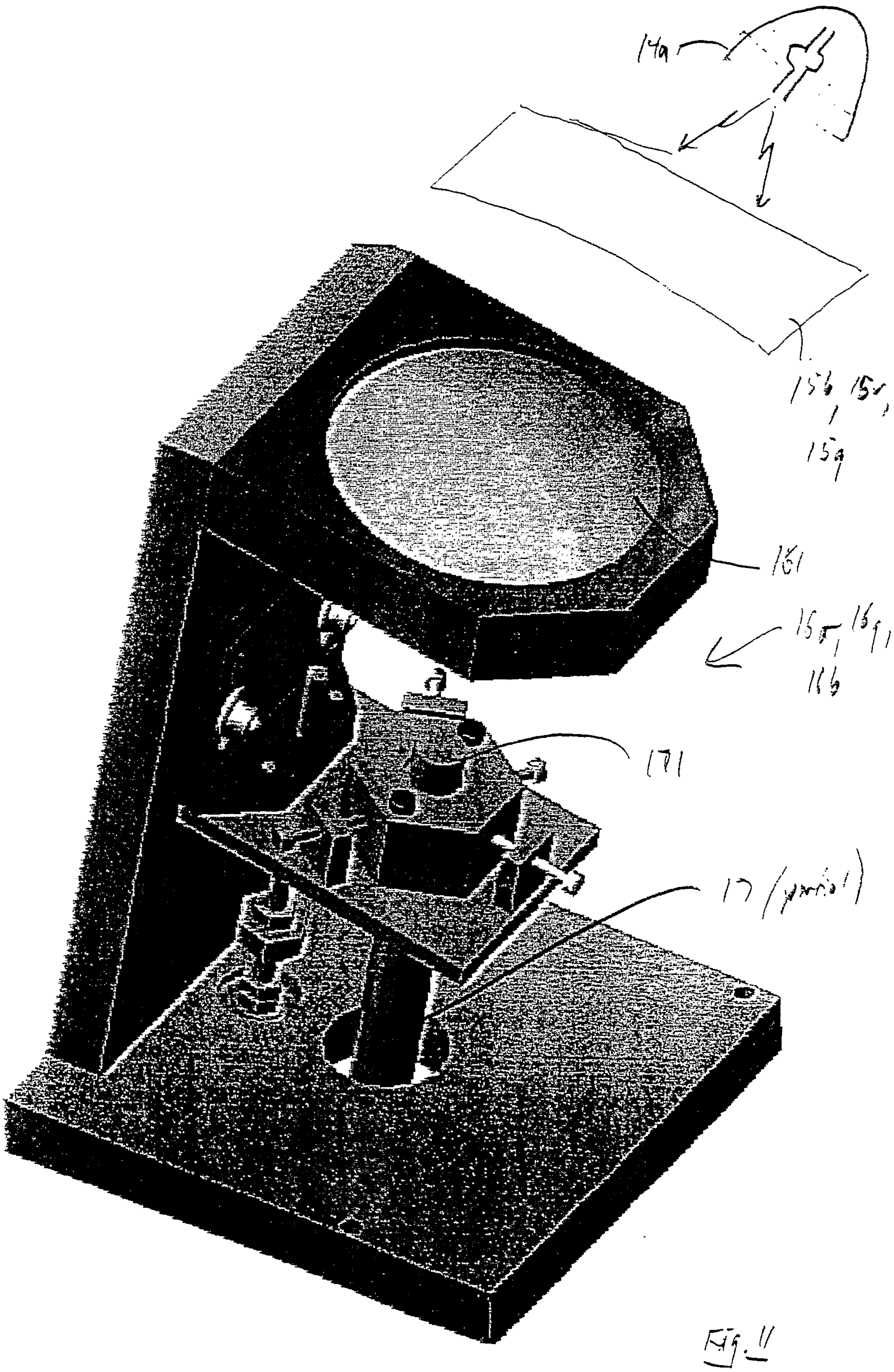


Fig. 11

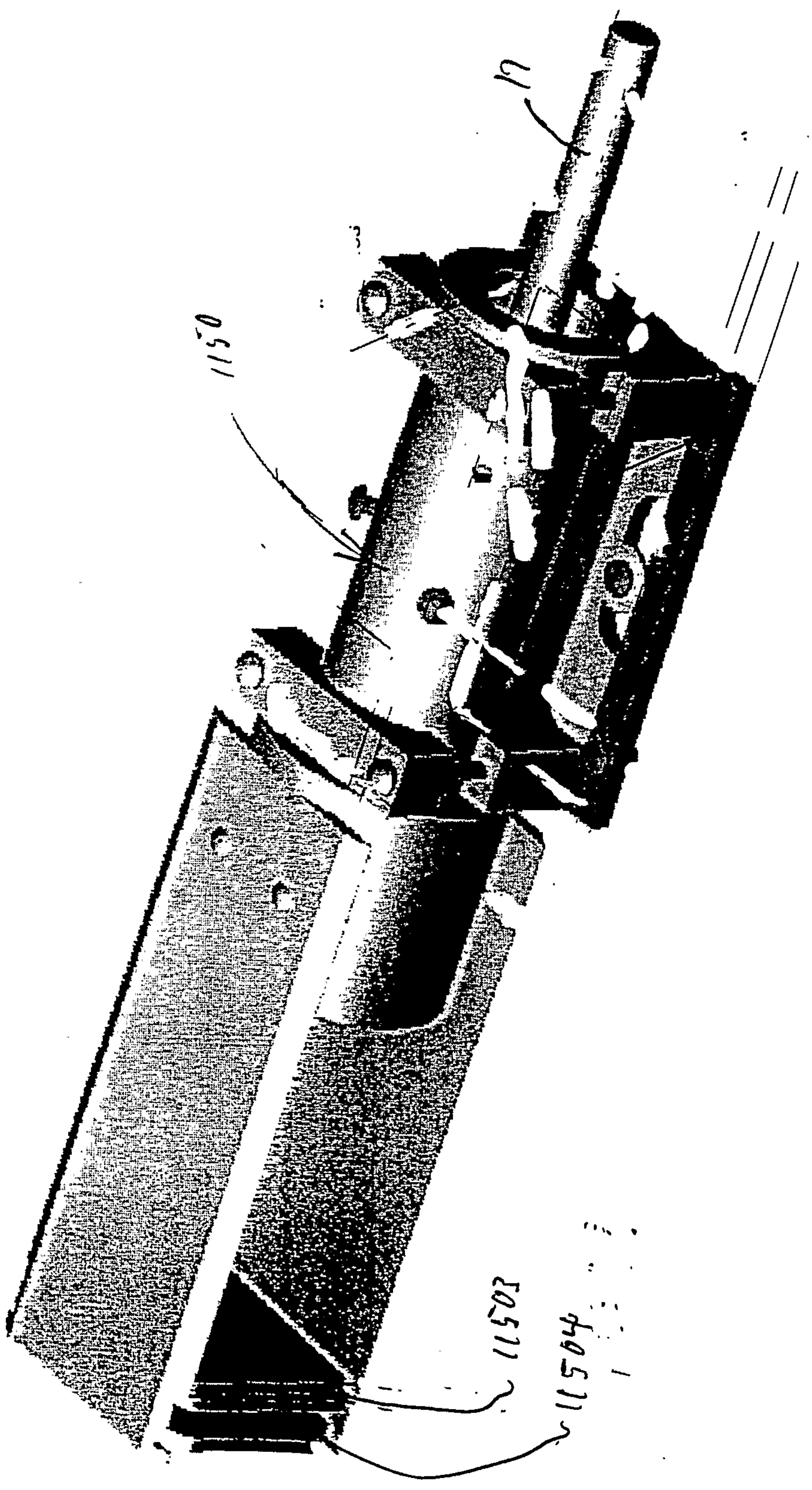


Fig. 12a

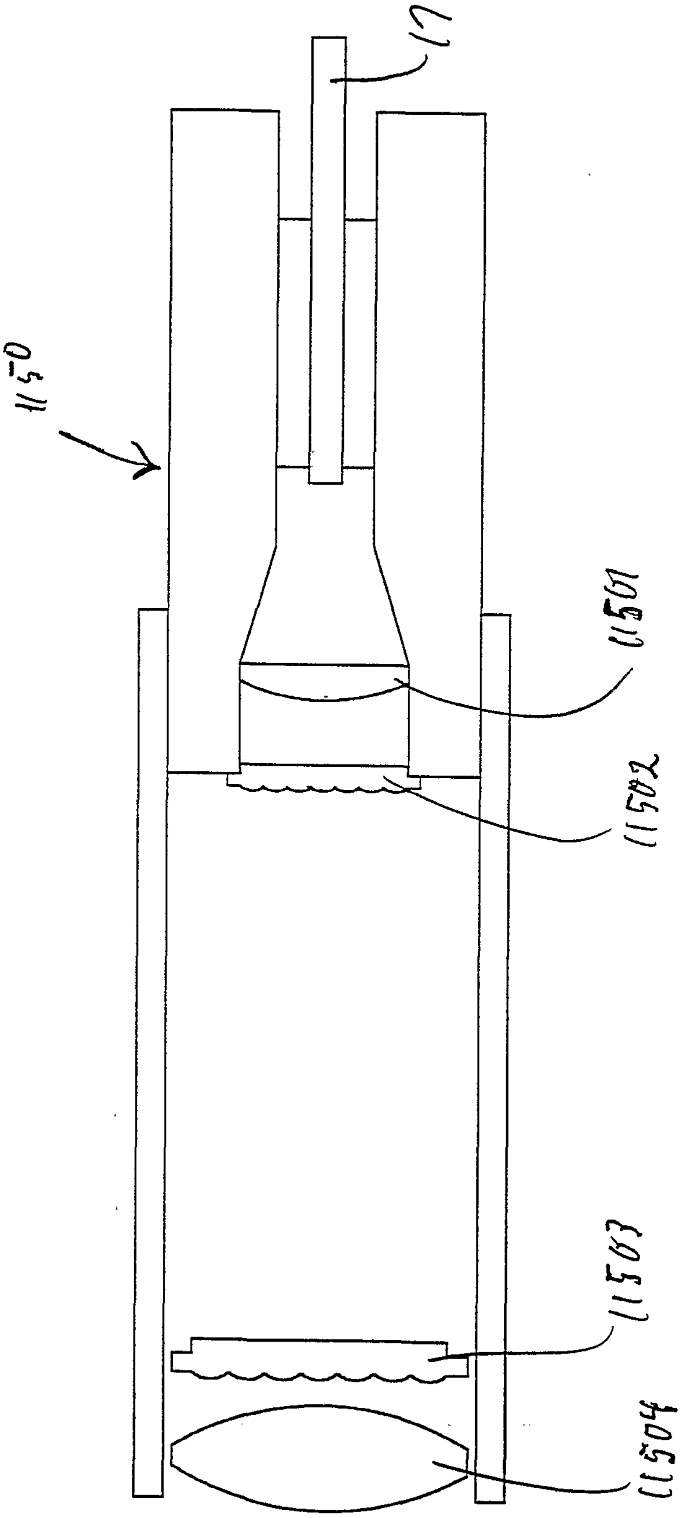
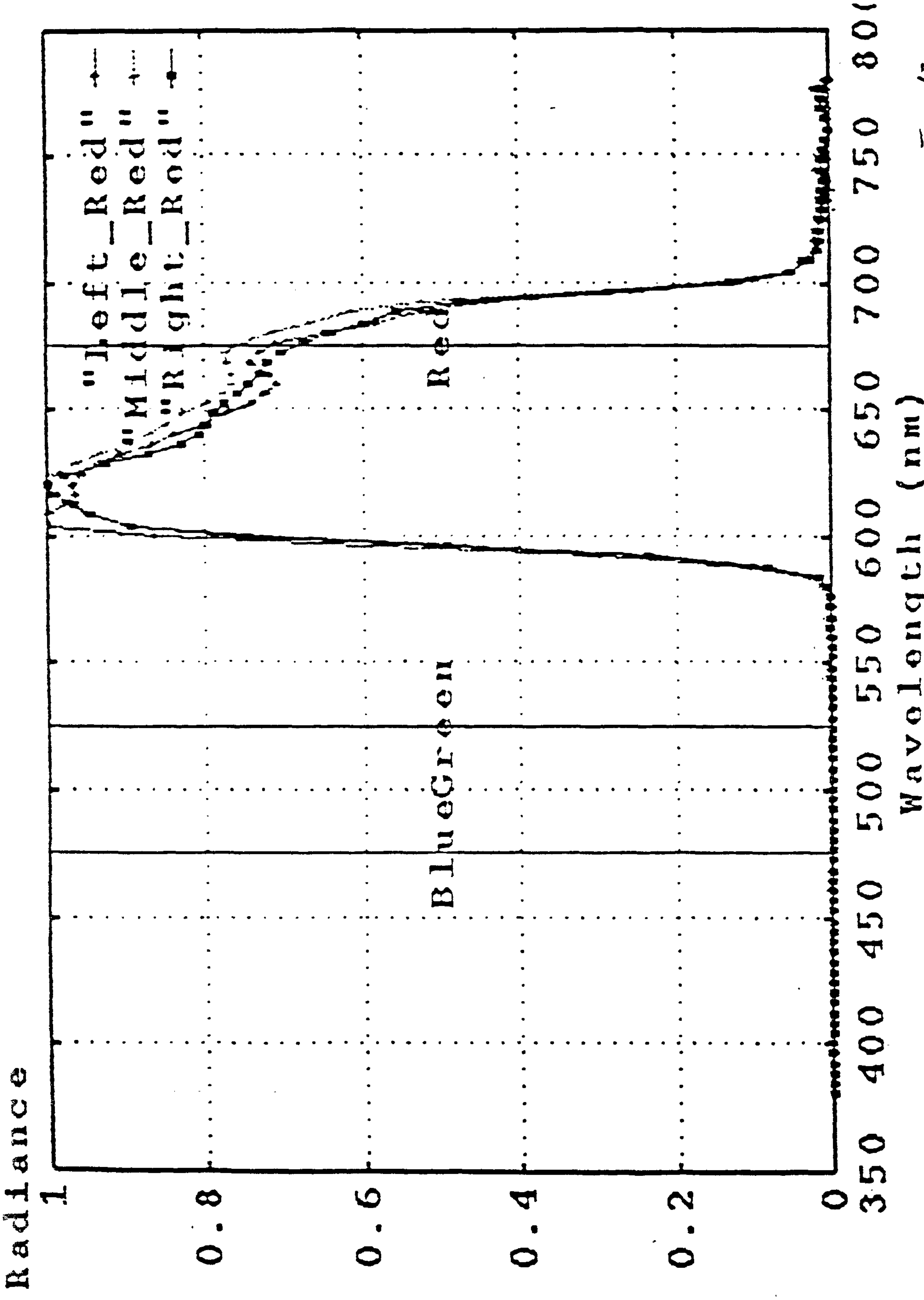


Fig. 12g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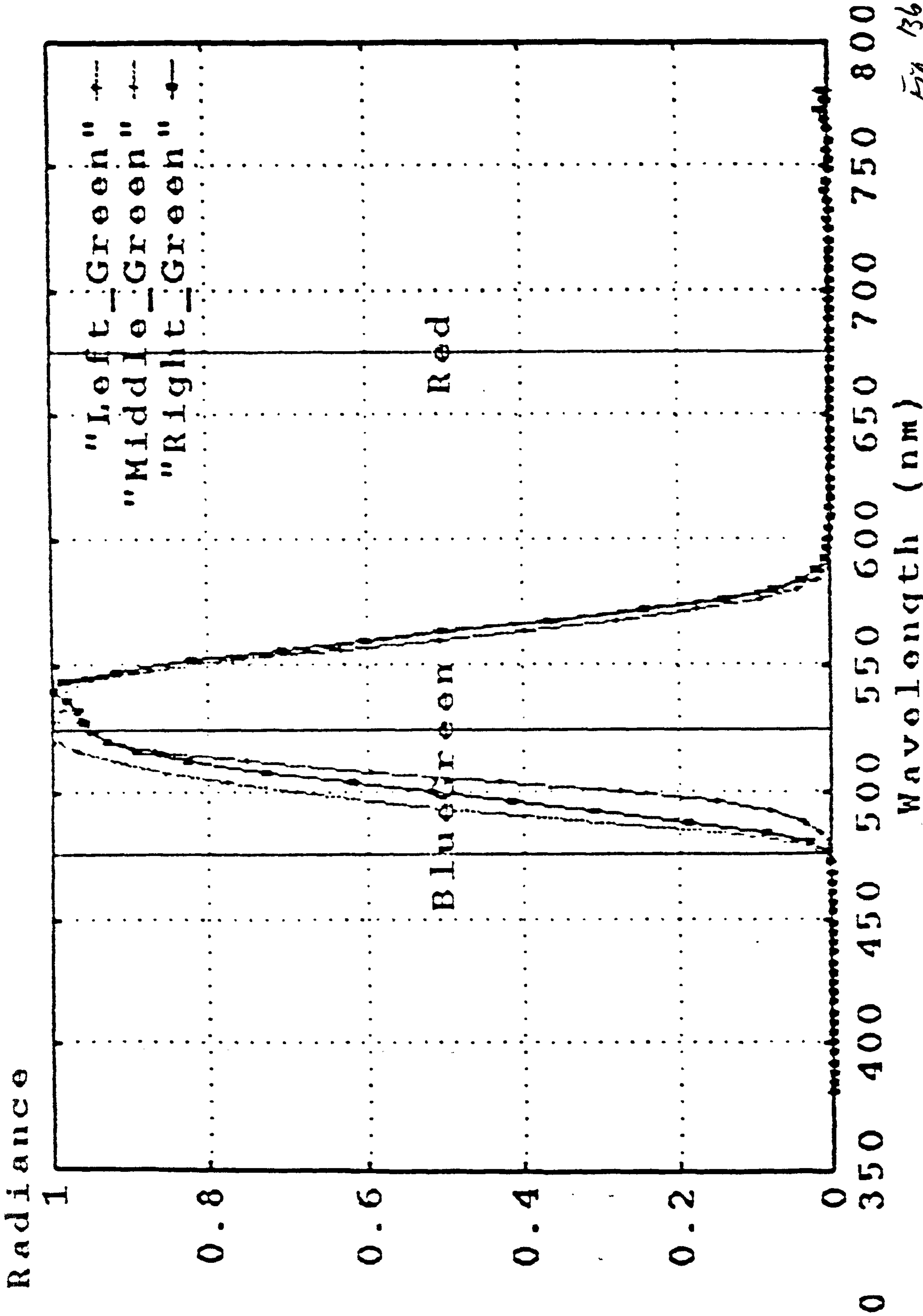
0.6
0.4
0.2
0
350
400
450
500
550
600
650
700
750
800
Wavelength (nm)
"Left_Red"
"Middle_Red"
"Right_Red"
Red
BlueGreen

Fig. 13a


Radiance
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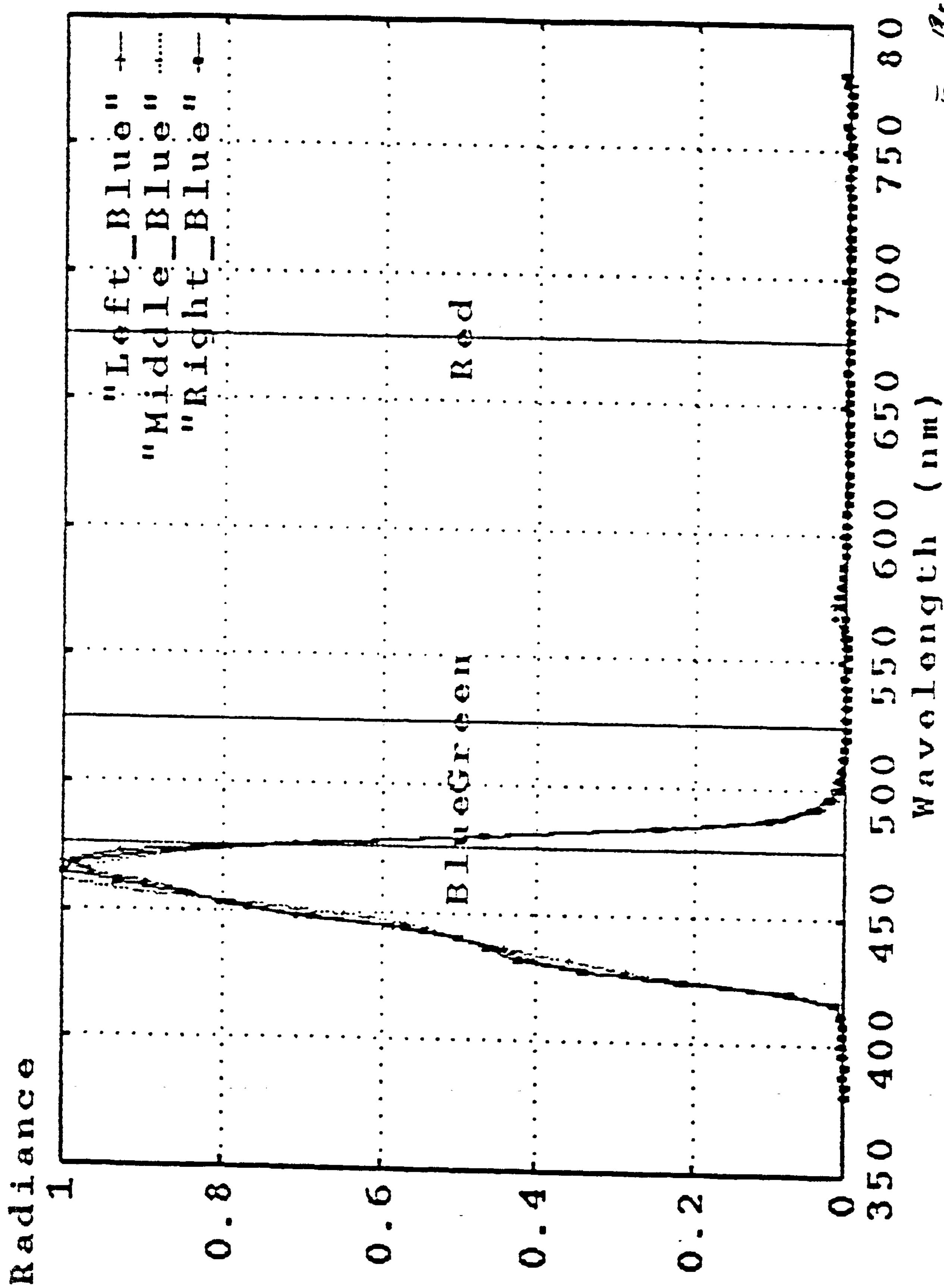
0.6
0.4
0.2
0
0
350
400
450
500
550
600
650
700
750
800
Wavelength (nm)
"Left_Green"
"Middle_Green"
"Right_Green"
Blue
Green
Red

Fig. 13b


Radiance
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0.6
0.4
0.2
0
350
400
450
500
550
600
650
700
750
800
Wavelength (nm)
"Left_Blue"
"Middle_Blue"
"Right_Blue"
Red
BlueGreen

Fig. 8c

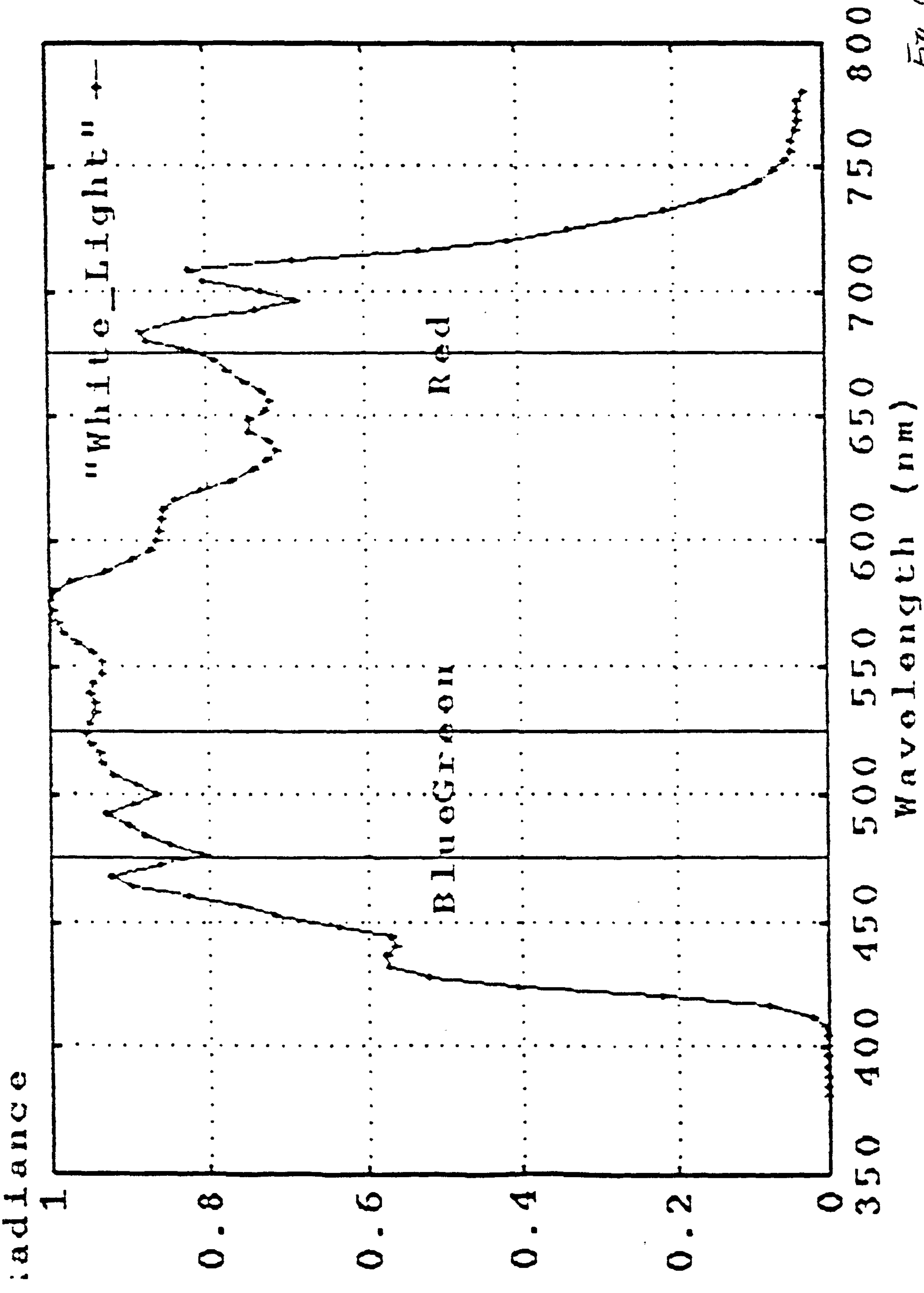
"White_Light"
Red
BlueGreen
Wavelength (nm)
350
400
450
500
550
600
650
700
750
800
0
0.2
0.4
0.6
0.8
1

Fig 13d