Projection television

A review of current practice in large-screen projectors

by Angus Robertson

Although projection television has been around since television was originally developed, it is only in recent years that considerable research has been directed towards developing new techniques for producing large-screen television projectors. Several TV projectors have been produced specifically for the consumer market, although at present their prices are far higher than direct-viewing receivers.

In the early days of television, it was not easy to manufacture cathode-ray tubes larger than 30cm diameter. To obtain larger pictures, manufacturers used a lens in front of a small, high-intensity c.r.t. and projected the raster onto a screen contained within the cabinet. Mirrors were usually used to fold the light path and enable smaller cabinets to be used. During the fifties, larger and brighter c.r.ts were manufactured and projection TV faded out. Although larger tubes have been produced for special applications, sizes have levelled off with diagonals of 66cm: larger pictures require special techniques.

The first large-screen television projector was invented by Professor Fischer at the Swiss Federal Institute of Technology in 1939. At that time, Prof. Fischer thought that the growth of television would come from the development of networks of neighbourhood "television theatres" and he invented the Eidophor with the capability of projecting TV pictures onto cinema-sized screens. The earliest Eidophors were cumbersone machines, which could project only black and white pictures in a darkened or semi-darkened room. They were not the most reliable of machines and for a number of years the Eidophor system was little known or used.

Later the American space programme called for a reliable, high-performance, large-screen projection system capable of working for long periods of time, to provide data displays in NASA flight control centres. Gretag AG, Zurich, a subsidiary of Ciba Geigy and patent holders and manufacturers of the Eidophor, successfully developed the projector's capability to meet NASA specifications. The latest Eidophors are able to project full-colour television pictures onto screens 18m wide. The Eidophor is still the only commercially-available projector able to project cinema-sized pictures, but colour versions cost over £100,000. Cheaper techniques have therefore been developed to provide projectors for industry, education and the home.

Three basic projection techniques are used. Eidophor, General Electric, Hughes, Westinghouse, IBM and Titus (Philips) use light-valve projectors, in which varied techniques are employed to modulate a light source, which is then projected onto tne screen. The second method is to use Schmidt optics (like the telescopes) to magnify and project the image from a small, high-intensity c.r.t. Advent, Pye (Mullard/Philips), Image Magnification, Ikegami, Kalart Victor and Pro-

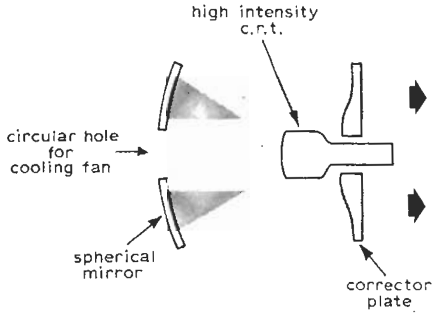


Fig. 1. Light path in Schmidt optical system.

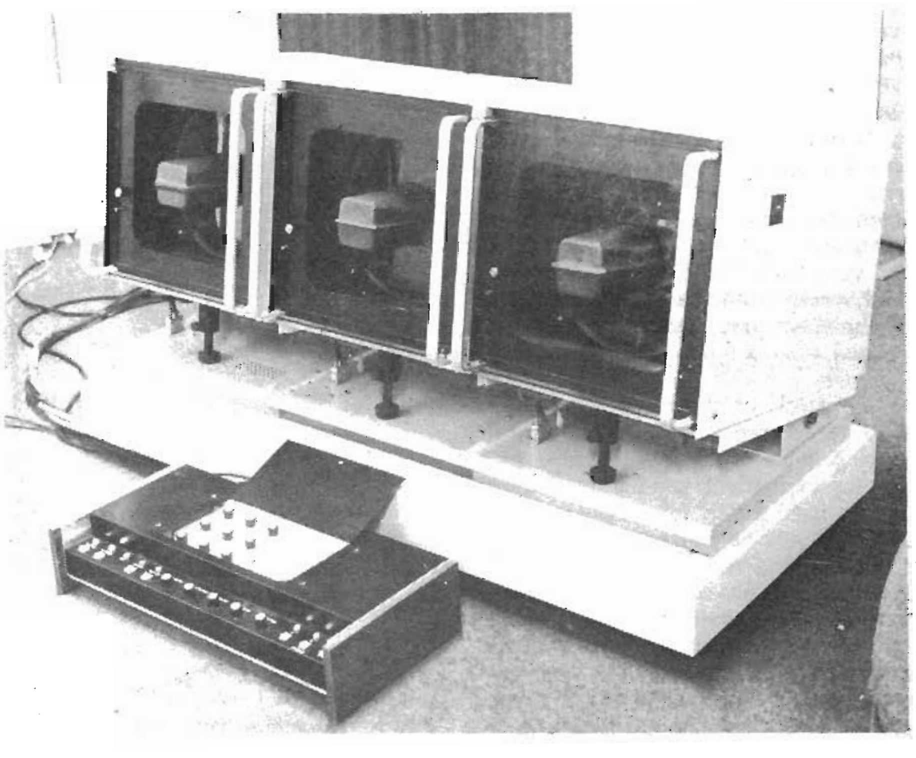


Fig. 2. Magna Image 111H colour Schmidt projector.

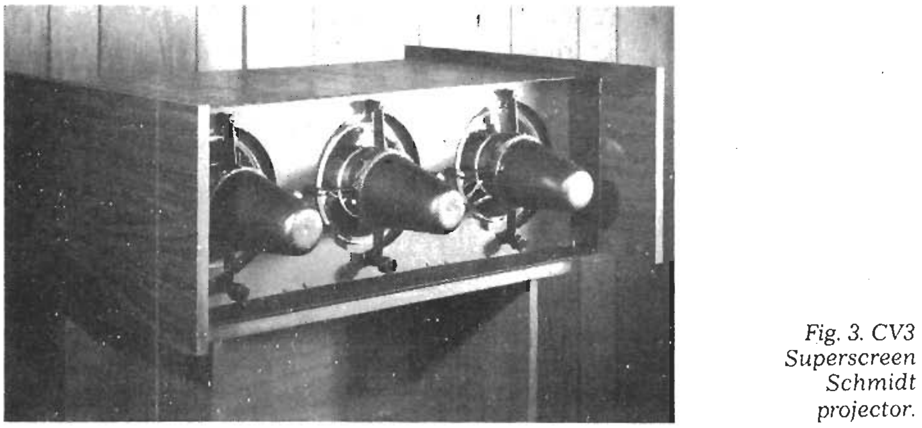


Fig. 3. CV3 Superscreen Schmidt projector.

jection Systems all use this technique. Finally, the refractive technique is the cheapest method, in which a glass or acrylic lens is placed in front of an ordinary c.r.t., usually a 33cm colour Trinitron, and the picture is projected onto a high-gain screen. We can expect to see lenses available separately soon to enable the handyman to modify his own TV set for projection.

Screens

Most video projectors, except possibly Eidophor, have low light outputs when compared with ciné projectors. For instance, refractive projectors have an output well below 50 lumens, Schmidt projectors emit between 200 and 500 lumens and the high power Eidophor produces 7,000 lumens. An ordinary 16mm ciné projector, with a 250W, 24V lamp, provides around 650 lumens while in motion and an overhead projector is usually rated at between 1,500 and 2,500 lumens.

To increase the apparent brightness of the projected image, it is common practice to use special screens which have "gain". Since no more light may be reflected from the screen than falls on it, the screen is made directional so that available light is concentrated into a small angle.

Projectors such as the Advent use an Ektalite-foil screen material, developed by Kodak. The material provides an on-axis gain of between eight and ten, with a 40° viewing angle but, to eliminate hot spots, the screen must be compound curved (both horizontally and vertically) and this necessitates a solid screen frame, usually fibreglass. Zygma Electronics use a specially-developed, solid, compound-curved screen that uses a highly-reflective spray-on paint instead of the more usual foil. Gain is 4.7 times with a horizontal viewing angle of 90°. While these are fine for permanent installations, they usually need a van for transportation and may only be concealed with difficulty, unlike a roll-up screen. A matt screen surface has a unity gain, while a beaded screen usually has a gain of 1.8. Projection Systems Inc. market a silver lenticule screen with a 2.5 gain and the exceptional viewing angle of 170°. This screen material, which is rollable, also has excellent ambient light rejection characteristics, this light being reflected sideways away from the viewers — ideal for hire work where the locations used rarely seem to have adequate black-out.

Mechanische Weberei, in West Germany, manufacture a projection screen with a gain of 3.5. This is also roll-up but it does not have the same ambient characteristics as the previous screen. It is however perfect for use where adequate black-out is provided. Ideal Image Inc. has produced a plastic lenticular screen with a gain of five but the lenticule (lens) size is such that minimum viewing distance is 6m and it must be compound curved. The company is presently developing a new plastic material similar to the Ektalite foil but which requires only horizontal curving rather than the compound curve. Single curves are used for large cinema screens and only require a curved frame lattice rather than the solid frame required for Ektalite. Although the screens being presently manufactured are 25m by 7.5m for wide-screen (and why not?) television projection, smaller sizes are available to order.

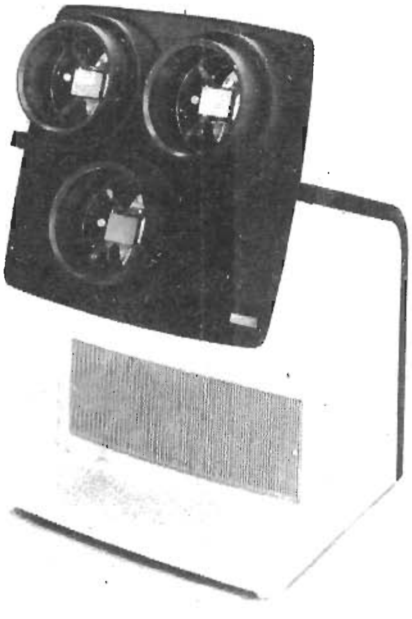


Fig. 4. Videobeam 1000A from Advent.

Rear projection. Although front projection is common there are certain applications where rear projection is preferred. For instance the Eidophors installed at the NASA flight control centre are rear projected for convenience; it would be impractical in that particular location to project the image onto the front of the screen. Screens used for rear projection are usually of high density and low gain in order to minimize "hot spots". To obtain the projected image the correct way round, current to the horizontal scanning coils is reversed. On some projectors scan reversal is achieved by a switch, on others, it is a case of resoldering two wires on each scanning yoke.

Although not yet commercially available, a rear projection screen has been developed in the USA with a gain of about eight. No further details are known nor do I know of any other rear projection screens with a gain greater than unity.

Screen brightness. Projector light output is usually quoted in lumens, which have the advantage of being identical in imperial and metric units. The illumination falling on the screen is measured in lumens/m² (lux) but since most screens provide some gain, luminance in candelas/m² (nits) is the unit used (except by the Americans who still use ft lamberts). **Example:** A projector light output is 500 lumens. Screen size is 3m x 4m = 12m². Screen illumination is

$$\frac{500}{12} = 41.7 \text{ lux.}$$

If the screen gain is two, screen luminance is

$$\frac{41.7 \times 2}{\pi} = 26.53 \text{ cd/m}^2.$$

Resolution. A 625-line, 50-field television signal has a bandwidth of 5.5MHz and a horizontal resolution of 570 lines. The resolution of colour c.r.ts is limited by the number of phosphor dots or stripes; therefore, the larger the screen, the higher the possible resolution. Since most colour projectors project each colour separately, resolution is usually only limited by the electronics associated with each channel. For the display of computer-generated data and command applications, higher definition is often required and the use of 1,029 lines per frame and video bandwidths of up to 40MHz enables a horizontal resolution of over 1,000 lines to be achieved. Digital techniques are sometimes used to obtain accuracy in the corners of the picture. When displaying characters which combine more than one colour, registration accuracy is critical; otherwise double characters will be displayed.

Schmidt projectors

Fig. 1 shows the principle of the external Schmidt c.r.t. projector, in which tube diameter can vary between 75mm and

150mm for different projectors. The reflector needs to be two or three times the raster size, which precludes the use of large colour tubes on purely physical grounds. The centre of the mirror is removed to prevent light being reflected directly back towards the c.r.t. faceplate and a fan is inserted in the hole to cool the high-intensity faceplate.

Light output from Schmidt projectors depends upon tube and reflector size. RCA quote a light output of 450 lumens from a 125mm c.r.t. when operating with 45kV and 500μA. Tubes operating with more than about 30kV produce X-rays and care is required in the construction of such projectors to provide adequate shielding. Some projectors include interlock circuits which remove e.h.t. when the protection covers are removed for maintenance.

For colour projection, three optical systems are used with green, red and blue c.r.ts. Usually, these are mounted in-line, but one manufacturer uses a triangle formation. Complex analogue circuits are included to enable registration of the three images in much the same way as a shadow mask tube – a process which is made easier by the in-line layout. Projectors usually have a built-in cross-hatch generator and basic registration controls are often mounted on a separate control unit for convenience.

Another facility usually included is keystone correction. When a projector is mounted on the ceiling (out of the way), the projected image is angled down at the screen giving a picture wider at the bottom than the top. Keystone correction enables the verticals to be electronically corrected, usually to correct for angles of ±15°. An optical keystone corrector may be provided which adjusts the c.r.t. position to provide equal focus over the screen. The tube is usually mounted on a carriage which enables it to be moved in relation to the reflector to provide optical focus for differing projection distances. The corrector plate is designed to compensate for deficiencies in the optical system and is optimized for a particular projection throw. Although most Schmidt projectors allow focusing at variable distances, often the corrector plates must also be changed if a wide range of projection distances is to be accommodated.

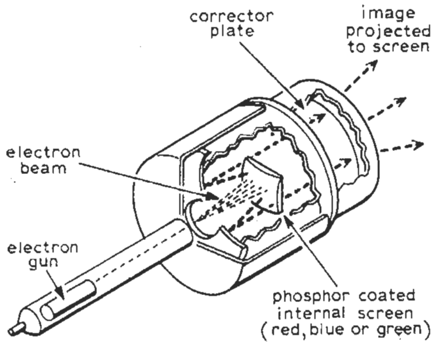


Fig. 5. Advent Lightguide tube, with complete Schmidt system inside envelope.


Fig. 6. Zygma Teleprojector.

Image Magnification Inc. The Magna Image I is a monochrome projector which uses a 125mm c.r.t. Picture width is variable between 1.2m and 6m with a resolution of 600 lines in the centre. Price: £3,500. The Magna Image IIIH, shown in Fig. 2, is a colour projector using three heads in-line. Picture widths between 2.4m and 6m with a resolution of 500 lines. Price: £12,750.

Kalart Victor Corp. The Telebeam II projects a monochrome picture between 1.8m and 3.6m wide (specified when ordered) with a resolution of 550 lines. Light output is 384 to 576 lumens from a 125mm tube. Price: £3,810.

Projection Systems Inc. The CV3 Superscreen, Fig. 3, projects a colour picture with widths between 1.8m and 2.4m from 75mm tubes. Light output is about 200 lumens. Price: £4,490. Model 270A is a monochrome projector with a light output of 800 lumens for screen widths between 1.8m and 6m. Resolution is 1,000 lines in the centre. Price is $11,800. Model 560 is a colour projector with a light output of 600 lumens for a screen width of 3.6m. Price: $14,750. Amphicolor 1000 uses three 150mm tubes for colour projection with 4800 lumens. Screen widths of either 2.4m or 4.2m. Price: $29,500.

Pye TVT. The Mammoth is a colour projector with a claimed light output of 800 lumens onto a 4m wide screen. Centre resolution is 600 lines and price is on application.

Ikegami. The TPP-2C is a colour projector with a light output of 360 lumens, intended for a maximum 4m by 3m screen. Price: £16,000.

Advent Corp. The Videobeam 1000A in Fig. 4 uses the Schmidt technique, but instead of having separate tube, reflector and corrector plate, all are vacuum sealed in the same envelope, as seen in Fig. 5. The electron beam scans a 75mm phosphor coated target (red, green or blue). Emitted light is then reflected onto the spherical mirror and back through the corrector plate to the screen. Although this approach has manufacturing advantages, the projection distance is fixed at 2.54m exactly, and light output is low since all parts are sealed within the tube and it is not possible to cool the target. Although not specified by Advent, working backwards from the screen brightness gives about 60 lumens light output. Thus a bulky, high gain screen is required to obtain an adequate screen brightness. Screen dimensions are 1.32m by 1.75m. Advent has however, recently announced a set of lenses which may be attached externally to the sealed tubes enabling a 2.4m x 1.8m picture on a flat screen. The screen brightness thus obtained would necessitate a well darkened room.

Advent are intending to introduce a new, cheaper projector on the American market this summer. No further details are available nor has a British launch date been announced.

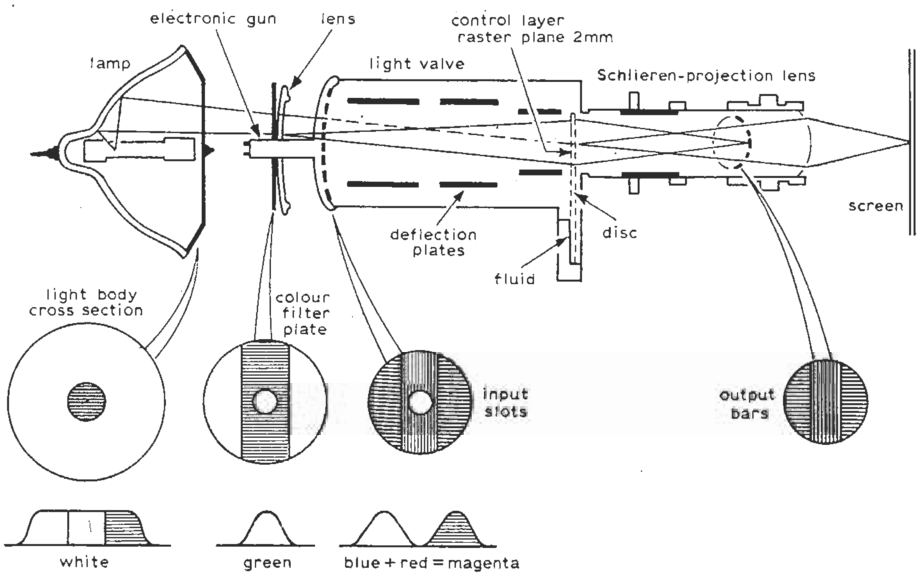


Fig. 7. General Electric light-valve projector.

Zygma Electronics manufacture a projector which has characteristics which are very similar to the Advent Videobeam. The Type 2001 Teleprojector shown in Fig. 6, uses internal Schmidt optics tubes with a fixed projection distance of 2.54m onto a high gain screen 1.75 x 1.32m. Screen brightness is 140cd/m and the price is £4,950.

Light valves

General Electric use transmission light valves in monochrome and colour projectors. Colour pictures are produced from a single projection tube using a diffraction grating to separate the colours. The projector, seen in Fig. 7, uses a separate xenon light source, a fluid control layer in the light valve, and a projection lens. Optically it is similar to a slide or ciné projector.

Miniature grooves are created on the deformable surface of the fluid control layer by electrostatic forces from the charge deposited by the electron beam, which is modulated with video information. These groove patterns are made visible by use of a "dark field" or schlieren optical system consisting of a set of input slots and output bars. The resulting television picture is imaged on the screen by the projection lens.

Cross sections of the light body, colour filters and input and output slots are shown below the light valve in Fig. 7. Green light is passed through the horizontal slots and is controlled by modulating the width of the raster lines themselves, by means of a high-frequency carrier applied to the vertical deflection plates and modulated by the green video signal. Magenta (red and blue) light is passed through the vertical slots and is modulated by the diffraction

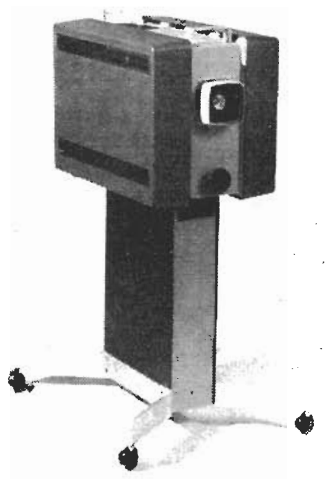


Fig. 8. General Electric PJ6000.

gratings created at right angles to the raster lines by velocity modulating the electron spot in the horizontal direction. This is done by applying a 16MHz (12MHz for blue) signal to the horizontal deflection plates and modulating it with the red signal. The grooves created have the proper spacing to diffract the red portion of the spectrum through the output slots while the blue portion is blocked. For the 12MHz carrier the blue light is passed and the red blocked. Thus, simultaneous and superimposed primary colour pictures are written with the same electron beam and projected to the screen as a completely-registered full-colour picture.

Because of problems of heat dissipation, and the avoidance of frequent repairs (the light valve costs about $12,000), the xenon lamp is limited in power to 650W. The PJ7000 monochrome projector has a light output of 750 lumens and is suitable for picture widths between 0.75m and 3.6m, with a typical horizontal resolution of 1,000 lines. Three lenses are available to accommodate different throw/width distances. The PJ6000, Fig. 8, and PJ5000 colour projectors have a light output of about 280 lumens, a resolution of 600 lines and the same focusing ability, although a 2.4m screen width is optimum for colour. Light output of the colour projectors is less than the monochrome projectors since light is lost in the diffraction process. Life of the light valve is usually over 3,000 hours but 7,000 hours has been achieved in the laboratory. Price of the PJ7000 is $46,000, and the PJ6000 and PJ5000 cost $52,500.

Titus light valve. Developed by the Laboratoires d'Electronique et de Physique Appliquée (LEP), part of the Philips organisation, the Titus projector uses the Pockels effect in a refractive light valve. This works on the principle that certain crystals, in this case potassium di-hydrogen phosphate, rotate the plane of polarization of a beam of incident light through an angle proportional to modulation by the accelerating voltage of a constant-current electron beam. Fig. 9 shows a tube using these principles in a monochrome projector. A peltier cooler is required to keep the temperature of the plate just above its Curie temperature of about —50°C.

The target is bombarded by an electron beam whose accelerating voltage lies between 500 and 1,000V, a grid

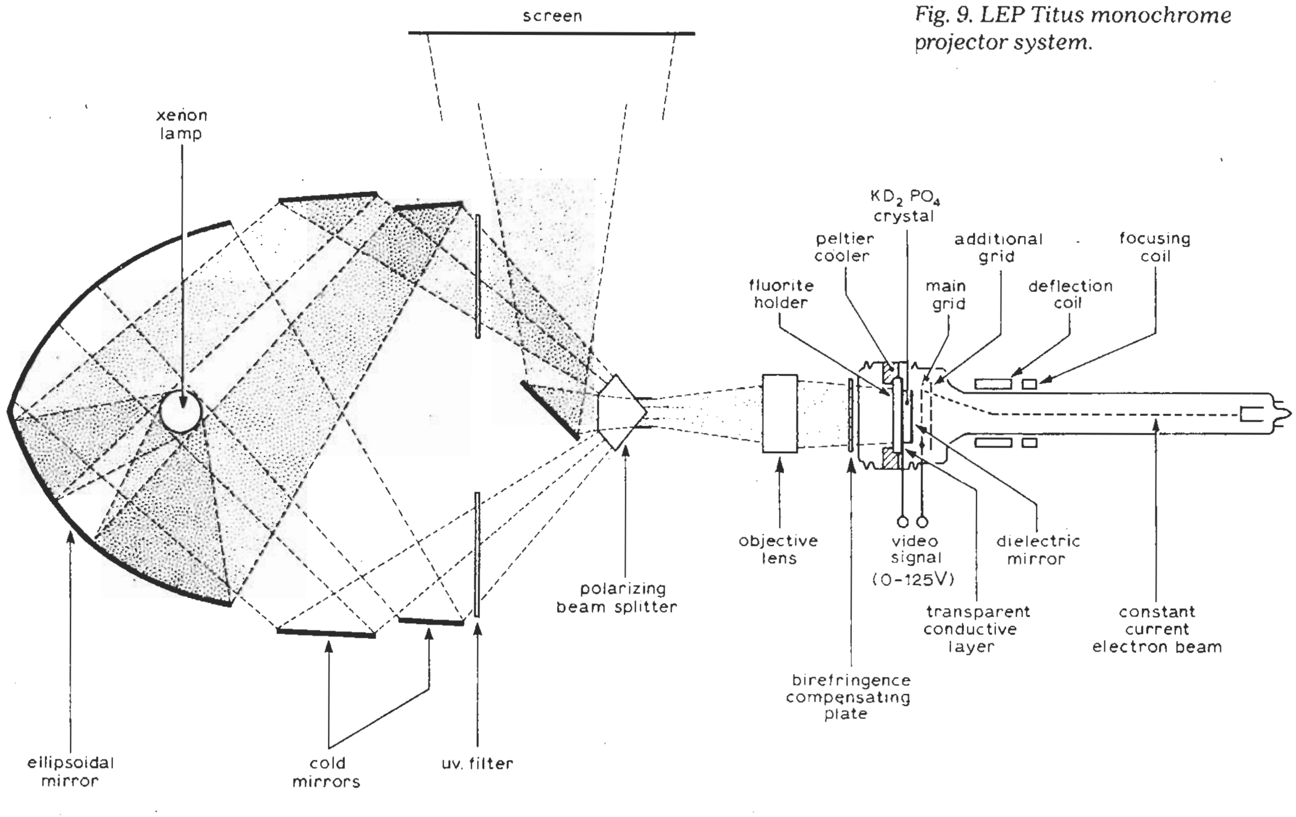


Fig. 9. LEP Titus monochrome projector system.

being placed in front of the target at a distance of about 40μm. The electron beam, of constant intensity, functions as a flying-spot short circuit between this main grid and the point of impact of the target, which thus reaches a potential close to that of the grid. The video signal is applied between the transparent conductive layer and the grid, to ensure that the various points of the target are charged to the corresponding video voltage when they are hit by the electron beam, irrespective of their previous potential. Erasure and writing are therefore simultaneous and this, coupled with the long discharge time-constant of the target, results in flicker-free operation. In addition, since the voltage pattern stored on the target does not depend on the intensity of the electron beam, it is found that no line structure is apparent on the picture. The absence of line structure, however, is not accompanied by loss of vertical resolution.

Twin ellipsoidal mirrors are used to provide high collection efficiency from the 2.5kW xenon lamp. A calcite polarizing beam splitter which transmits only light whose electric vector is parallel to the plane of Fig. 9 is used to transmit light to the Titus tube. The projection lens is placed between this polarizer and the tube and acts as a collimating lens so that the luminous beam incident on the plate has a mean directional normal to the latter. When the light beam is reflected at the dielectric mirror and passes through the lens and beam splitter again, only the light component with its electrical vector perpendicular to the plane of Fig. 9 is transmitted to the screen. In practice, light output from the monochrome projector is about 2,500 lumens, with a horizontal resolution reaching 750 lines. A 4kV xenon lamp may be used to increase this output.

A colour projector using Titus tubes is shown in Fig 10, in which two dichroic mirrors are used to split away blue and red beams. Ellipsoidal mirrors similar to those of the monochrome projectors are used but not shown here. Using a 4kW xenon lamp, 3,200 lumens output have been obtained from an experimental prototype.

The Titus is the only television projector that has an output capability comparable to the Eidophor. Efficiency is about half that of the Eidophor since half the light is lost in the original polarization.

Hughes liquid crystal. This projector uses a liquid-crystal reflective light valve which is addressed by a c.r.t. Fig. 11 shows the various layers which make up the liquid-crystal light valve. In operation the cadmium sulphide photoconductor acts as a high-resolution, light-controlled voltage gate for the liquid-crystal layer. The dielectric layer serves to reflect the projection light while the cadmium telluride light-blocking layer prevents residual pro-

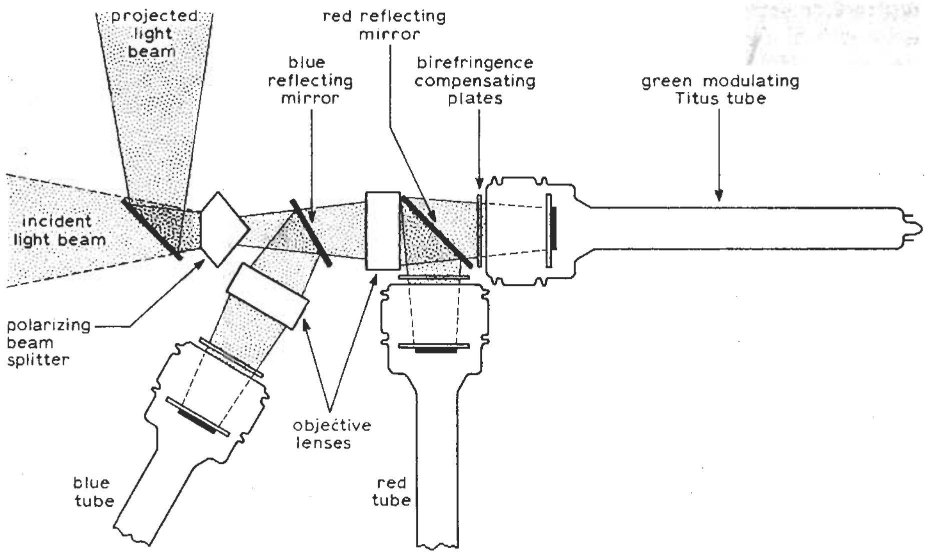


Fig. 10. Three Titus tubes used for colour projection.

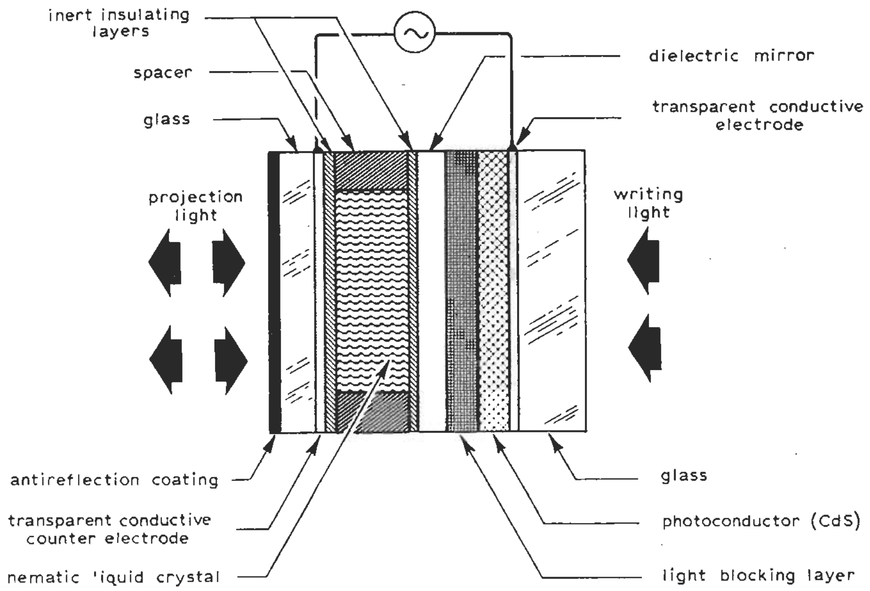


Fig. 11. Sectional view of a liquid-crystal light valve.

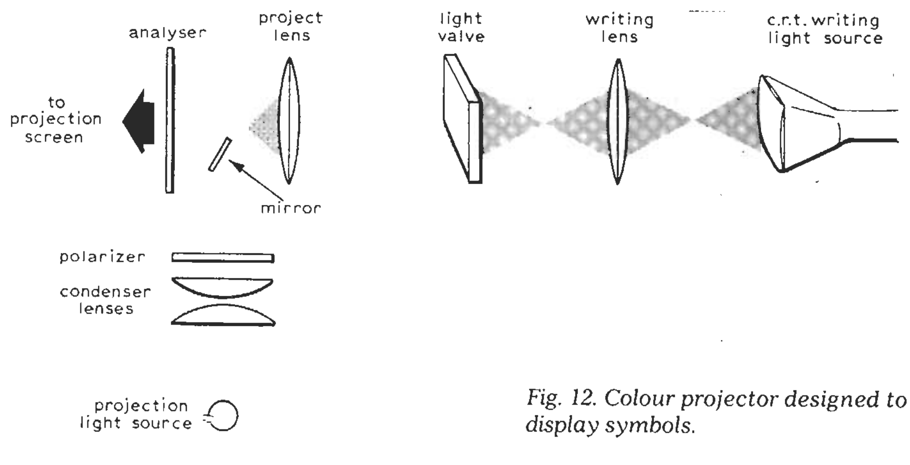


Fig. 12. Colour projector designed to display symbols.

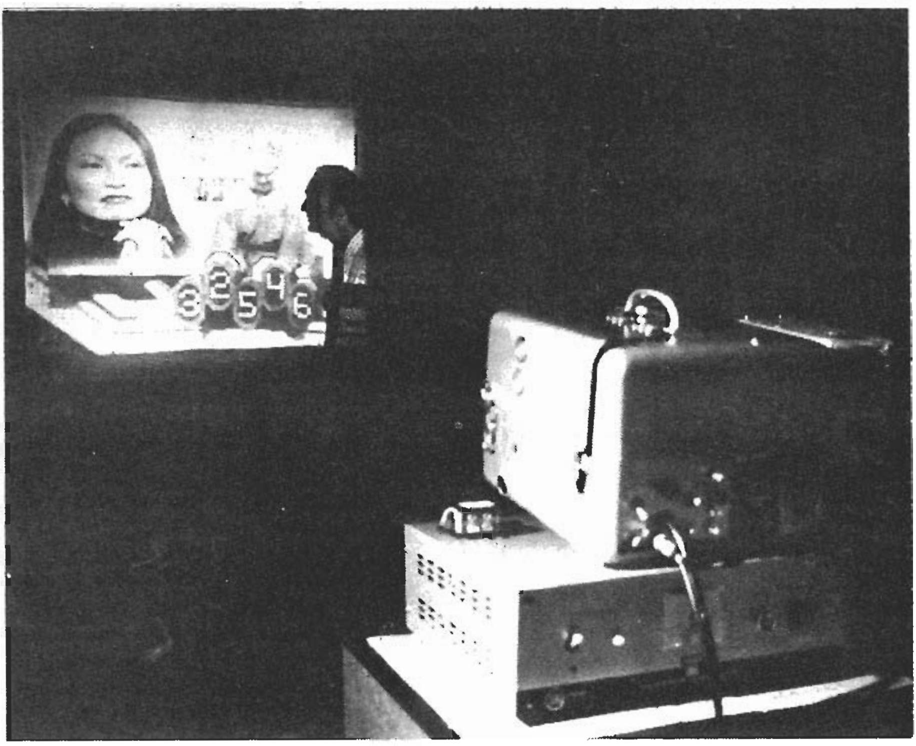


Fig. 13. Hughes light valve projector.

jection light reaching the photoconductor. Because of the high d.c. resistivity of the dielectric mirror, the device is operated with an alternating voltage impressed across the sandwich structure. This has the added benefit of extending the life of the liquid crystal. The device is used in the optical system shown in Fig. 12. Light from the projection lamp is collimated, polarized and directed to the cell. The light passes through the liquid crystal and is reflected from the dielectric mirror.

The second polarizer, which is crossed with respect to the first, is placed in the projection beam that is reflected from the light valve. The display operates in the following manner. The liquid crystal is aligned with its optical axis nearly perpendicular to the device electrodes so that, in the off state, no phase retardation occurs and the projection light is blocked from the screen by the crossed polarizers. With imaging light incident on the photoconductor, a voltage above the field effect threshold is switched onto the liquid crystal layer. The liquid crystal has negative dielectric anistropy, so that the molecules tend to align normally to an applied electric field. Thus the applied voltage rotates the molecules from their initial state parallel to the field and introduces a phase retardation between ordinary and extraordinary rays in proportion to the spatial intensity variation of the imaging light. This phase retardation changes the polarization of the projection light and, due to the dispersion effect, allows selected colours to pass the crossed polarizers.

In the display of symbols, the colour of a selected character in the projected image may be selected by the level of intensity of the input imaging light. Low imaging light intensity (low voltage switched to the liquid crystal) leads to a white (all colours present) on black image, while higher imaging intensity increases the alternating voltage on the liquid crystal and leads to the selection of certain colours; blue, green, yellow and magenta. These colours have only one luminance and are thus suitable only for displaying coloured characters or symbols superimposed upon a black and white grey-scale picture

So far, images of 350 lumens have been projected, using a 150W lamp, by the equipment shown in Fig. 13. This projector was developed by Hughes in co-operation with the US Navy, and in its present form is intended for symbol displays.

To be continued next month with a look at refractive projectors

75MHz counter

A set of p.c.bs is now available for the 75MHz counter which was published in the 1976 Wireless World Annual. The set comprises six boards to accommodate the count-store-display circuitry, divider, crystal clock, function select, input amplifier, and power supply. Wire links are used where necessary to avoid the expense of double-sided boards. The set is priced at £12.00 inclusive of v.a.t. and postage and is available from M. R. Sagin at 11 Villiers Road, London N.W.2.

Projection television—2

Refractive projectors

by Angus Robertson

The simplest form of television projection is to project the raster of an ordinary c.r.t. onto a screen using a lens. Light output depends upon the accelerating voltage and the efficiency and aperture of the projection lens; wide-aperture glass lenses are extremely expensive. There are two groups of refractive projectors, which are dealt with separately.

Trinitron projectors

Sony. The principle of the Sony VPP-2000, seen in Fig. 14, is shown diagrammatically in Fig. 15. A special 33cm Trinitron colour c.r.t. is used as the source, the light from which is directed, via a mirror, through the projection lens, with six elements, a focal length of 29cm, a diameter of 12.5cm and aperture f/2. A high-gain, solid screen, 1.02m by 0.76m, is used to obtain a quoted 34 nits (cd/m^2) luminance and, working backwards from this, the calculated light output is 10 lumens. Price is £1,500. Sony also produce a self-contained projection system, the KP-4000, whose principle is illustrated in Fig. 16. A Trinitron tube projects onto an internal 81cm by 61cm high-gain screen with a brightness of about 34 nits. Although not presently available in the UK, price in the States is similar to the VPP-2000. The VPK-1200E uses three 33m single colour tubes to project a 1.8m by 2.4m picture onto a high gain screen. Light output is about 200 lumens. Only two lenses are used; the outputs of the red and blue tubes are combined by a dichroic mirror. Lenses are f/2 with 30cm focal lengths. Price is expected to be around £16,000.

Fig. 14. Sony VPP-2000 uses a Trinitron source

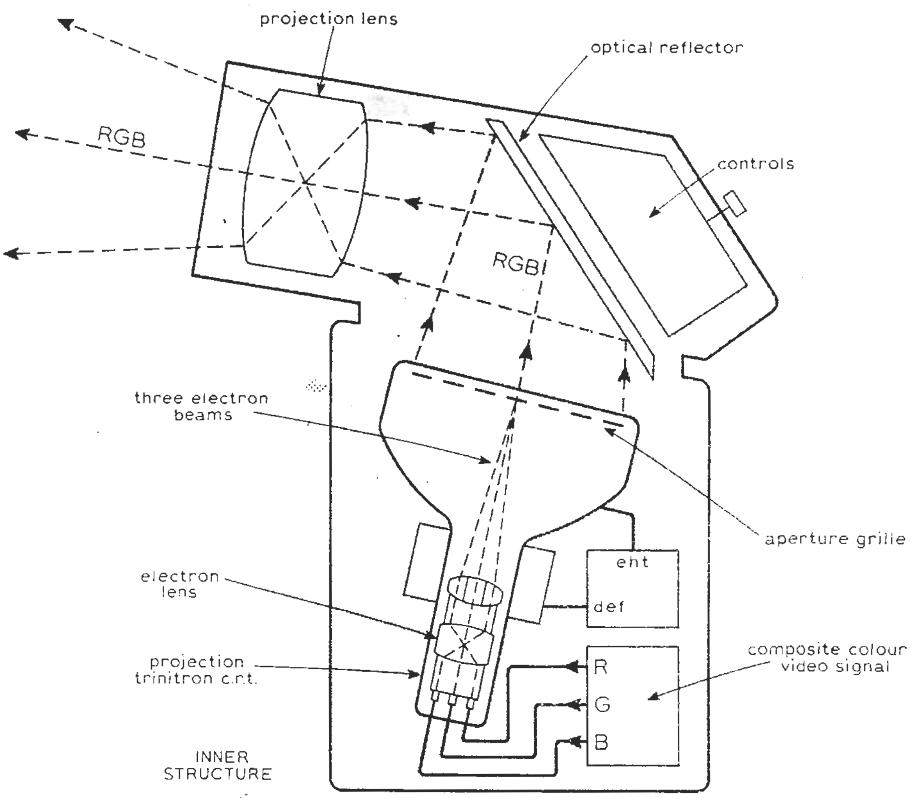


Fig. 15. Principle of the Sony VPP-2000

Muntz/Markoff Theatre Vision Inc. and **Tele-Theatre** (Fig. 17) both manufacture refractive projectors using a Trinitron colour tube and a separate 1.02m by 0.76m high gain screen. Tele-Theatre price is £1,000.

Shannon Communications Inc. has developed a 30cm diameter lens system moulded from acrylics. It fits in front of a Trinitron tube and unlike the previous systems is focusable. Unfortunately little experience exists in the moulding of lenses of this diameter and the British company who were originally going to manufacture the acrylic lenses now feel unable to guarantee production. Whether the Shannon projector will be marketed in the near future now remains to be seen.

The problem with the manufacture of acrylic lenses is still to be solved. Lenses may be ground down from a solid blank which is an expensive process. Alternatively they may be hot moulded from acrylics. However when using this process to mould large diameter lenses (30cm), problems with expansion and cooling make accuracy extremely difficult. Until these snags are overcome, Mullard are going to try polishing lenses hot moulded to obtain greater accuracy.

The basic difficulty encountered with the previous refractive projectors is that the smallest colour tube available is the 33cm Trinitron. This uses an aperture grill and vertical stripes of coloured phosphor on the screen. About 400 groups of stripes are deposited across the screen and as mentioned earlier, this limits the resolution to 280 lines. It is not presently feasible to manufacture a colour tube of smaller dimensions because of the difficulties of maintaining sufficient resolution. Thus projector manufacturers are stuck with the problems of large diameter, wide-aperture lenses. There difficulties are not so prevalent when separate high-intensity, single-colour tubes are used. Shadow mask tubes may of course be used instead of the Trinitron tube.

Aeronutronic Ford

The refractive principle used by these projectors is perhaps the simplest to explain, but requires highly specialised techniques to obtain sufficiently high light outputs.

A 175mm c.r.t. is used as a basis for the projectors, shown in Fig. 18. The standard tube uses a glass faceplate with an active area of 10cm by 12.5cm; accelerating voltage used is 60kV with a very high beam current. To obtain a higher light output a sapphire faceplace may be used, which has a much higher thermal conductivity than glass, allowing power dissipation of up to 40W (six to seven times that of glass) from the faceplate. Such a large plate is bonded to the tube by an exclusive process that compensates for varying thermal stresses between the glass tube and sapphire faceplate.

The projectors are fully refractive using nine element lenses with a speed of f/0.87. Analogue circuits are used for coarse colour registration with a digital correction system using semiconductor storage to obtain an accuracy of half a picture element over the *entire* screen, not just the centre. To combine the outputs of the three colour tubes, two of which are not normal to the screen, the Scheimphlug condition is used where the plane of the screen, plane of the c.r.t. and plane perpendicular to the axis of the lens, intersect at a common line to preserve focus at expense of distortion (which can be corrected at the same time as the convergence errors).

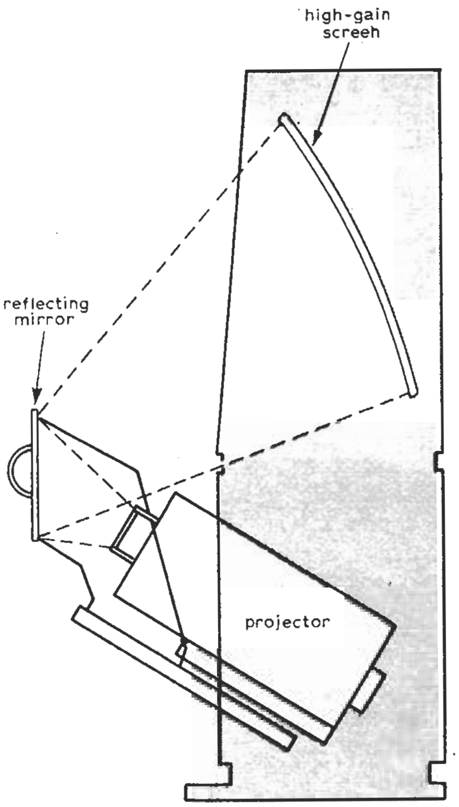


Fig. 16. Self-contained version of the Sony VPP-2000, the KP4000

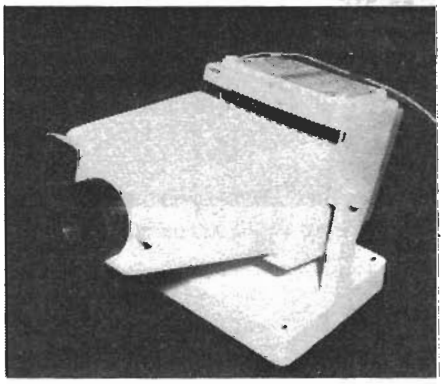


Fig. 17. Tele-Theatre refracting projector

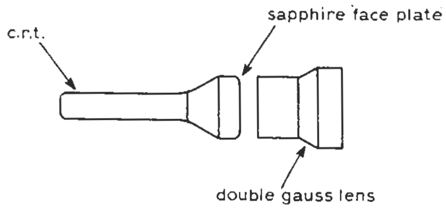


Fig. 18. Refractive projector from Aeronutronic Ford

Surprising compactness is obtained with these projectors; a single c.r.t. unit is 76cm high, 40cm wide and 106cm deep. Three units mounted vertically are used for colour and two colour units mounted side by side for high-power colour projection.

The ATP-1000 is a monochrome projector with a light output of 280 lumens using a glass-faceplate c.r.t. Resolution is 1,000 lines and contrast ratio 1:8. Price is $35,000 to $70,000. The ATP-3000 projects a 1,000 lumen colour picture, which is sufficient for a 2.7m by 3.6m picture. Price is $200,000 to $400,000. Finally the ATP-6000, shown in Fig. 19, is basically two ATP-3000 units providing 2,000 lumens with a 1,000 line horizontal resolution. Price is $400,000 to $500,000.

Advent has just introduced a refractive projector in the USA, fig 19a, which is effectively a baby version of the Aeronutronic Ford projectors. The Videobeam 750 uses three 12.5cm diameter c.r.t.s focused onto a 1.55m x 1.15m high gain screen using three 12.5cm refractive acrylic lenses. Price is presently $2,495 and introduction is expected in the UK during 1977.

Eidophor light valve

The Eidophor is a projector which, by means of a high-intensity light source and an oil layer influenced by the video signal, can project a black-and-white or coloured image by way of light valves.

The principle of the Eidophor is sketched in Fig. 20. The light source is a high-pressure xenon lamp which uniformly illuminates an aperture and is projected onto mirror bars with the aid of a condenser lens. The aperture image is reflected from the bars onto the concave mirror within the tube envelope. This arrangement of mirror bars is called a "dark field" projection system and ensures that no light can fall on the picture screen in spite of the concave mirror being intensely illuminated by the xenon lamp.

An oil layer 0.1mm thick is applied to the concave mirror and as long as its surface is completely smooth, the reflected light is not deflected and the picture screen remains dark.

However if this oil layer is deformed, part of the light is slightly deflected from its normal path and will pass between the mirror bars. This deflected light is focused by the projection lens onto the screen, the brightness increasing with increasing deformation of the oil layer.

The deformations are caused by an electron beam which exerts electrostatic forces on the oil and causes deformation. The electron spot size on the oil is chosen so that the resultant lines touch each other, distributing the charge evenly over the entire scanned area (72mm by 54mm): consequently the layer remains smooth. However, if the electron spot size is reduced, the lines no longer touch and the charge distribution assumes a line structure because the interline spacing carries no charge. This causes deformation of the surface and the smaller the spot, the larger the deformation. Thus, light reflected from the oil layer on the concave mirror is deflected past the

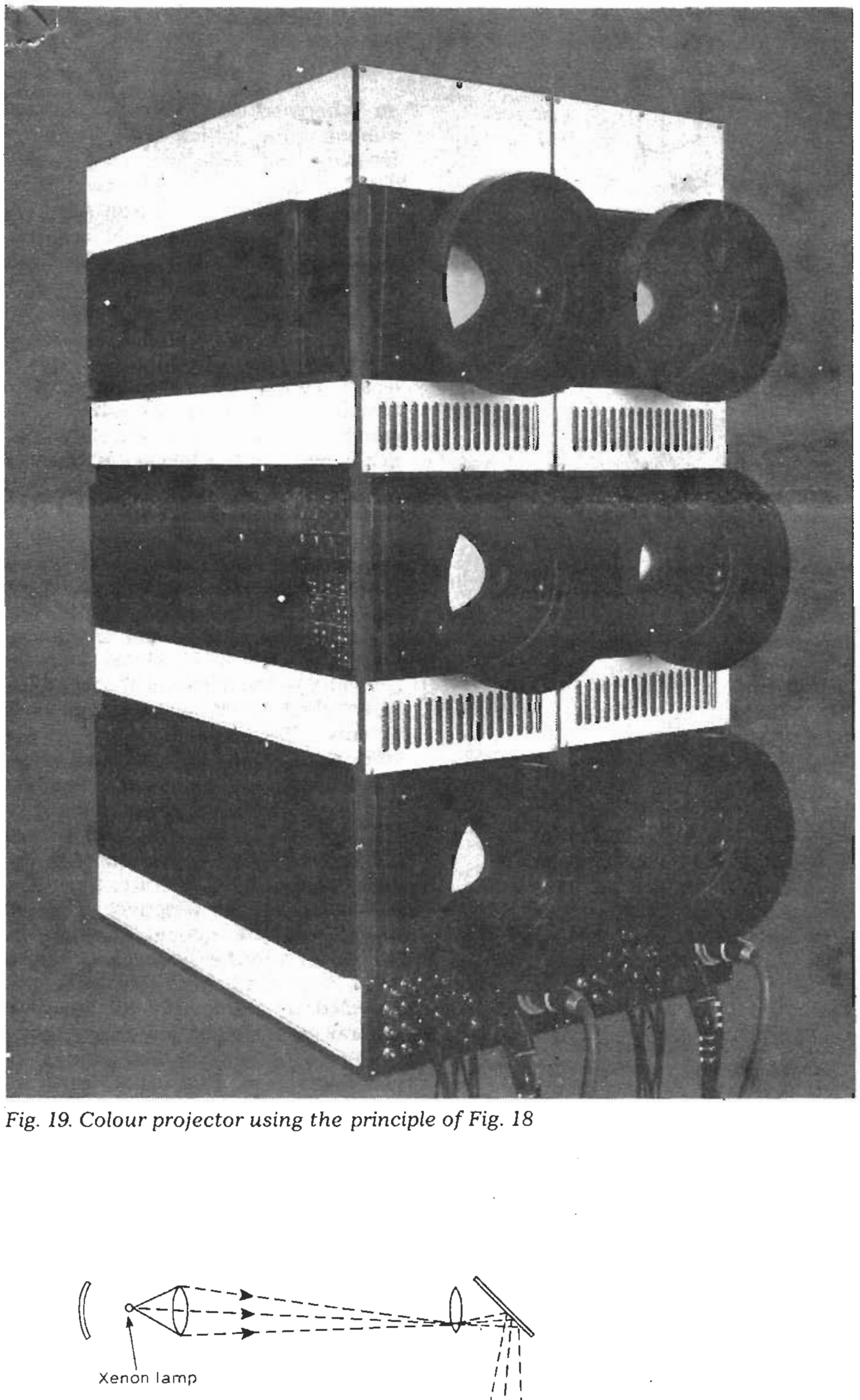


Fig. 19. *Colour projector using the principle of Fig. 18*

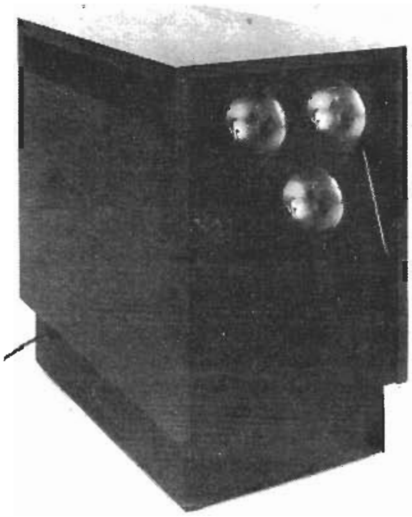


Fig. 19(a). Advent Videobeam colour projector – essentially a smaller version of half the Fig. 19 type

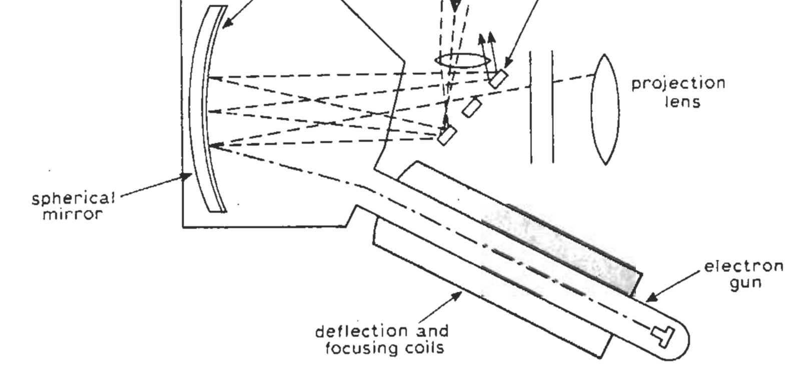


Fig. 20. Principle of the Eidophor. The lower ray is reflected between the mirror bars by the deformed oil layer

mirror bars and onto the screen. By continuously varying the spot size, a full brightness range may be obtained.

The nonconductive oil is made partially conductive and this, combined with the surface tension of the oil, provides for the oil to be smoothed after each field in readiness for new deformations. The great advantage of this technique is that the light source intensity is independent of the electrical power of the electron beam. Another feature inherent in the dark field technique is the contrast ratio of 1:100.

A colour Eidophor is arranged as shown in Fig. 21. The light from a single xenon source is split, using dichroic mirrors, into red, green and blue light, each beam being separately treated in a similar tube to the monochrome projector.

The EP8 monochrome Eidophor projector has an output of 4,000 lumens from a 2.5kW lamp. Maximum picture size is about 12m by 9m. A wide range of lenses are available for varying projection distances. Price is 250,000 Swiss Francs. A new range of monochrome projectors will soon be available. The 5170 in Fig. 22 is a colour projector with 3,000 lumen output. Resolution is 800 lines in the picture centre, registration accuracy being 0.1% in a circle 80% of picture height. Price is 600,000 Swiss Francs. Finally the 5171 is a high intensity colour Eidophor which has a 7,000 lumen output with a 4.8kW lamp. Maximum picture size is 18m by 13.5m. Seven different lenses are available. This unit, the highest-powered TV projector available, costs 690,000 Swiss Francs.

Westinghouse mirror matrix

This is a reflective light valve which uses a matrix of mirrors built into a vidicon camera tube.

The light-reflecting Schlieren system employed is shown in Fig. 23, where the light valve is seen to be the faceplate in

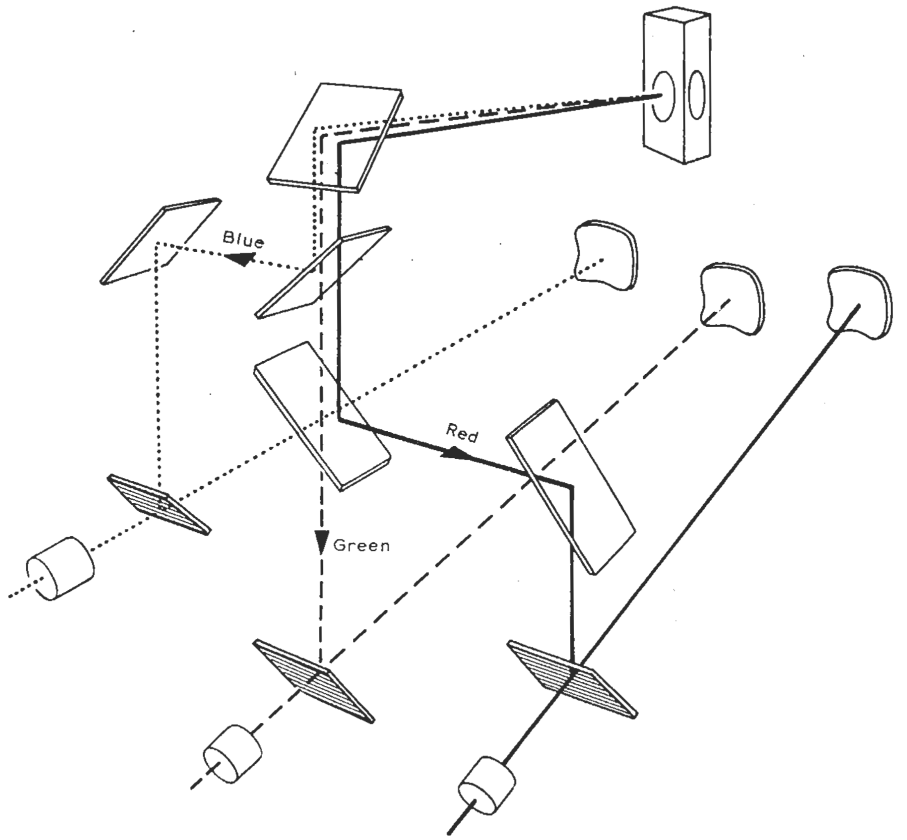


Fig. 21. Optical system of the colour Eidophor

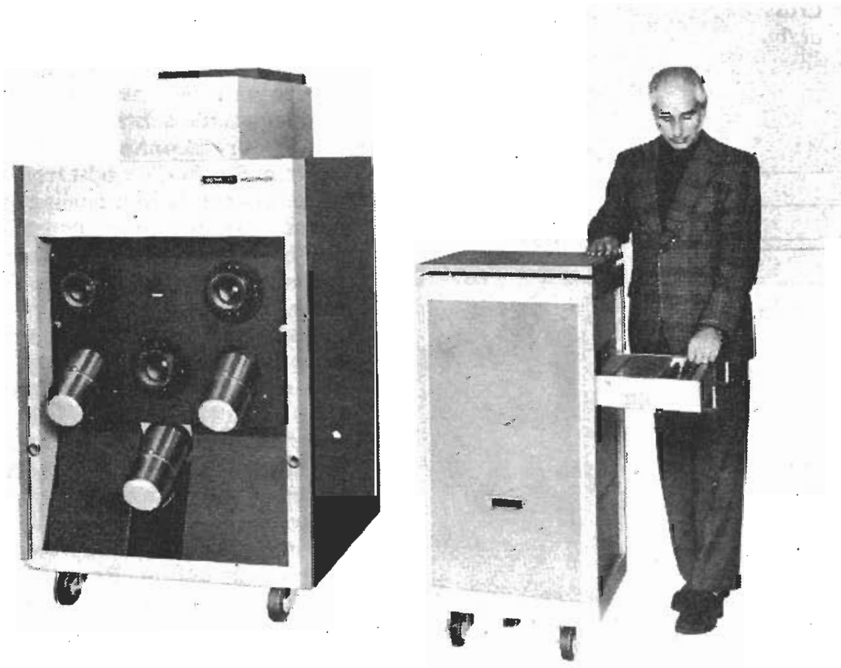


Fig. 22. Gretag 5170 colour Eidophor. Control circuitry is in separate console on right

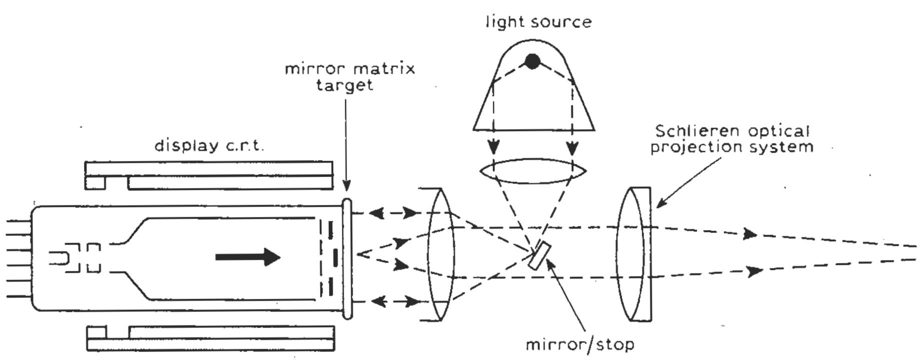


Fig. 23. Reflective type of light valve used in the Westinghouse mirror-matrix system

an otherwise conventional sealed-off vidicon tube which uses standard focusing and deflection components. The target is fabricated from monocrystalline silicon-on-sapphire substrates, using high yield semiconductor techniques. It is composed of a dense matrix (25.5 elements/mm) of aluminised silicon dioxide membranes (about 3,000Å thickness) supported centrally on small silicon posts 4-5μm in height above the transport sapphire faceplate. These flat, stress-free oxide membranes can be deflected electrostatically by up to 4° when addressed with the electron beam. Thus, because light scattered by activated mirror elements is directed around the central stop in Fig. 23, an intensity-modulated display of the deposited charge pattern on the mirror matrix is produced on the screen.

Mechanical and optical considerations have led to a special four-leaf geometry of the mirror elements in Fig. 24, enabling operation at a voltage level of only 175V) and an optical gating efficiency of about 50% to be achieved. The latter stems from the fact that light from activated mirror elements is spatially separated from the fixed diffraction background produced by the segmented target structure. Since the modulated light is effectively directed away from the optical axis of the Schlieren projection system, high screen brightness and high contrast are provided simultaneously by use of a central, cross-shaped Schlieren stop.

The mirror matrix is fabricated using chemically-inert, low vapour-pressure materials, so its inclusion within the sealed-off vidicon envelope shows no detrimental effects on tube life. In addition, the electrical insulation properties of the mirror matrix structure give long storage times for the charge pattern and its low thermal impedance suggests its suitability for high light-level flux handling capabilities.

At present, the write and erase time of 1/30s is such that real-time video cannot be projected, but the storage time inherent in the tube (many hours) makes the projector very suitable for single frame display such as might be used for computer displays, Travel indicators and such applications. A 1.3m × 1m screen was used with the prototype projector, which exhibited a 400-line resolution and 15:1 contrast ratio, with full grey scale. Total gated light output was about 90 lumens using a 150W xenon lamp and f/3.5 lens. Substantially higher luminous flux outputs can be expected with a larger light source and improved optics. A limiting resolution of 600 lines has been achieved using a 750,000 element array with fewer than 30 defective elements in a 50mm sealed tube. Price is expected to be between $2,500 and $3,500.

General Dynamics

A projection system similar to that of the Schmidt type is used by General Dynamics. The techniques uses a correction lens mounted between the c.r.t. and spherical mirror. Although providing better optical correction than the standard Schmidt, the large physical size and cost of the lens have prevented its wide use.

Lasers

Various attempts have been made to construct a projector using lasers as the light source. Although it is reasonably simple to modulate the laser light, scanning must be mechanical, using mirrors or prisms rotating at high speeds. However since the light path is very complex, efficiency is very low and this coupled with mechanical problems has frustrated development.

IBM deformographic

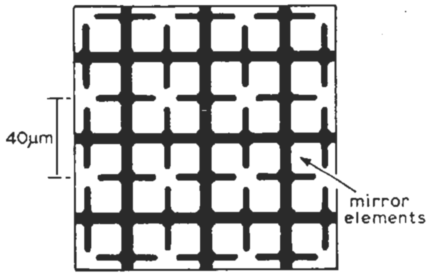
This uses a light valve containing a deformable target. Fig. 25 shows the principle of operation of the deformable storage display tube (d.s.d.t.) which uses a Schlieren optical system to convert the deformations of an optical surface into visual imaging points.

The heart of the d.s.d.t. is a dielectric membrane (target) which consists of an electronically-controllable storage substrate, a deformable material layer and a reflective layer. The target is mounted in the tube envelope so that the storage substrate faces the electron gun chamber of the tube. Deformations, created in the deformable material as a result of negative electrostatic charges deposited by the write gun of the d.s.d.t., are converted into a visual image by the off-axis Schlieren optical system. Since the substrate is a good insulator, it provides long-term image storage. Also, because of its secondary emission characteristic, the effective polarity of the deposited charge may be varied as a function of electron beam energy. Thus a deposited charge can be written and erased in a controlled manner by appropriately directed electron beams of selected energies.

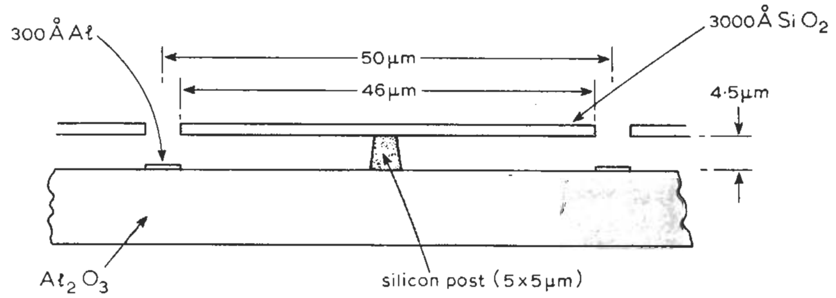
Since the deformable material is isolated from the electron gun chamber, cathode poisoning is eliminated. By employing an elastomer as the deformable material, a simple mechanical restoring force provides the actual erase function once the deforming charge is removed. An additional advantage is the placing of the reflective layer on the deformable material, which allows an efficient reflective optical system to be employed instead of a complex transmissive system. Two electron guns are used mounted in the tube's rear. The write gun provides a magnetically deflected pencil beam while the erase gun is designed to cover the entire substrate with its electron beam cloud. Electronic control of these guns with time sequencing provides for such facilities as storage, variable persistance, selective erase, coloured images and optical processing.

Storage is achieved by sequentially writing and erasing. A single writing operation places information on the target where it is stored until neutralized by the erase gun up to several minutes later. Variable persistance is arranged by simultaneous operation of write and erase guns, the degree of persistence being controllable by varying the erase current. Selective erase may be arranged by altering the potential of the writing gun to produce a directional erase beam. Although theoretically possible, deflection problems with two different beam potentials could cause problems.

Coloured data may be displayed by exploiting the Schlieren plane effect. Fig. 26 shows two methods of producing coloured symbolic data. The top portion shows two E's generated from horizontal and vertical strokes. Because of the optical pattern created as a result of the stroke patterns, and crossed configuration separates the two characters into different colours at the image plane. The lower characters show colour generation by controlling depth of deformation. The lightly drawn character limits the reflective pattern to the inner annular filter ring while a heavily written character causes a large share of the reflected light to fall on the outer filter. The relative sizes of the characters shown in Fig. 26 are significant since the coloured characters made from directional strokes must be larger than black and white characters. Various other filter arrangements may be



(a)



(b)

Fig. 24. Mirror-matrix light valve. Cross-section of one element is shown at (b)

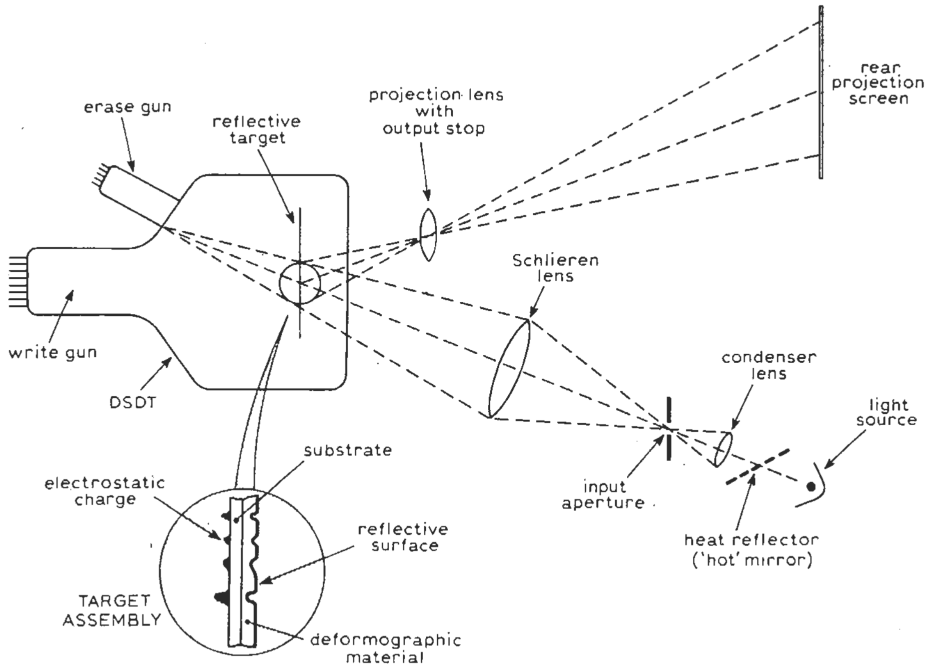


Fig. 25. System by IBM using a reflective, deforming surface – similar in some respects to that of Fig. 23

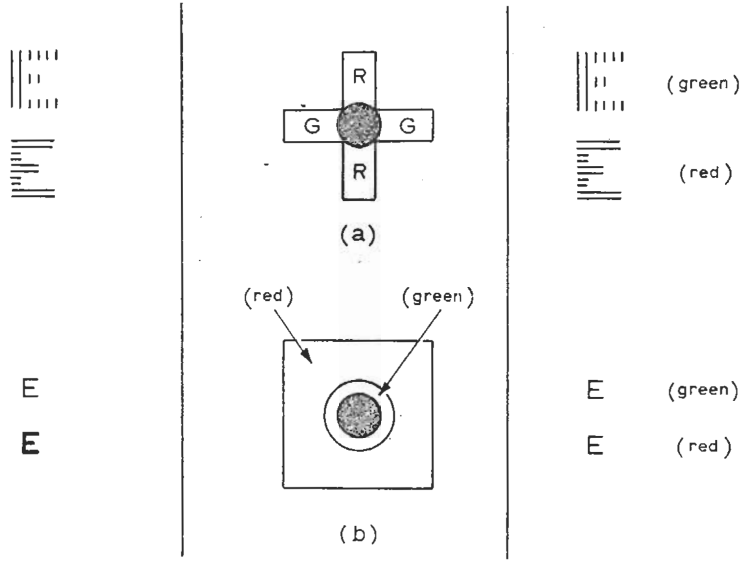


Fig. 26. Production of coloured symbols by crossed filters and symbols made up of vertical or horizontal lines is at (a), while (b) shows the method using differing degrees of deformation to include varying amounts of dissimilar filters

used in the Schlieren plant to enhance or interrogate the displayed tube.

Presently, a 150W xenon lamp is used as the light source and this provides a light output of between 300 and 500 lumens. Up to four different colours may be displayed, with a contrast ratio of 40:1. Rear-projected display systems suitable for computer generated alphanumerics and graphics projected on a 1.5m square screen are now available for purchase from IBM. Projectors are constructed individually by hand and cost around $200,000 but this will be reduced to about $28,000 when production starts.

Prices quoted in sterling indicate that the equipment is imported into the UK while those quoted in dollars would have to be purchased from the USA with all the additional costs that are incurred (freight, taxes etc).

I should like to thank the following people from both Europe and the USA who have provided the information necessary to write this article. Dr G. Baenziger, Gretag AG; Jacques Donjon, LEP; Vincent Donohoe, Speywood Communications Ltd; Patrick Gamuti, Projection Systems Inc; William Good, General Electric; Tom Holzel, Ideal Image Inc; John Huggett, Crown Cassette Communications Ltd; Alexander Jacobson, Hughes Research Laboratories; Harvey Nathanson, Westinghouse Research Laboratories; Michael Spooner, Redifon Flight Simulation; Jerrett Stafford, Aeronutronic Ford; Ronald Freeman, IBM.

Makers and importers

Advent: Crown Cassette Communications Ltd, 3 Soho Street, London, W1.

Aeronutronic Ford, 3939 Fabian Way, Palo Alto, California, USA.

Eidophor: Televictor Ltd, Channing House, Wargrave, Berks.

General Electric Co, Building 6, Electronics Park, Syracuse, New York.

IBM Corp, Department 102B, Building L91, Awego, State of New York 13827.

Ikegami: Dixon's Technical Ltd, 3 Soho Square, London, W1.

Image Magnification: REW Audio Visual Ltd, 10-12 High Street, Colliers Wood, London SW19.

Kalart Victor: British Films Ltd, 260 Balham High Street, London SW17.

Projection Systems: Speywood Communications Ltd, Northfield Industrial Estate, Beresford Avenue, Wembley, Middlesex.

Pye TVT Ltd, PO Box 41. Coldhams Lane, Cambridge.

Sony (UK) Ltd, 134 Regent Street, London W1.

Tele Theatre: Speywood Communications Ltd, Northfield Industrial Estate, Beresford Avenue, Wembley, Middlesex.

Westinghouse Electric Corp, R. and D. Centre, Beulah Road, Pittsburgh, Pennsylvania 15355.

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RECENT ADVANCES IN THE SINGLE-GUN COLOR TELEVISION LIGHT-VALVE PROJECTOR

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ABSTRACT

This new color television light-valve projector consists of a deformable fluid control layer and electron gun in a sealed vacuum tube, an external light source and projection lens. It is being used for large screen color television applications such as simulation, entertainment, and control centers.

Continued development of this type of light-valve projector has resulted in improvements in resolution, sealed light-valve life, higher TV line standards, and higher brightness.

Resolution gains in both color and black and white are due to refined optics and in applying new concepts for the "grating" modulators. The life of the sealed light valve has been extended to over 6500 hours by improvements in the cathode, ion pump and fluid. Operation at the 1029 TV line standards has been achieved for the monochrome light valve and prospects look good for pushing the single gun color projector to the same limit. Recent experiments have shown the feasibility of creating a "wide screen" format for either color or monochrome by the addition of an anamorphic lens and supplying the projector with a "squeezed" format picture signal.

Applications of these projectors to simulation and other fields will be discussed.

Introduction

The single-gun color TV light-valve projector was introduced several years ago. (1) It uses a separate xenon light source, a fluid control layer and a projection lens. Optically it is much like a slide or movie projector. Miniature grooves are created on the deformable surface of the control layer by the electrostatic forces from the charge deposited by the scanning electron beam which is modulated by video information. These groove patterns are made visible by use of a "dark field" or schlieren optical system consisting of a set of input slots and output bars. The resulting television picture is imaged on the screen by the projection lens. See Fig. 1.

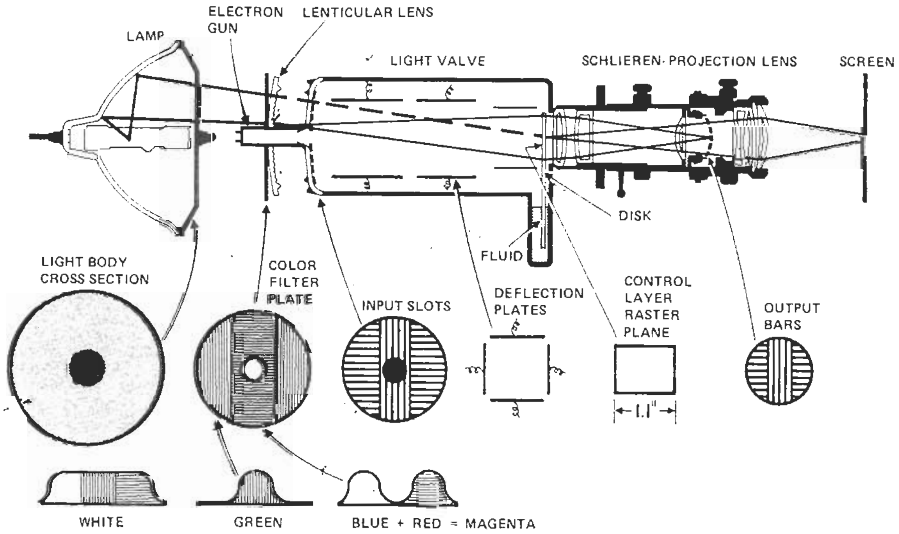

Fig. 1. The schematic diagram of the G.E. single-gun color TV light-valve assembly shows the xenon lamp, sealed light valve, and schlieren-projection lens. The cross-sections of the light body, color filters, and input slots and output bars are shown below the light valve. Green light is passed through the horizontal slots and is controlled by modulating the width of the raster lines themselves. This is done by means of a high frequency carrier applied to the vertical deflection plates and modulated by the green video signal. Magenta (red and blue) light is passed through the vertical slots and is modulated by diffraction gratings created at right angles to the raster lines by velocity modulating the electron spot in the horizontal direction. This is done by applying a 16 MHz (12 MHz for blue) signal to the horizontal deflection plates and modulating it with the red video signal. The grooves created have the proper spacing to diffract the red portion of the spectrum through the output slots while the blue portion is blocked. For the 12 MHz carrier the blue light is passed and the red is blocked. Thus, three simultaneous and superimposed primary color pictures are written with the same electron beam and projected to the screen as a completely registered full color picture.

Colors are created by writing miniature diffraction gratings within each picture element on the fluid surface by manipulating the single scanning electron beam. These gratings break up the transmitted light into its spectral colors which appear at the output bars where they are spatially filtered to let the desired color reach the screen. This technique (2) permits a full color TV picture to be written on a single control layer with no need for further registration.

The practicality of such a scheme has been demonstrated by the introduction of several models of commercially available projectors for use in the entertainment, military, educational, and simulator markets. Improvements that have been made since their introduction will be covered in this paper.

Why an Oil Film?

In spite of the difficulty of working with a fluid layer in a sealed and evacuated tube, this type of layer has demonstrated the ability to deform and decay at TV rates in such a way as to give good integration or storage of each picture element so that good light efficiency is achieved without visible trailing or smearing of a moving image. In addition the fluid gives a continuity or smoothness to the image that is difficult to achieve with structured elements. Finally, because of the nature of the fluid it is possible to refresh the writing surface from a reservoir to achieve very long life times. Only in light valves where the control layer or its substrate are not directly bombarded by the high energy electron beam does it seem possible to avoid this need to refresh the control layer. Systems (3) which will hopefully avoid this need are still in the research and development stages.

Longer Life for the Sealed Light Valve

The life of the sealed light valve has continued to increase each year due to a better vacuum environment and to more tolerant cathodes.

In fact, it is the three basic elements of the light valve: 1) the fluid, 2) the cathode, and 3) the ion pump that determine its useful life. Failure is usually due to loss of emission of the cathode. However, this is normally due to the failure of the ion pump to keep the initial vapors and the vapors due to bombardment at a sufficiently low level. The cathode has been ruggedized for this atmosphere by the use of a thoriated-tungsten type of dispenser cathode. The initial vapor pressure of the contained fluid has been reduced by more exotic processing techniques. The integral ion type vacuum pump has been increased in capacity by the use of a new combination of sorptive materials which permit it to pump and sustain a vacuum of better than 10^{-6} mmHg. This pump is used only when the light valve is in operation.

By improvements in these three areas we have been able to achieve life times in the laboratory of over 6500 hours while product tubes are consistantly averaging 3500 hours in the field. A sealed light-valve assembly is shown in Fig. 2.

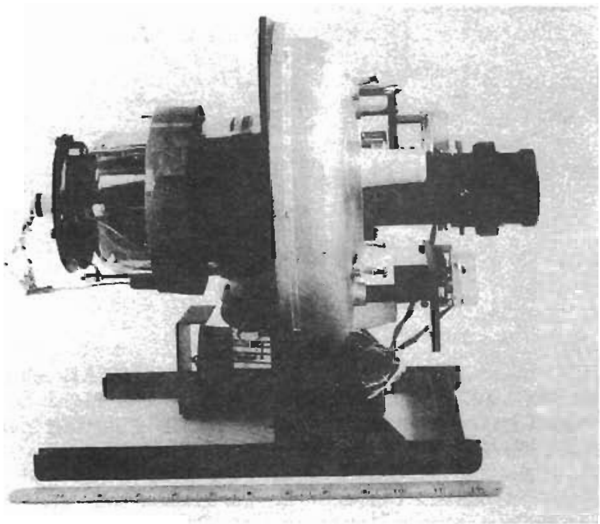

Fig. 2. A color TV light valve assembly showing the single electron gun at the extreme left, the sealed light valve in the center, and the schlieren-projection lens to the right.

Improved Resolution

The resolution or sharpness of the projected image depends on the quality of the projection optics, the diffraction limit of the output slots, and the definition of the actual patterns created on the fluid surface itself. Recently T. True and W. Bates (4) have been able to improve this latter situation by developing modulation techniques that consider the filtering action of the output bars and slots, in the frequency plane, to the sidebands that exist in the first and second order optical spectra due to the video modulation. By a combination of the above technique and the use of higher performance optics, the horizontal resolution of the green image of the single-gun color unit has been increased to over 900 TV lines. The horizontal resolution of the red and blue pictures has been increased to over 500 TV lines, being restricted primarily by the diffraction limit of the output slots. The combined horizontal resolution of a white picture tends to be more of an average and may be as high as 800 TV lines due to the luminance contribution of the green picture. These improvements are particularly helpful in reproducing the output of high quality television sources such as an R.G.B. color TV camera, a computer generated image, or computer generated graphics and alphanumerics. The quality of an off-the-air broadcast is somewhat better but in this case the bandwidth has already been limited to 270 or 280 TV lines by the encoding and decoding of the NTSC color signal.

Improved Light Output

The light output of the color projector has more than doubled since the original projector was introduced due to increased lamp power (650W vs. 500W), the use of low reflection optical surfaces and optimized fluid writing conditions. Recently, experiments have shown that light output can be increased several fold by further increase in lamp power.

Current light output for the single gun color unit is typically around 300 lumens on white or equivalent to 800 open gate lumens as measured for slide and movie projectors. In fact, this value is higher than the output of most 35mm slide projectors. The black and white projector produces about 1000 lumens on white or 1800 open gate lumens. The 1000 lumen figure would provide 13 foot candles of incident light on a 7-1/2 x 10 foot screen or a viewable brightness of over 30 foot lamberts for a screen gain of 2.5.

A second generation projector (Fig. 3) has recently been designed (PJ5000) which incorporates many of these improvements as well as other desirable features that were determined from the experience of having more than 300 of the original projectors in the field. This new projector is appreciably lighter (125 pounds vs. 460 pounds) and smaller than its predecessor which makes it much easier to handle in most applications. This was achieved by the use of high frequency power supplies and state-of-the-art electronic circuit design.

This new model can be readily converted to other standards with plug-in modules and by the use of the appropriate black and white or color light valve.

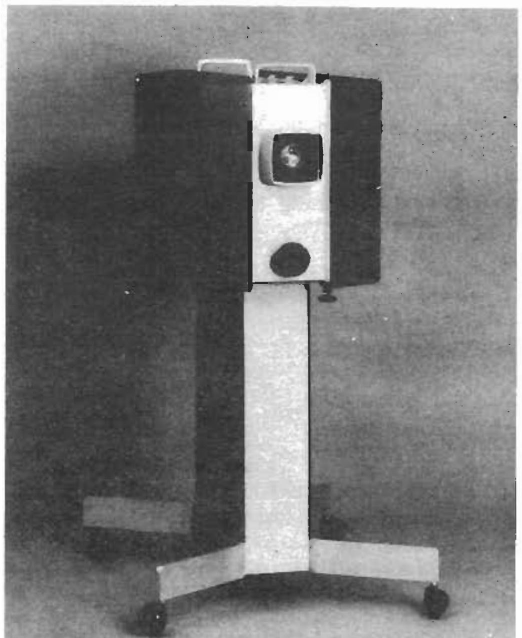

Fig. 3. A front view of the new G.E. PJ5000 color TV light valve projector. The projector is 17" x 22" x 30" in size and weighs 125 lbs. It can project pictures as large as 20 feet with excellent brightness and resolution.

Applications

These light valve projectors have found many applications in the large screen field due to their high light output and inherent registration.

The fluid layer has proved to be extremely stable under motion platform accelerations so that the light-valve projector is serving in the flight simulation field at a number of locations both with camera and probe pick-up as well as with computer generated images.

Applications are being made in decision centers by the military, NASA, and industry. The military use is primarily for command and control and the industry use is in boardrooms. In both cases the units are fed from a variety of signal sources such as computer generated graphics, TV camera pickup and video tape recorders. The screens are typically 5 to 10 feet wide and usually used in the rear-projection mode.

All kinds of training applications are being made by the schools, hospitals, military, and industry.

The entertainment field is using them for closed circuit sports and programs as well as closed circuit business meetings.

Recently, a "wide screen" color TV demonstration was given at Lincoln Center in New York City which showed the feasibility of using this projection system in a mode which is analagous to cinemascope or panavision in the movies.

In the above case, a standard cinemascope anamorphic lens was added to the projector which increased the picture width by a factor of two. The projector was driven from a video tape which had been recorded from a "squeezed" format cinemascope movie film. No changes were made in the NTSC signal or the original raster format. The resulting 4 foot by 11 foot picture appeared quite acceptable in spite of the limited bandwidth of the NTSC encoded video signal. It is anticipated that this new format may find use in the simulation and the entertainment industry.

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A NEW APPROACH TO COLOR TELEVISION DISPLAY AND COLOR SELECTION USING A SEALED LIGHT VALVE

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I. INTRODUCTION

A color television projection system has been developed which makes use of the light valve principle. A single electron gun is used to write appropriate diffraction gratings on a transparent oil film. A slot and bar system in conjunction with a light source permits the desired color to be selected from the spectrum developed by each diffraction grating.

Simultaneous color pictures of high brightness and excellent color fidelity can be projected to any reasonable size using standard NTSC color television transmissions.

Previous light valve color television projectors have used either three guns and three rasters such as the Eidophor(1) or the GE two gun-two raster Talaria(2). The former used one raster for each of the primary colors, while the latter used one raster for green and the other for both red and blue. In either case, the resulting color images must be optically registered at the screen. The same is true for the Schmidt type color projectors in which the phosphor image on the face of three small cathode ray tubes is optically projected to the screen(3).

This new system uses one electron gun and one raster, and thereby obviates the need for registration of the three color images. The "writing" of color-determining diffraction-gratings within each picture element gives rise to simultaneous color images which require no further registration. Details will be given on how these gratings are written on the fluid surface with the electron beam, and how the desired colors are selected at the output bars. A sealed light-valve utilizing these principles is described. Photographs of color TV pictures produced by this device are shown. The small size of this sealed tube makes this system attractive for commercial, military and educational TV.

Dr. William E. Glenn(4) suggested this basic method of generating colored light by selecting the desired portion of the developed spectra from a phase grating written on a fluid surface.

II. PRINCIPLES OF OPERATION

A basic light-valve (see Fig. 1) consists of a light source, a set of input slots, a fluid surface, schlieren lens, output bars, projection lens and electron gun.

If the fluid surface is perfectly smooth, the input slots of light are imaged onto the output bars and no light reaches the screen. When the electron beam deposits a charge on the fluid surface, a groove is formed due to the electrostatic forces and light is refracted off the output bars through the slots and forms a spot of light at a corresponding point on the screen. The brightness of the spot of light is proportional to the depth of the groove that was created on the fluid surface. By modulating the electron beam with video information and scanning in the usual manner, a Black and White TV picture may be written and projected to the screen.

To develop a color picture with this system, it is necessary to write a multiplicity of grooves or a diffraction grating within each picture element which determines its color and brightness. While it may be possible to write differently pitched diffraction gratings for each of the infinite number of desired colors, it has been found more convenient to write just three specifically pitched diffraction gratings - one for each of the primary colors. This requires that the three gratings be written simultaneously on the fluid surface so that each picture element will contain the necessary information for the determination of its brightness and hue. In order to minimize the interaction between these gratings we have chosen to write two of the gratings (red and blue) at right angles to the third grating (green).

The green grating makes use of the natural grooves that are formed by the scanning of a focussed electron beam (Fig. 2). This side view shows the washboard type of grating formed on the fluid surface. Green light from the input slots is diffracted off the output bars and to the screen. In a dark field or black portion of the picture the fluid surface must be smooth. This can be done by defocussing the spot vertically until it meets its neighboring lines above and below, and a uniform charge is developed on the oil surface. A green picture can be written by modulating this spot-defocussing-voltage with green video information. We are presently accomplishing this modulation function with a VHF "wobbulation" voltage applied to the vertical deflection plates. Only a volt of R.F. is required for complete modulation of the green picture.

The red and blue color selection is achieved by writing diffraction gratings at right angles to the raster lines. This is accomplished by velocity modulating the spot with a high frequency voltage applied to the horizontal deflection plates. This causes the electron spot to speed up and slow down in synchronism with the high frequency carrier which in turn causes a regularly spaced differential charge pattern to be placed on the oil surface. The magnitude of the differential charge in this pattern determines the depth of the grooves that are developed and, consequently, the amount of light diffracted off the bars and to the screen. The pitch or frequency of the red grating is chosen so that the red light from the developed spectrum is passed through the slot and the blue light is blocked. A frequency of 16mHz is used for the red grating signal. Again the amplitude is approximately one volt. Another frequency is chosen for blue so that the blue light will be passed through the slot and the red will be blocked. We now have a way of writing a full color picture by applying the Red, Green and Blue video signals from a color camera to the three color modulators whose outputs are connected to the appropriate deflection electrodes.

Let us examine more closely how a phase grating works (Fig. 3). Typically, a sinusoidal deformation in the surface of a refractive medium will give rise to the Fraunhofer diffraction spectrum consisting of several orders in both directions from the geometrical image depending on the depth of the deformation. The magnitude of the energy in the different orders is related to the amplitude of the deformation by the bessel functions of the first kind in the same manner as the sidebands in FM transmission are related to the index of modulation.

Consequently, the total energy in the first two orders can be instantaneously as high as 93% of that in the zero order or geometrical image. This permits a very high degree of utilization of the incoming light, providing the design of the slots and bars are properly done, and providing the dynamics or decay times of the grooves are properly chosen. A rapidly decaying groove would give low light efficiency because the "valve" would be on for only a short part of the available time. A long decay time would be very efficient but would give rise to "sticky" pictures and trailers with moving objects. Therefore, the decay time must be adjusted to about one field period (1/60 sec.) in order to optimize the efficiency without undue stickiness. Under these basic conditions it is possible to realize efficiencies in the individual colors of over 50%.

Adjusting these decay times to an appropriate value is quite a technical problem because these build-up and decay times are not only a function of the fluid viscosity, surface tension, fluid depth and the electrical conductivity, but also a function of the grating spacing. Because the three gratings necessarily have different spacings to achieve color selection, it was necessary to control the fluid properties in such a way as to maintain nearly equal decay times or persistence to prevent color trailers like those developed in the early color tubes with their unequal decay times of the phosphors.

III. THE SEALED LIGHT VALVE

(Fig. 4) is a schematic diagram of the present light-valve assembly showing the lamp, the lenticular plates, the dichroic color filters, the electron gun and its electrostatic deflection system, the input and output bars, the oil film or picture plane, the schlieren and projection lens, and the screen. The lower part of the picture shows the cross section of the light body and the characteristics of the color filters and bar systems.

There are several novel optical features which should be mentioned. First is the sealed beam Xenon lamp which has been developed for the project by the GE Large Lamp Department. It has a 500 W rating and a cold coating reflector, and collects about 50% of the light from the arc. It is an ellipse with the second focus at the raster plane. The sealed construction protects the optical surfaces, eliminates ozone generation, and protects the user against explosion hazard. The dichroic color filter trims the light into green and magenta, and eases the color selection job of the bar system. The lenticular plates consist of several hundred rectangular but spherical lenslets which are so spaced as to reimage the arc source through the input slots and thus increase the light utilization of the source. The lenslets in the second lenticular array act as field lenses for the first set and image the many rectangular light bodies onto the raster plane. These superimposed rectangular light bodies give excellent uniformity of illumination and at the same time convert a circular light body into a rectangular one. The resulting improvement in optical efficiency, as compared with no lenticular plates, is about a factor of four.

The input slots are located on the vacuum side of the second lenticular plate. The vertical slots are for magenta light, the horizontals for green. The combined schlieren and projection lens was the culmination of several successive optical designs in order to prove feasibility of this type of precision optics. The schlieren portion must accurately image the input slots onto the output bars. It must do this sufficiently well to permit a light field (no output bars) to dark field (output bars - smooth oil) ratio in excess of 300 to 1. In other words, only 1/3 of one percent of the light may pass through the output slots during a dark field by virtue of scattering, multiple reflections or excessive image aberrations. The blur spot for this part of the lens is 0.004 inches.

The projection lens must focus the raster onto the screen. This double conjugate lens has a speed of f/3 and was designed by the John R. Miles Corporation of Elk Grove Village, Illinois.

(Fig. 5) shows a typical light-valve tube which is sealed and contains its own fluid supply and electronic vacuum pump.

At the left is the 500 W sealed beam Xenon lamp. Next is the first lenticular plate with its color filter applied. Next is the vacuum window lenticular plate and input slots to which the electron gun is mounted. One can see the electrostatic deflection system through the glass envelope. The fluid writing surface is near the front of the tube. The combination schlieren and projection lens is at the right. The vacuum pump is at the top of the tube. It is completely self contained and pumps hydrogen and broken down organic vapors.

This view (Fig. 6) shows the output window region where the picture is written. The disk continuously brings up a fresh layer of writing fluid from the sump. The magnetic drive magnet can be seen at the right. A small motor drives the disk through the glass wall at a speed of three revolutions per hour.

This tube has evolved from the efforts of many people within the General Electric Company Laboratories at Schenectady, Syracuse and Cleveland. The goal has been to make a system that would produce the best pictures possible within the limits of the NTSC 525 line color standards and to achieve a life substantially in excess of 1000 hours. This has now been realized after the development of a synthetic fluid, a special cathode and electronic vacuum pump.

The associated circuitry has about the same complexity as that of a conventional color TV monitor after eliminating the usual convergence circuitry and yoke. The anode voltage is 8 kv and, therefore, can cause no radiation hazard.

The primary colors developed by this technique are very close to those of a phosphor type color tube. Color rendition from this additive system provides a pleasing color display in sizes up to 6 x 8 feet either in front or rear projection. Because of the single projection lens it is a simple matter to change screen size by changing the distance between the projector and the screen and refocussing the lens. No other adjustments are necessary. A companion monochrome unit which has only one modulator and a wider bar system has sufficient light output to fill a screen 12 feet in width.

Both projectors are capable of 50 to 1 contrast ratio and the resolution limit of the 525 line NTSC standards.

(Fig. 7) shows a photograph of a picture from a film camera of an encoded NTSC signal.

Because of its performance characteristics, modest size, weight and power consumption (1250 watts), this projector is finding applications in instruction, training, simulation and graphic display such as Educational TV, Broadcast Studios, Medical Schools, and Computer readout.

IV. CONCLUSIONS

A color television light-valve projector has been described which uses a single gun and a single raster. The red, blue and green pictures are written simultaneously therefore there is no registration or convergence problem.

Color television pictures can be projected up to 6' x 8' using the standard NTSC signals.

The small, sealed light-valve permits the projector package to be mobile.

The author wishes to thank his associates at General Electric and its management for making this project a success.

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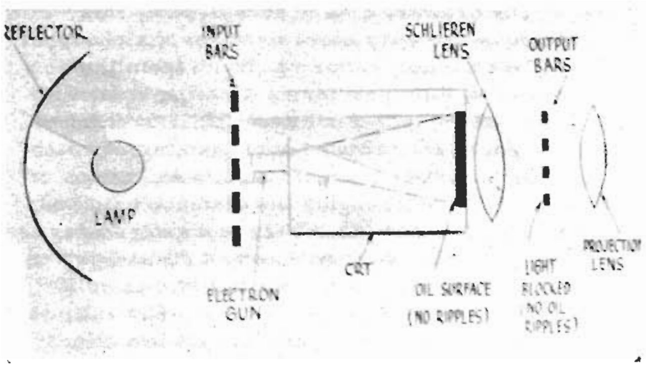

Fig. 1. Light Valve Schematic

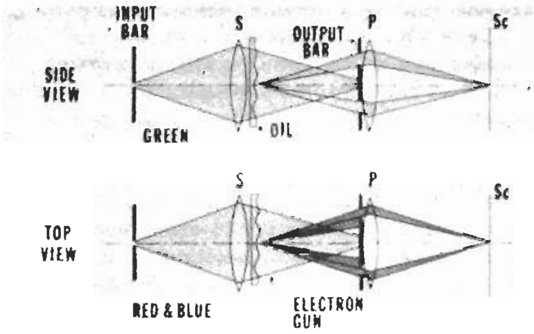

Fig. 2. Principle of Color Selection

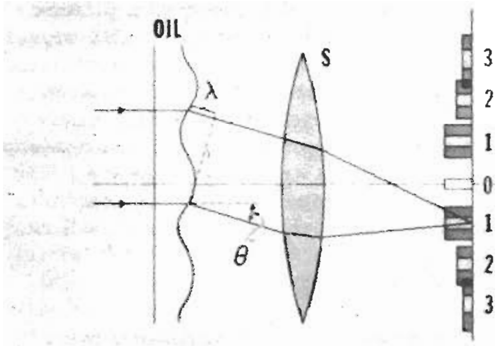

Fig. 3. Phase Grating with Spectral Orders

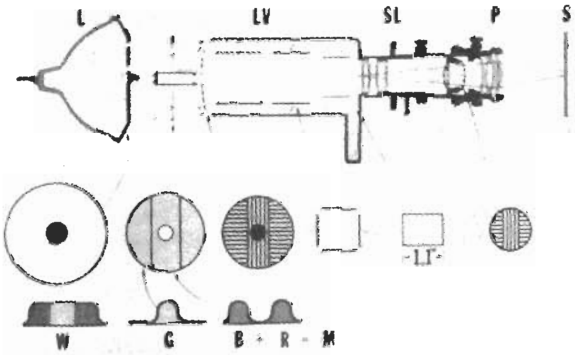

Fig. 4. Sealed Light Valve Schematic

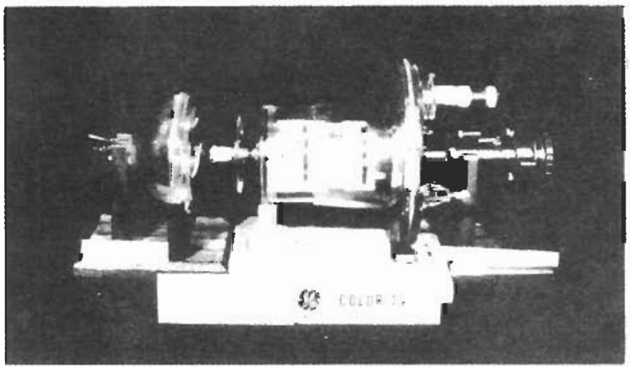

Fig. 5. Light Valve Assembly (length - 22")

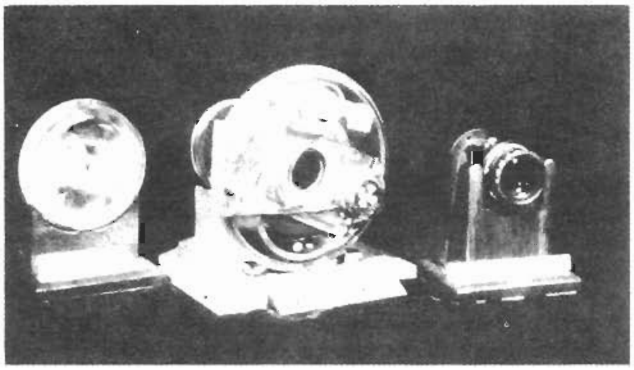

Fig. 6. Light Valve Assembly

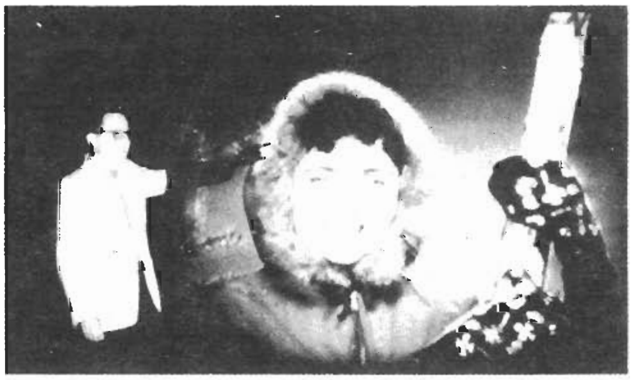

Fig. 7. 6'x8' Picture from Encoded NTSC Signal