

PATENT SPECIFICATION

DRAWINGS ATTACHED

1,087,250

No. 45986/65

Date of Application and filing Complete
Specification: October 29, 1965.

Application made in United States of America (No. 439857) on
March 15, 1965.

Complete Specification Published: October 18, 1967.

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Index at Acceptance:—H4 F (2B2, 6F, 6M, 6N).

Int. Cl.:—H 04 n 3/08, H 04 n 5/66.

COMPLETE SPECIFICATION

Laser Display

We, TEXAS INSTRUMENTS INCORPORATED, a Corporation organized according to the laws of the State of Delaware, United States of America, of 13500 North Central Expressway, Dallas, Texas, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to projection display systems and more particularly to a display system using a laser light source.

An object of the invention is to provide a display system having improved intensity and resolution.

The present invention is a display assembly comprising a fiber optic device having first and second opposite end portions, said first end portion having a configuration such that a projection thereof presents a substantially closed curved path on an intersecting plane, said second end portion having a configuration such that a projection thereof presents a substantially straight linear path on an intersecting plane, horizontal scanning means spaced from said first end portion, vertical scanning means spaced from said second end portion, and means directing a modulated beam of light toward said horizontal scanning means, said horizontal scanning means reflectively projecting said modulated beam of light and successively tracing closed curved paths of light incident upon said one end portion of said fiber optic device, said fiber optic device transmitting said light incident upon said one end portion and emitting said light from said second end portion in such a manner as to successively trace substantially straight linear paths of light incident upon said vertical scanning means, and said vertical scanning means reflectively project-

ing successive lines of light traced thereon in transversely spaced relationship to each other, whereby an image may be formed on a screen intercepting said successive lines of light.

Laser light sources offer advantages not found in conventional light sources, the significant distinguishing properties being: high intensity, spacial coherence, monochromaticity and polarization. Some of these features may be more important than others depending upon the application. For example, the laser's high intensity together with the spacial coherence removes the necessity of using larger aperture optics for efficient energy transfer. At best, perhaps a few percent of the light from a tungsten filament may be used in a conventional transparency projector. Essentially all the light from the laser is usable, and several scanning and light modulation techniques make use of the laser spectral purity or the linear polarization of its output.

Said means directing a modulated beam of light towards said horizontal scanning means may include a laser.

Other objects and features of the invention will be apparent from the following detailed description when read in conjunction with the appended claims and accompanying drawings, in which:—

Fig. 1 is a functional layout of a display assembly according to the invention;

Fig. 2 is a functional block diagram of the display system;

Fig. 3 is a fiber bundle used in the optical transmission of light;

Fig. 4 is a diagram showing the light modulation and optical system;

Fig. 5 is a drawing of a circular resonant scanner; and

Fig. 6 is a drawing of a galvanometer light beam scanner.

[Price 4s. 6d.]

The display assembly described herein is adapted for the projection of commercially produced television pictures, which require that the horizontal and vertical scan rates be the same as those used in conventional television equipment. However, this identity of scan rates is not a limiting feature of the invention. A standard TV display normally has 525 active vertical lines, whereas a vertical resolution in excess of 1000 lines and beyond is possible with the present invention.

Referring now to FIGURE 1 of the drawings, the basic layout of a complete laser display assembly is shown. The laser is operated in a hemispherical geometry so that all the output is generated in a single spacial mode. This allows a diffraction-limited optical system to be used, and assures maximum resolution with a limited optical aperture. The lens 2 is used to diverge the light emitted from the laser 1. The light is collimated through lens 3, projected through the modulator 4 and polarizer 5 onto a rotating mirror 6 which is part of the horizontal scanner 7. Because of the motion of the mirror, the modulated light beam is reflected in a circular pattern onto end 8 of the fiber optic device 9.

The horizontal scanner 7 generates a lissajous pattern at 15,750 cycles per second, which is the horizontal TV line rate. This is accomplished by driving the two axis of the scanner with 15,750 cycles per second sine waves which are 90° out of phase. This circular scan pattern is then rectified by a fiber optic into a linear line scan with near zero flyback time. This is possible since the light beam is projected from mirror 6 onto the circle portion 8 of fiber optic 9 in the circular lissajous pattern. The light beam travels through the fibers making up the fiber optic assembly and is projected out the end 10 of the optic fiber onto the oscillating mirror 11. In passing through the fiber optic 9, the light beam is scattered and emerges as an f/4 cone of light. Because of this scattering the vertical scanner mirror 11 must be considerably larger and turn through a larger angle than the horizontal scanner.

A d'arsenval type galvanometer is used to produce the vertical scan which is explained hereinafter. The reflection from the mirror 11 is projected through projection lens 12 onto an ordinary light screen (not shown).

FIGURE 2 is a block diagram of the laser display system. A light beam generated within the laser A is modulated by modulator B. The modulator is driven by a video amplifier C which amplifies the video input signal to a level suitable for acting upon the modulator. The modulated light beam is then transformed into hori-

zontal segments by the scanner F and projected by the projection optics G onto a screen H. The video input signal includes a synchronization pulse which is used in synchronizing the horizontal and vertical scanners. The sync pulse is separated from the video signal by the sync separation circuitry D and applied to the synchronization and driving circuitry E. Responsive to the signal from the synchronization and driving circuitry, the horizontal and vertical scanners operate synchronously to change the modulated light beam into modulated line segments which are combined to form a display.

There are three basic types of lasers; solid state, gaseous and semiconductor injection. Although all three can be operated continuously, only the gas laser can be operated continuously without employing cryogenic cooling techniques.

Since the laser beam is monochromatic, the use of a single laser will produce a projection in one color. The neon-helium gas laser produces a ruby red light, as does the krypton laser. Blue and green lights may be produced by an argon laser. Full color displays are possible by combining the output of three lasers; a neon-helium or krypton laser producing a red light, and two different argon lasers producing blue and green light, the combination of the three producing white light or any color combination thereof.

One particular laser used in producing a display system was a 50 milliwatt helium-neon gas laser model 125 produced by Spectra-Physics, Mountain View, California. The resonator mirrors and plasma tube of the laser were mounted on a rigid structure with suitable adjustments to allow easy alignment. Radio frequency excitation was used in addition to dc excitation to increase the power output by 25 percent. The hemispherical resonator was operated in the uniphase or TEM mode. Other modes were discriminated against by proper mirror orientation. All the power was taken out of the spherical end by using a flat mirror on the opposite end with an extremely high reflectivity. The power output of the laser was not necessarily a limiting factor; however, the larger the projection and the greater the intensity, the greater the power the laser would have produced.

Light modulator B, Figure 2, was made of two matched pieces of 45° Z-cut KDP oriented at a 90° angle for temperature compensation. That is, two single-crystal rectangular pieces of potassium dihydrogen phosphate were each cut so that X and Y axes of the crystal extended at a 45° angle to a particular surface thereof and the Z axis extended parallel to that surface. The pieces were then placed together with the

Z axis of one piece extended perpendicularly to the Z axis of the other piece and in such a manner that the collimated polarized light from the Ne-He laser passed through the two pieces in series perpendicularly to the Z axis of each piece and at 45° angles to the X and Y axes of each piece. An electric field was applied to each piece in a direction parallel to the Z axis of the particular piece, causing elliptical polarization of the light emerging from the second piece. A modulator of this type can be operated at 75% modulation efficiency over a 5 megacycle bandwidth with 600 V peak voltage with a contrast of greater than 100 to 1.

Fig. 4 shows the laser, modulator and polarizer. The linearly polarized light from the laser 1 passes through the modulator 4 and emerges with a variable amount of elliptical polarization due to the modulating of the light beam. A polarizer 5, oriented perpendicularly to the input polarized light, converts the varying elliptically polarized light into linearly polarized amplitude modulated light. By selecting an initial bias voltage, almost no light is allowed to pass through the modulator. A good polarizer may have a transmission as low as 10% in the crossed axis condition. A video signal applied to the modulator can then allow from 0 to nearly 100% of the incident light to pass through the modulator.

The video amplifier, Block C, along with the synchronization and driving circuitry, Block E, and sync separator, Block D, are all conventional circuitry as used in present day television systems. The high level video amplifier C drives the light modulator B while the synchronization circuitry E is necessary to form a stable display and provide suitable driving waveforms for the light beam scanner F. The video amplifier should supply 500 volts or more peak voltage to the light modulator from a 1.5 volt video input. A two stage video amplifier of conventional design is used with D.C. restoration to provide the highest possible quality display.

The projection optics, Block F and G, include the horizontal scanner, the fiber optic, and the vertical scanner. The horizontal scanner's primary function is to convert the light beam into a circular trace. It is well known that various patterns may be generated by the selection of voltages which have differing phase relationship. One example of this is the lissajous patterns which may be generated on the face of an oscilloscope. By combining two sinusoidal waves of equal magnitude, 90° out of phase, a circle may be generated. Using this principle, the scanner in FIGURE 5 was developed. The horizontal scanner consists primarily of a piezoelectric transducer driven

ver 21, a resonant fiber 20 and a mirror 6. The piezoelectric transducer drives the resonant fiber, which has a mirror attached to the end thereof. The resonant fiber acts as a mechanical transformer amplifying the deflection of the transducer caused by applying two sinusoidal signals 90° out of phase to the transducer. The transformed motion causes the mirror to rotate in a circular mode.

The transducer is a standard lead titanate zirconate (PZT) piezoelectric transducer such as Clevite No. 60099, and the resonant fiber is, for example, a .010 inch diameter quartz rod. The mirror is a .050 inch diameter circular concave mirror.

The horizontal scanner is not limited to a piezoelectric transducer. A mirror may be suspended upon two wires placed 90° to each other. By placing the suspended mirror in a magnetic field and driving both wires with two sinusoidal currents 90° out of phase, the mirror is deflected substantially in a plane in such a manner as to produce a circular scan.

The light beam impinging on the mirror 6 is therefore converted into a circular pattern which is projected upon the end 8 of the fiber optic 9. The fiber optic 9 is shown in FIGURE 3. The function of the fiber optic is to provide a scan rectification to convert the circular light pattern projected from the horizontal scanner into a linear sweep with near zero flyback time. Light impinging on one end of a fiber within the fiber optic device will be radiated through the fiber and be omitted at the other end. Interference between fibers by light of one fiber radiating into the other is eliminated by coating each fiber with an opaque material. The fiber optic assembly 9 consists of a layer of optical fibers flat at one end and bent to form a circular array 8 at the opposite end. The unit is constructed from multifiber ribbons. A multifiber may consist of, for example, a 6 x 6 array of optically distinct 10 micron coated fibers fused into a single strand. These strands are then cemented side by side to form a ribbon. A number of ribbons are clamped together to form the linear end, and the circular end is formed by wrapping the ribbons around a tube and securing them with a shrink-fit plastic sleeving. After potting with epoxy ribbon, the scan converter is completed by polishing the ends. Various means of fabricating the fiber optic may be utilized, but the above-mentioned means has been found to be the simplest. The shape is not limited to the ones shown in the figures of the drawings, but may be formed into any required configuration.

The linear sweep projection from the end 10 of the fiber optic 8 is projected onto mirror 11 of the vertical scanner. One basic

configuration of this scanner is shown in FIGURE 1.

In the development of the vertical scanner, both piezoelectric and electromagnetic devices were used. One approach was to reflect the beam vertically with a piezoelectric driven mirror, in which two bimorph piezoelectric transducers were used as flexure elements for the driving mirror 11.

10 The scanner used in this embodiment of the invention was a galvanometer light beam device as shown in FIGURE 6. Therein depicted is a magnet 31 having pole pieces 32 and 33. Between the pole pieces is coil 34, which is suspended on a torsion wire 35, thus eliminating the need for bearings. Mounted upon the coil and extending therefrom is the mirror 11. This mirror receives the light from the end 10 of fiber optic 9 and projects it through a projection lens 12 to produce the vertical scan. The mirror oscillates back and forth projecting each line of the horizontal scan onto the screen. This method of achieving a linear trace with rapid flyback works quite well with the present system. A flyback time of less than 1 millisecond together with a deflection of greater than 10° has been possible with small mirrors. The galvanometer is driven with positive and negative current pulses combined with a sawtooth waveform.

Although the present invention has been shown and illustrated in terms of specific preferred embodiments, it will be apparent that changes and modifications are possible without departing from the scope of the invention as defined in the appended claims.

WHAT WE CLAIM IS:—

1. A display assembly comprising a fiber optic device having first and second opposite end portions, said first end portion having a configuration such that a projection thereof presents a substantially closed curved path on an intersecting plane, said second end portion having a configuration such that a projection thereof presents a substantially straight linear path on an intersecting plane, horizontal scanning means spaced from said first end portion, vertical scanning means spaced from said second end portion, and means directing a modulated beam of light towards said horizontal scanning means, said horizontal scanning means reflectively projecting said modulated beam of light and successively tracing closed curved paths of light incident upon said one end portion of said fiber optic device, said fiber optic device transmitting said light incident upon said one end portion and emitting said light from said second end por-

tion in such a manner as to successively trace substantially straight linear paths of light incident upon said vertical scanning means, and said vertical scanning means reflectively projecting successive lines of light traced thereon in transversely spaced relationship to each other, whereby an image may be formed on a screen intercepting said successive lines of light.

2. A display assembly as claimed in claim 1, wherein said first end portion of said fiber optic device has a circular configuration.

3. A display assembly as claimed in claim 1 or 2, wherein said horizontal scanning means includes a mirror reflectively projecting said modulated beam of light, and driving means driving said mirror in a manner such that the reflected beam of light successively traces said closed curved paths of light incident upon said one end portion of said fiber optic device.

4. A display assembly as claimed in claim 3, wherein said driving means includes a piezoelectric transducer connected to said mirror.

5. A display assembly as claimed in claim 4, wherein said piezoelectric transducer is connected to said mirror by an elongated resonant fiber having opposite ends secured respectively to said piezoelectric transducer and said mirror.

6. A display assembly as claimed in any of claims 1 to 5, wherein said vertical scanning means includes a generally flat second mirror reflectively projecting successive lines of light traced thereon, and driving means oscillating said second mirror about a pivotal axis generally parallel thereto.

7. A display assembly as claimed in any of claims 1 to 6, wherein said means directing a modulated beam of light toward said horizontal scanning means includes a laser.

8. A display assembly as claimed in claim 7, wherein said means directing a modulated beam of light toward said horizontal scanning means also includes an electro-optic modulator modulating said beam of light by changing the polarization thereof.

9. A display assembly substantially as described herein with reference to the accompanying drawings.

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tion in such a manner as to successively trace substantially straight linear paths of light incident upon said vertical scanning means, and said vertical scanning means reflectively projecting successive lines of light traced thereon in transversely spaced relationship to each other, whereby an image may be formed on a screen intercepting said successive lines of light.

2. A display assembly as claimed in claim 1, wherein said first end portion of said fiber optic device has a circular configuration.

3. A display assembly as claimed in claim 1 or 2, wherein said horizontal scanning means includes a mirror reflectively projecting said modulated beam of light, and driving means driving said mirror in a manner such that the reflected beam of light successively traces said closed curved paths of light incident upon said one end portion of said fiber optic device.

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