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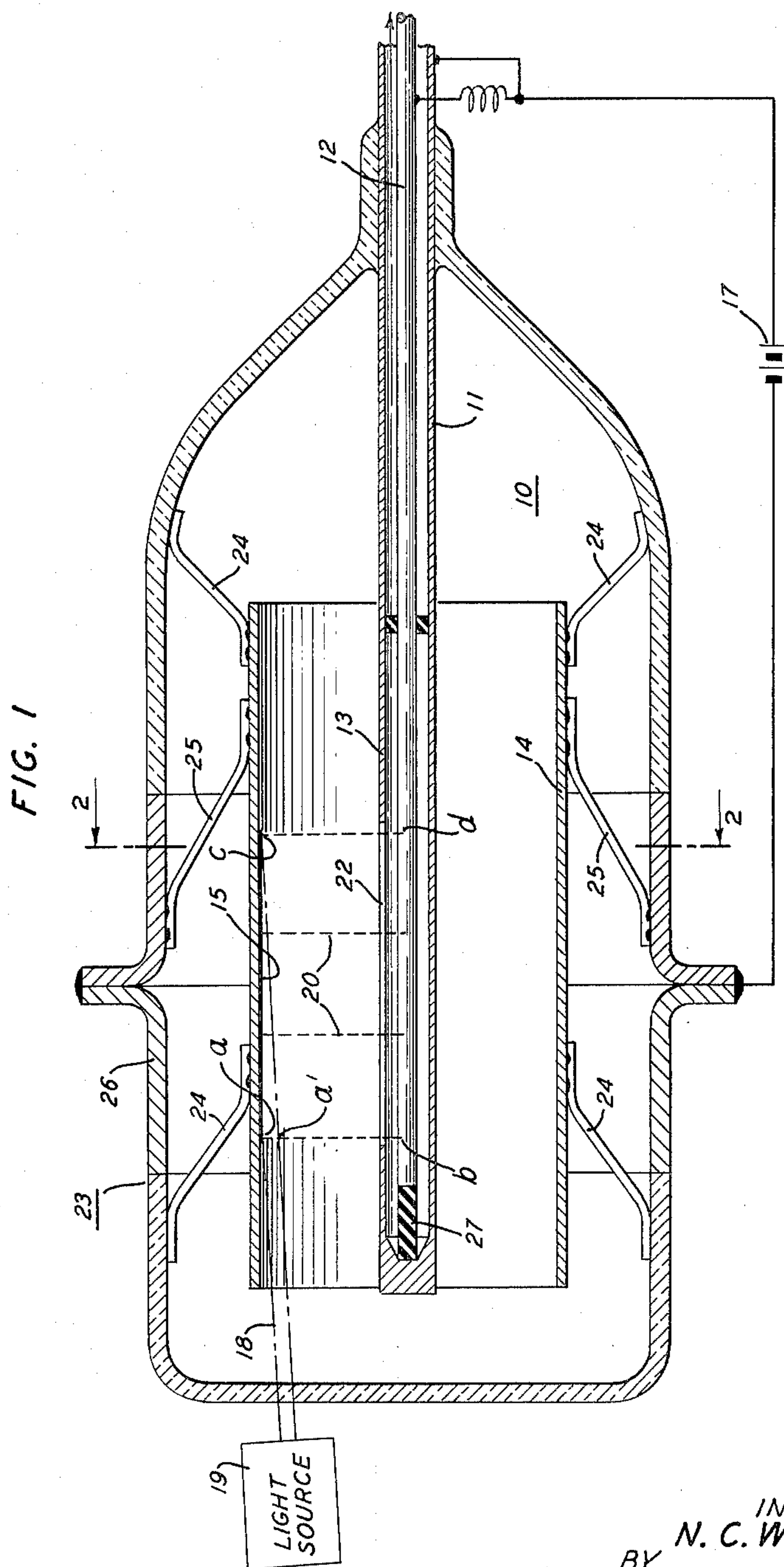
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PHOTOSENSITIVE BROADBAND COUPLER USING WAVE GUIDE

Filed March 22, 1963

2 Sheets-Sheet 1



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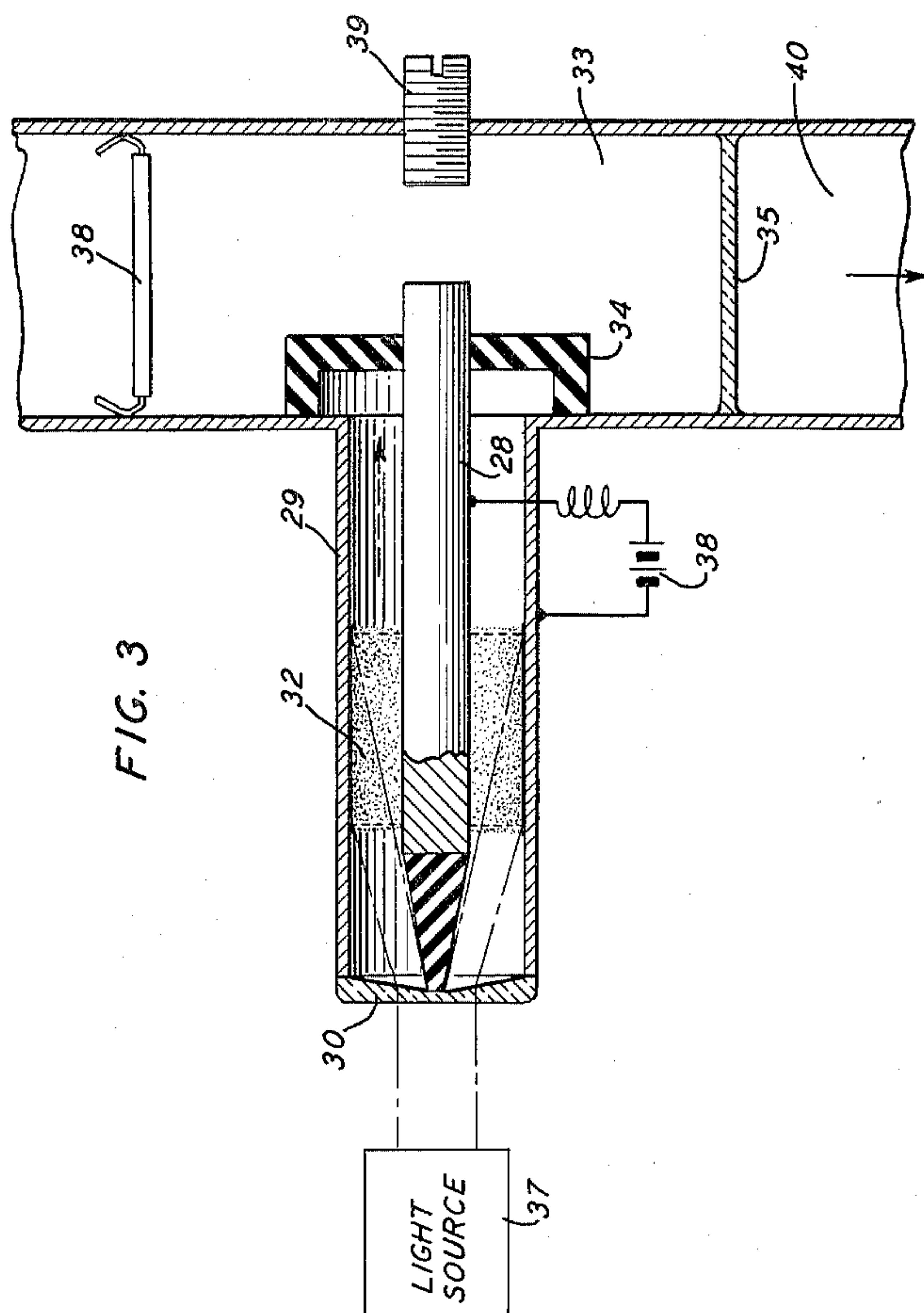
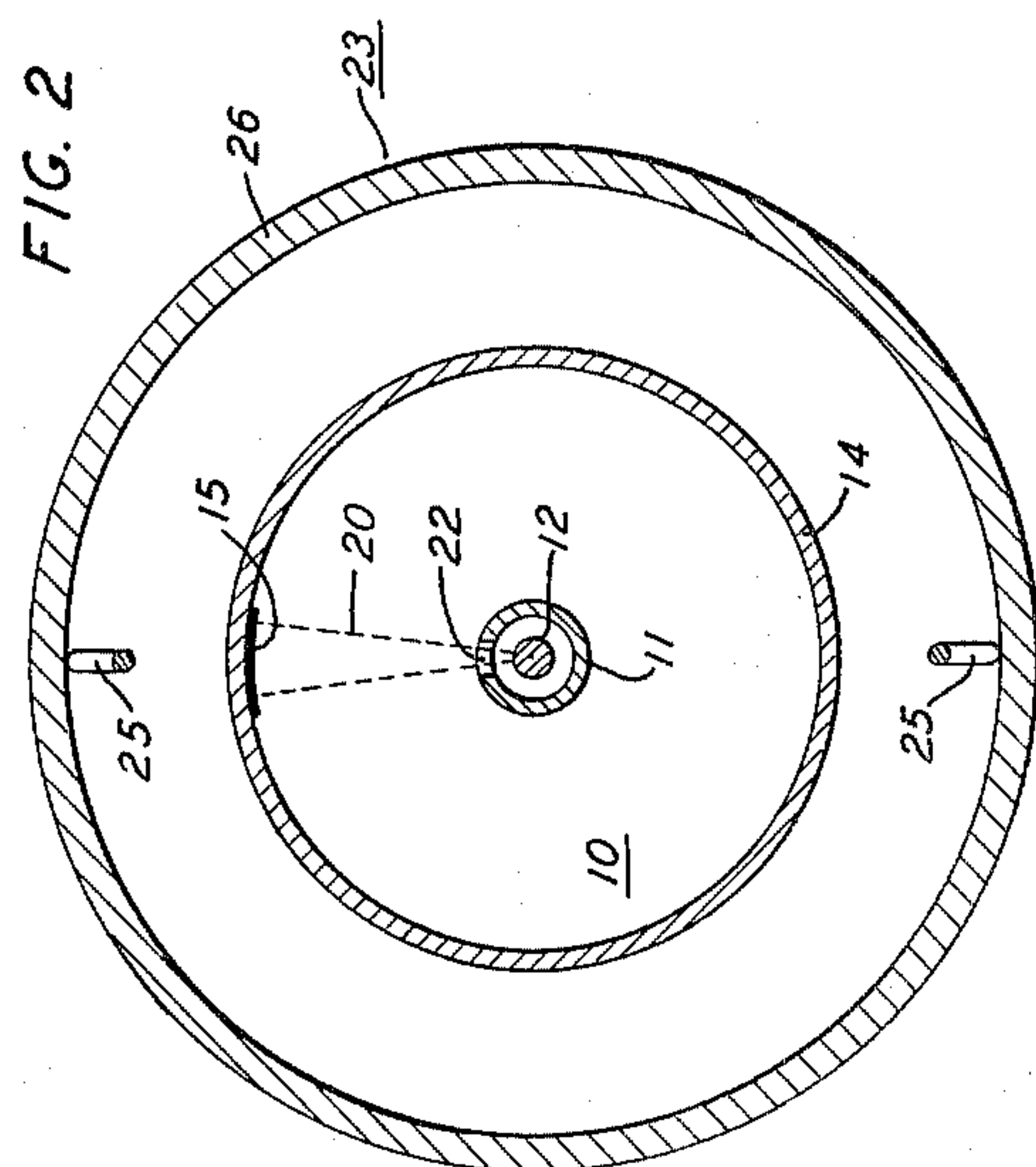
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PHOTOSENSITIVE BROADBAND COUPLER USING WAVE GUIDE

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8 Claims. (Cl. 250—211)

This invention relates to photodetectors and, more particularly, to devices for removing high frequency modulation energy from light waves.

This application is closely related to my copending application, Ser. No. 214,302, filed Aug. 2, 1962 and assigned to Bell Telephone Laboratories, Incorporated.

My above-mentioned copending application describes the use of a coaxial cable as a broad band output coupler for use in a photomultiplier. Devices of this type are particularly useful for detecting and amplifying modulations of low-power light waves. During operation, the light energy is first converted to electron energy and amplified by the photomultiplier in a conventional manner. It is then converted to electromagnetic wave energy by directing the photoelectrons from the last dynode of the photomultiplier through a slot in the outer conductor of the coaxial cable to be collected by the inner conductor. One end of the cable is terminated; the moving charges excite electromagnetic fields in the cable which propagate toward the other end to an appropriate load. The bandwidth of the device is almost unlimited because all of the output reactances are distributed uniformly along the cable rather than being lumped, as in conventional photomultiplier collectors.

Several problems have appeared when the device of my copending application is used as a detector for the high-power outputs of pulsed ruby lasers. First, considerable energy is lost by converting the light energy to electron energy because ordinary photoemissive materials saturate at an energy level lower than that of most such pulses. Secondly, the coaxial cable must be terminated in its characteristic impedance which lowers efficiency by decreasing the effective load impedance. Third, and most important, the width of the optical beam creates a dispersion effect which, because of resulting phase differences, may cancel out much of the power. Elimination of these losses enhances considerably the efficiency of the detection process and in many instances may make it unnecessary to resort to photomultiplication.

It is, therefore, an object of this invention to convert efficiently light wave modulations to electromagnetic wave energy.

This and other objects of the invention are attained in an illustrative embodiment thereof comprising a coaxial cable having a slot along part of the outer conductor. The cable is surrounded by a hollow conductive cylinder having a photocathode formed by a coating of photoemissive material on part of its inner surface, opposite the slot. An envelope surrounds the outer cylinder to keep it in a substantial vacuum. The ends of the cylinder are open so that the modulated light can be easily directed at an angle against the photoemissive coating. The coaxial cable is maintained at a positive potential with respect to the cylinder so that when light strikes the photoemissive coating, emitted electrons are directed through the slot in the outer conductor and are collected by the inner conductor. This launches electromagnetic wave energy in the coaxial cable in the manner explained in my copending application.

In accordance with a feature of this invention, light is directed against the photocathode at an angle with the surface normal of more than 75 degrees. This reduces the power density of the incident light which, if too

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great, would saturate the photocathode. Secondly, dispersion due to the finite width of the light beam is substantially eliminated. Third, under certain conditions, the quantum efficiency of photoemission is increased when polarized light is used. Finally, the device behaves as a directional coupler at high frequency which eliminates the need for termination of the backward wave.

Another advantage stems from the use of cylindrical electrode elements which produce a radial electric field. With this configuration, the emitted photoelectrons are inherently focused by the radial lines of force and can thereby be collected by a relatively thin central conductor, even though the photoemissive coating is spread over a larger area. This is desirable because, as pointed out above, large area photoemission is necessary for efficiently converting high-power light pulses to electron energy.

An alternative embodiment of my invention comprises a coaxial cable having a diverging lens at one end. A part of the inner surface of the outer cylindrical conductor is coated with a photoemissive material to form an annulus surrounding the inner conductor. Light is directed through the lens at the end of the coaxial cable in a direction parallel with the cable axis. The lens diverges the light beam so that it impinges evenly on the annular photoemissive surface, thereby giving even wider area impingement than in the foregoing embodiment. The emitted electrons are collected by the inner conductor which is biased at a positive potential with respect to the outer conductor. For some purposes, the need for a voltage between the inner and outer conductors could be a problem because direct-current blocking would normally be required. This potential disadvantage can be avoided by extending the inner conductor into a waveguide so that the electromagnetic wave energy in the coaxial cable excites an electromagnetic wave in the waveguide.

These and other objects and features will be better understood from a consideration of the following detailed description, taken in conjunction with the accompanying drawing, in which:

FIG. 1 is a cross-sectional view of one embodiment of the invention;

FIG. 2 is a view taken along lines 2—2 of FIG. 1; and
FIG. 3 is a cross-sectional view of another embodiment of the invention.

Referring now to FIG. 1, there is shown a photodetector 10 comprising a coaxial cable 11 having an inner conductor 12 and an outer conductor 13. Surrounding part of the coaxial cable is a hollow conductive cylinder 14. Part of the inner surface of the hollow cylinder is coated with a photoemissive material to form a photocathode 15. The coating may be, for example, S-1 photoemissive material which is a well-known mixture of silver oxide and cesium, and which is responsive to high-frequency modulated light energy. The two conductors of the coaxial cable are maintained at a positive direct-current potential with respect to the photocathode by a voltage source schematically shown as 17.

In operation, a light beam 18 is projected by a light source 19 through an open end of the hollow cylinder 14 at an angle to the photocathode 15. The light source may typically be a source of high-power pulsed energy such as that produced by a pulsed ruby laser. When the light beam impinges on the photocathode, electrons are emitted which are attracted toward the coaxial cable, as shown schematically by dotted lines 20. A slot 22 in outer conductor 13 permits the electrons to be collected on the inner conductor 12. As the electrons pass between the inner and outer conductors, they launch electromagnetic waves which travel in the direction shown by the arrow.

Surrounding the outer hollow cylinder 14 and the slotted portion of the coaxial cable is an envelope 23 which maintains the stream of electrons in a substantial vacuum to prevent ionization. The hollow cylinder is positioned by eight spring tabs 24 while an external connection to the photocathode is made by four wires 25 which are attached to a Kovar section 26 of the envelope. The remainder of the envelope may be of glass or some other appropriate material which is transparent to the incident light. The part of the coaxial cable which is sealed to the glass envelope may also be made of Kovar which is a particularly good metal for sealing purposes.

In accordance with a primary feature of the invention, wide area impingement of the optical beam is assured by the angle at which it strikes the surface as shown in FIG. 1. If the beam were directed perpendicularly against the emissive surface, it can be appreciated that the light would be concentrated on a much smaller area and, under conditions of high power, saturation would occur; i.e., the photoemission would not increase with increasing power of the light beam.

Directing the light at an angle to the photoemissive surface is also useful because it reduces dispersion due to the finite width of the optical beam. If the beam were directed perpendicularly against the photocathode, a phase difference in the excited electromagnetic wave equal to the width of the beam would inevitably result. That is, if the light beam were two centimeters wide, a maximum phase difference of two centimeters would occur in the excited wave, which could be serious at high frequencies. In FIG. 1, energy at one extreme edge of the light beam impinges at point *a*, while light at the other extreme edge impinges at point *c*. Both energy increments reach point *d* at the substantially same instant of time, and therefore in phase, because they both travel substantially the same distance regardless of the width of the beam. This can be understood if one considers that the cosine of a small angle is nearly unity; that is, in FIG. 1 distance *a-c* substantially equals distance *a'-c*. This factor also makes the device act as a directional coupler at high frequencies because it inherently prevents energy from traveling backwards toward the terminal impedance 27.

Experiment has shown that modulation frequencies of more than 30 kilomegacycles per second can be efficiently detected when the angle of incidence of the light beam 18 on the photoemissive surface (i.e., the angle with the surface normal) is more than 75 degrees. Under certain conditions of polarization, this high angle of incidence also increases the efficiency of photoelectron production; see "Astrophysics Journal," vol. 60, No. 209, 1924. This latter effect is maximized for certain photoemissive surfaces when the angle of incidence is approximately 85 degrees. There does not appear to be any inherent critical angle of incidence at which the other above-described advantages are optimized. If, however, the angle is reduced below 75 degrees, the problems of dispersion and saturation become rapidly more acute.

As can be seen in FIG. 2 the particular construction of the electrode elements inherently focuses the emitted photoelectrons. The electric field between coaxial cable 11 and outer cylinder 14 is radial, which forces the emitted electrons to follow radial lines. As a result, all of the emitted electrons are focused to a point at the center of the device and can be efficiently collected by a relatively thin inner conductor 12. This permits a relatively large area of photoemissive surface 15 in the cross-sectional dimension shown in FIG. 2 which also helps to avoid saturation of the photoemissive surface which would occur if the light beam were concentrated on a smaller area.

Referring now to FIG. 3 there is shown an alternate type of photodetector comprising a coaxial cable portion having an inner conductor 28 and an outer conductor 29. Sealed to one end of the coaxial cable is an optical diverging lens 30. An annular photoemissive surface 32 is coated on the inner surface of outer conductor 29 and

surrounds part of the inner conductor 28. The end of inner conductor 28 opposite the lens protrudes into a waveguide cavity 33 and is supported by an insulator mount 34. The coaxial cable and waveguide cavity are maintained within a substantial vacuum by an electromagnetic wave permeable window 35.

Modulated light energy is formed and projected by a source 37 in a direction parallel with the axis of the coaxial cable. When the light beam passes through diverging lens 30 it is diverged to assume a conical form and impinge around the entire surface of the annular photoemissive coating 32. The inner conductor 28 is maintained at a high positive potential with respect to the other conductor 29 by a voltage source 38 so that emitted photoelectrons from coating 32 are attracted to, and collected by, the inner conductor 28. The photoelectrons excite a highly directional electromagnetic wave which travels in the direction of the dotted arrow in the same manner as in the device of FIG. 1.

If the inner and outer conductors 28 and 29 were connected to a conventional coaxial cable which had no potential difference between the inner and outer conductors, direct-current blocking would be required in order to maintain the required voltage for purposes of photoelectron collection. This problem is avoided by coupling the coaxial cable to a waveguide through the waveguide cavity 33. Proper impedance matching between the waveguide and coaxial cable is attained by adjusting a plunger 38 and a tuning slug 39, as is well known. After the electromagnetic wave is excited in the cavity 33 it propagates out through waveguide 40 in the direction shown by the solid arrow.

The embodiment of FIG. 3 may be advantageous for some purposes because it is simpler and smaller than the device of FIG. 1. The device of FIG. 1, on the other hand, is advantageous because the inner and outer conductors of the coaxial cable can be maintained at the same direct current potential, thereby avoiding the problems associated with direct-current blocking.

It can be appreciated that the various features of FIGS. 1 and 3 can be combined in any of various manners. It should also be understood that these particular embodiments are described only for purposes of illustrating the invention and that various modifications thereto can be made. For example, a photomultiplier can be used to increase the current density, if such increase is desired; a strip line can be substituted for the coaxial cable as described in my aforementioned application. Numerous other devices may be made by those skilled in the art without departing from the spirit and scope of the invention.

What is claimed is:

1. A photodetector comprising:

a coaxial cable having inner and outer conductors; a conductive cylinder surrounding the coaxial cable; the cylinder having a photoemissive material on at least part of its inner surface;

means for directing modulated light energy against the photoemissive surface at an angle of incidence of more than 75 degrees;

a slot in the coaxial cable outer conductor for permitting passage of photoelectrons from the photoemissive surface;

means comprising part of the inner conductor for collecting electrons emitted by the photoemissive surface;

and means for maintaining the photoemissive surface and the electron collecting means in a substantial vacuum comprising an envelope which is at least in part light transparent.

2. The photodetector of claim 1 further comprising: means for biasing the conductive cylinder at a negative potential with respect to the coaxial cable, thereby producing a radial electric field between the coaxial cable and the cylinder which focuses the photoelectrons;

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and wherein the slot subtends approximately the same angle as the emissive surface.

3. In combination:

a photoemissive surface;

means for directing modulated light energy against said photoemissive surface at an angle of incidence of more than seventy-five degrees, whereby a modulated electron stream is emitted from the photoemissive surface;

said incident light energy having a major velocity component in a first direction;

a coaxial cable transmission line having parallel co-extensive inner and outer conductors;

the coaxial cable being adapted to propagate electromagnetic waves in said first direction;

part of the outer conductor of the cable having an opening therein which faces the photoemissive surface;

and means comprising part of the inner conductor for collecting said modulated electron stream, whereby a low dispersion electromagnetic wave is excited in the coaxial cable which propagates predominantly in said first direction.

4. In combination:

a photoemissive surface;

means for directing modulated light energy against said photoemissive surface at an angle of incidence of more than seventy-five degrees, whereby a modulated electron stream is emitted from the photoemissive surface;

said incident light energy having a major velocity component in a first direction;

a dual-conductor electromagnetic wave transmission line comprising a first conductor that is parallel to, and coextensive with, a second conductor;

the transmission line being adapted to propagate electromagnetic waves in said first direction;

a part of the first conductor of the transmission line having an opening therein which faces the photoemissive surface;

and means comprising part of the second conductor for collecting said modulated electron stream, whereby a low dispersion electromagnetic wave is excited in the electromagnetic wave transmission line which propagates predominantly in said first direction.

5. A device for converting light modulation energy into electromagnetic wave energy comprising:

a coaxial cable having inner and outer conductors; one end of the coaxial cable being transparent to light energy;

part of the inner surface of the outer conductor being coated with a photoemissive material forming an annulus which surrounds part of the inner conductor; means including a diverging lens at the transparent end of the coaxial cable for deflecting light which flows parallel with the coaxial cable against the annular coating;

and means for maintaining the inner conductor at a positive direct-current potential with respect to the outer conductor.

6. A device for converting light modulation energy into electromagnetic wave energy comprising:

a coaxial cable having inner and outer conductors; one end of the coaxial cable being transparent to light energy;

part of the inner surface of the outer conductor being coated with photoemissive material;

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means for directing light energy through the transparent end against the photoemissive coating;

means for maintaining the inner conductor at a positive direct-current potential with respect to the outer conductor;

the outer conductor being conductively connected to a wall of a waveguide;

the inner conductor protruding into the waveguide;

and means for matching the impedance of the coaxial cable and the waveguide.

7. In combination:

a photoemissive surface;

a source of modulated light energy;

means for directing the modulated light energy against said photoemissive surface at an angle of incidence of more than 75 degrees, whereby a modulated electron stream is emitted from the photoemissive surface;

said incident light having a major velocity component in a first direction;

a coaxial cable transmission line having parallel co-extensive inner and outer conductors which extend in the first direction;

the coaxial cable being adapted to propagate electromagnetic waves in said first direction;

the photoemissive surface being included on the inner surface of the outer conductor of the coaxial cable;

and means comprising part of the inner conductor for collecting said modulated electron stream, whereby a low dispersion electromagnetic wave is excited in the coaxial cable which propagates predominantly in said first direction.

8. In combination:

a photoemissive surface;

a source of modulated light energy;

means for directing modulated light energy against said photoemissive surface at an angle of incidence of more than 75 degrees, whereby a modulated electron stream is emitted from the photoemissive surface;

said incident light energy having a major velocity component in a first direction;

a dual-conductor electromagnetic wave transmission line comprising a first conductor that is parallel to, and coextensive with, a second conductor, and which extends in the first direction;

the first conductor having a surface that faces the second conductor;

the transmission line being adapted to propagate electromagnetic waves in said first direction;

the photoemissive surface being included on the surface of the first conductor that faces the second conductor;

and means comprising part of the second conductor for collecting said modulated electron stream, whereby a low dispersion electromagnetic wave is excited in the electromagnetic wave transmission line which propagates predominantly in said first direction.

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