

Nov. 2, 1965

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3,215,844

BROADBAND OUTPUT COUPLER FOR PHOTOMULTIPLIER SYSTEM

Filed Aug. 2, 1962

FIG. 1

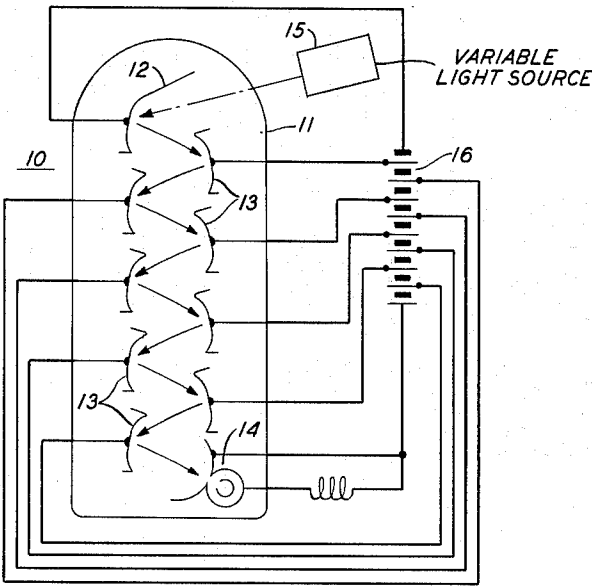


FIG. 2

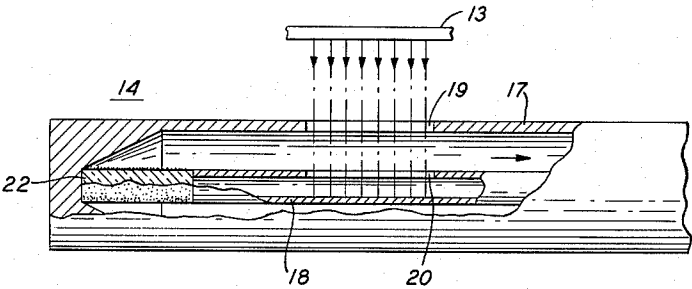
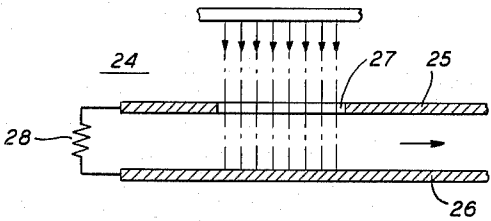


FIG. 3



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BROADBAND OUTPUT COUPLER FOR PHOTOMULTIPLIER SYSTEM

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Filed Aug. 2, 1962, Ser. No. 214,302

5 Claims. (Cl. 250-207)

This invention relates to broadband output couplers and, more particularly, to output couplers for removing modulation energy from an electron beam over a wide frequency band.

The increased use of pulse codes in communication systems has necessitated devices that are frequency responsive over extremely wide bands that include low frequencies as well as high frequencies. For example, in certain systems using pulse modulated light waves, it would be desirable to use a photomultiplier that is responsive to frequencies from zero to twenty-five kilomegacycles per second. Present photomultipliers are not capable of such operation partly because their bandwidths are limited by lumped shunt capacitance and series inductance in their output circuits. Although devices such as klystrons and traveling wave tubes have relatively large bandwidths, the known cavity resonators and interaction circuits used in these tubes cannot extract beam modulation energy over both low frequencies and high microwave frequencies simultaneously.

Accordingly, it is an object of this invention to extract modulation energy from an electron beam over an extremely wide frequency band which includes both low frequencies and high microwave frequencies.

These and other objects of my invention are attained in an illustrative embodiment thereof comprising a photomultiplier for detecting and amplifying fast light pulses. The light pulses strike a photosensitive cathode thereby releasing electrons that are directed to a succession of dynodes having a high ratio of secondary emission. As is known, the electron current, which is a manifestation of the original light pulses, is multiplied by the secondary emission of the dynodes.

According to a feature of one embodiment of my invention the pulse modulated stream of electrons is collected by the inner conductor of a coaxial cable. The electrons are directed from the last dynode through a slot in the outer conductor of the coaxial cable and impinge upon the inner conductor. One end of the cable is terminated; the moving charges excite electromagnetic fields in the cable which propagate out through the other end to an appropriate load. Because all of the load reactances are distributed uniformly along the cable, there are no lumped reactances to limit the bandwidth of the device.

It is another feature of this embodiment that the inner and outer conductors of the coaxial cable be at the same D.-C. potential. This is advantageous because they both may be at D.-C. ground and still be at any arbitrary voltage above that of the dynodes. Further, no D.-C. blocking will be required and operation down to a zero frequency will be possible. A possible disadvantage is that secondary electrons from the inner conductor may degrade the pulse modulations.

This disadvantage is obviated by another feature of this embodiment: the inner conductor of the cable is hollow and contains a slot for admission of the electron stream. The modulated electrons pass through the slot and impinge on the interior of the hollow conductor so that most of the secondarily emitted electrons are trapped within the conductor and prevented from drifting into the dynode region.

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According to a feature of another embodiment of this invention, the electrons are passed through a slot in one of the conductors of a "strip line" transmission line and are collected on the other conductor. As in the foregoing embodiment, the strip line is terminated at one end and both conductors are at the same D.-C. voltage.

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

FIG. 1 is a schematic sectional view of a photomultiplier which employs one embodiment of the invention;

FIG. 2 is a sectional view of the output coupler section of the photomultiplier of FIG. 1; and

FIG. 3 is a sectional view of another embodiment of the invention.

Referring now to the drawing, FIG. 1 shows a schematic sectional view of a photomultiplier 10 of the general type described in detail in the patent of Teal, 2,245,624. Enclosed within a substantial vacuum by an envelope 11 are a cathode 12, a plurality of dynodes 13, and an output coupler section 14. Cathode 12 is coated with a material that is photoelectrically active, that is, it emits electrons when light strikes it. Dynodes 13 are coated with a material having a high ratio of secondary emission. When a given number of electrons strike such a material a larger number of secondary electrons are emitted from the material. In operation, information in the form of light pulses from a source 15 strikes cathode 12 causing a modulated electron stream to be emitted. The electrons follow a path indicated by the arrows and impinge on the succession of dynodes 13. The electron current is multiplied by each dynode because of the large number of secondary electrons that are emitted. As a result, the pulse code modulations on the electron stream are greatly amplified by the time they reach output coupler 14. The electrons are directed along the indicated path by the curvature of the dynodes and by the progressively higher D.-C. voltages on the dynodes through their connection to a battery 16.

Referring to FIG. 2, output coupler 14 comprises a coaxial cable having a hollow outer conductor 17 and a hollow inner conductor 18. A slot 19 in conductor 17 and a slot 20 in conductor 18 permit passage of the electron stream into the interior of the hollow inner conductor 18. As the electron stream passes into the collector section, the electron modulations excite an electromagnetic wave between conductors 17 and 18 which is conducted in the direction shown by the arrow to an appropriate load. The other end of the coaxial cable is terminated by a characteristic impedance 22 which may, for example, be a ceramic material coated with carbon. Outer conductor 17 is tapered toward impedance 22 to minimize reflection. Alternatively, this end of the cable could be open-circuited by removing impedance 22 in which case energy would be reflected back in the direction of the arrow rather than being absorbed by the impedance. At low frequencies, the distortion resulting from phase differences is slight and is counterbalanced by increased power output. If the device is to be used solely at high frequencies and over a narrow band of frequencies, a short-circuit termination can be used which again reflects energy and thereby increases power output. However, when the device is used over a broad frequency band including both low and high frequencies the cable should advantageously be terminated in its characteristic impedance as shown in FIG. 2.

As shown in FIG. 1, inner and outer conductors 18 and 17 are maintained at the same voltage by battery 16. It can be shown that with these potentials the output coupler section 14 is responsive to all low frequencies down to zero frequency. Under these conditions, how-

ever, there is some danger of interference by secondary emission and for this reason the inner conductor 18 advantageously is hollow. The inner conductor acts as a secondary electron trap because few electrons can escape out through slot 20. Secondary emission interference can alternatively be prevented by biasing inner conductor 18 at a positive voltage with respect to outer conductor 17. In such a case, however, D.-C. blocking of conductor 18 is required and the collector section will not be responsive to zero frequency modulations.

In conventional photomultipliers the electron stream is collected by an electrode which inherently displays a lumped shunt capacitance with respect to the dynodes and a lumped series impedance. These reactances inevitably limit the upper frequency response of the device. The coaxial cable output coupler, however, constitutes a circuit in which these inherent reactances are completely distributed and therefore can have only a small effect on frequency response. For this reason, the upper frequency limit of the device shown is limited only by second order effects and the device can easily be operated in the kilomegacycle range. This high frequency response is attainable simultaneously with the aforementioned low frequency response. It should be pointed out that operation over such a large frequency band presupposes the incorporation of various known elements into the photomultiplier of FIG. 1 to minimize transit time dispersion of the electron stream and thereby make the frequency response of the photomultiplier consistent with that of the output coupler.

An alternative embodiment of my invention, which can be substituted for output coupler 14 of FIG. 1, is shown in FIG. 3 and comprises a strip line 24 composed of parallel plate conductors 25 and 26. As the modulated electrons pass through a slot 27 in plate 25, they excite and electromagnetic wave between the plates which propagates toward an appropriate load as shown by the arrow. The other end of the strip line is terminated by an impedance, shown schematically as 28, which may be tapered in a number of known ways to minimize reflection. The strip line embodiment is sometimes advantageous because the slot 27 can be made larger than the analogous slot 19 in the coaxial cable without undue interference with transmission characteristics. This, of course, permits less precise focusing of the electron stream, which can be an important consideration. Further, the strip line is normally characterized by a larger radiating area and a larger thermal mass than the coaxial cable.

No specific dimensions of any of the elements of either of the foregoing embodiments have been found to be critical to the operation of the device. It can be shown that the transit time for electron travel between the outer and inner conductors 17 and 18 of FIG. 2 and between the conductors 25 and 26 of FIG. 3 limits the upper frequency response of the device. In a coaxial cable version having a .138-inch outer diameter and a .06-inch inner diameter, a transit time of 1.67×10^{-11} seconds can be shown to limit frequency response to 26.5 kilomegacycles per second. This response can, of course, be increased by decreasing the distance between the inner and outer conductors or by increasing the accelerating voltage. The slot 19 in coaxial cable conductor 17 and the slot 27 in strip line 24 should not be so wide as to interfere unduly with wave transmission, but again, there is no critical dimension. A slot .04 inch wide in the outer conductor of a coaxial cable of .138 inch in diameter was found to have a negligible effect on the transmission line properties since it is parallel to the direction of current flow.

Although the invention was shown as being used in a photomultiplier, it is also potentially useful in any electron beam device that uses charge density modulation or longitudinal velocity modulation. For example, the output coupler shown could be substituted for the output cavity resonator of a klystron. The charge density modulations of the klystron beam are capable of exciting an

electromagnetic wave in a coaxial cable or strip line in the same manner as described with reference to the photomultiplier of FIG. 1. Various other embodiments may be devised by those skilled in the art without departing from the spirit and scope of the invention.

What is claimed is:

1. A photomultiplier device comprising:
 - a source of pulse modulated light energy;
 - a cathode of photoelectrically active material for emitting a pulse modulated electron stream in response to said pulse modulated light energy;
 - an output coupler spaced from said cathode;
 - a series of dynodes each with a surface having a high ratio of secondary emission being arranged between said cathode and said output coupler;
 - a battery comprising means for biasing said dynodes at progressively higher positive D.-C. potentials in proportion to their distance from said cathode;
 - said dynodes comprising means for emitting pulse modulated electrons in response to impingement of electrons from said cathode or from other dynodes;
 - said output coupler comprising a coaxial cable having a hollow outer conductor coaxially surrounding a hollow inner conductor;
 - a slot on one side of each of said conductors, said slots being in alignment;
 - said dynodes being positioned to direct electrons through said slots to the interior of said hollow inner conductor;
 - the coaxial cable on one side of said slots being terminated by a characteristic impedance connection between the inner and outer conductors;
 - the coaxial cable on the other side of said slots constituting a transmission line for propagating pulse modulation energy to an appropriate load;
 - and means connected to said battery for maintaining said inner and outer conductors at the same D.-C. voltage.
2. A photomultiplier amplification system comprising:
 - a source of modulated light energy;
 - at least part of the light modulations having frequencies in the kilomegacycle frequency range;
 - a cathode of photoelectrically active material for emitting a modulated electron stream in response to the modulated light energy;
 - an output coupler spaced from the cathode;
 - a series of dynodes each with a surface having a high ratio of secondary emission being arranged between the cathode and the output coupler;
 - said dynodes comprising means for multiplying the flow of electrons, whereby the electron stream modulations are amplified;
 - the output coupler comprising a coaxial cable having a hollow outer conductor coaxially surrounding an inner conductor;
 - a slot on one side of the outer conductor;
 - the dynodes being positioned to direct the electrons through said slot, to impinge upon the inner conductor, whereby electromagnetic wave energy is excited in the coaxial cable;
 - the coaxial cable on one side of the slot constituting a transmission line for propagating the electromagnetic wave energy to an appropriate load.
3. The photomultiplier system of claim 2 wherein at least a portion of the inner conductor is hollow, the hollow portion having a slot which is closely adjacent to, and in alignment with, the slot in the outer conductor, whereby the electron stream is directed through both slots to impinge on the interior of the inner conductor.
4. A photomultiplier system comprising:
 - a source of modulated light energy;
 - at least part of the light modulations having a frequency in the kilomegacycle range;

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a cathode for emitting a modulated electron stream in response to the modulated light energy;
 an output coupler spaced from said cathode;
 a series of dynodes each with a surface having a high ratio of secondary emission being arranged between the cathode and the output coupler;
 said dynodes comprising means for amplifying the modulated electron stream;
 said output coupler comprising a strip line having first and second parallel conductors which are capable of propagating electromagnetic wave energy therebetween;
 one end of the first conductor being adjacent the dynodes and having a slot therein;
 said dynodes being positioned to direct electrons through the slot to impinge upon the second conductor, whereby electromagnetic wave energy is excited between the first and second conductors of the strip line;
 and a load;
 said strip line comprising means for transmitting said electromagnetic wave energy to said load.

5. A photomultiplier system comprising:
 a source of modulated light energy;
 at least part of the modulations having a frequency in the kilomegacycle range;
 a cathode for emitting a modulated electron stream in response to the modulated light energy;
 an output coupler spaced from said cathode;
 a series of dynodes each with a surface having a high ratio of secondary emission being arranged between the cathode and the output coupler;
 said dynodes comprising means for amplifying the modulated electron stream;

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said output coupler comprising a coaxial cable having first and second parallel conductors which are capable of propagating electromagnetic wave energy therebetween;
 the first conductor being hollow and surrounding the second conductor;
 one end of the first conductor being adjacent the dynodes and having a slot therein;
 said dynodes being positioned to direct electrons through the slot to impinge upon the second conductor, whereby electromagnetic wave energy is excited between first and second conductors;
 that portion of the second conductor which collects the electron stream being hollow and having a slot which is adjacent to and aligned with the slot in the first conductor, whereby the electron stream is directed against the interior of the second conductor;
 and a load;
 said coaxial cable comprising means for transmitting electromagnetic wave energy to said load.

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