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[54] **PHOTOMULTIPLIER TUBE CIRCUIT EMPLOYING VARISTOR**
8 Claims, 4 Drawing Figs.

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[50] **Field of Search** 250/207, 214; 356/205

[56] **References Cited**
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ABSTRACT: The output of a photomultiplier tube circuit is disclosed as being developed across a varistor, thereby to linearize such output as a function of a logarithmically variable input to the photomultiplier tube.

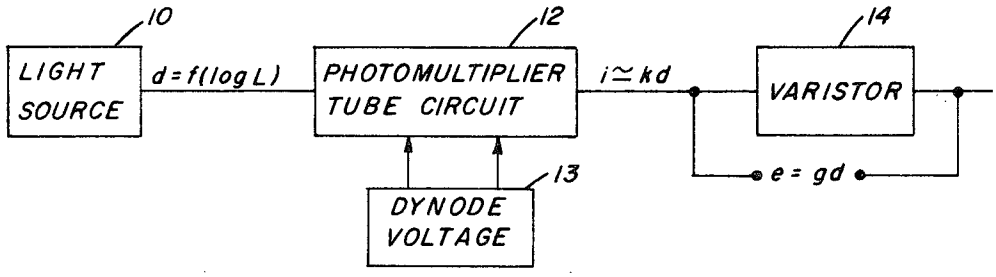


FIG. 1

FIG. 2

FIG. 3

FIG. 4

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PHOTOMULTIPLIER TUBE CIRCUIT EMPLOYING VARISTOR

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates in general to photomultiplier tube circuits. In particular the invention provides means for making the useful output of a photomultiplier tube circuit linearly variable as a function of a parameter which varies logarithmically with input radiation to the photomultiplier tube.

2. description Relative to the Prior Art

The invention is best appreciated cast in the environment of a densitometer, for it is in the field of the densitometry that the invention has its closest known prior art, and in which field the problem solved by means of the invention has been most perplexing. Optical density is a property of concern in the photographic field, and it is defined as the inverse logarithm of the light transmitted by a sample. Thus, if 100 percent of the source light passes through the sample, the sample has zero density; if 10 percent of the source light passes through the sample, the sample has an optical density of one; if 1 percent of the source light passes through the sample, the sample has an optical density of two, etc.

A photomultiplier tube connected into a circuit in the manner taught by Gunderson, U.S. Pat. Nos. 2,413,706 and 2,454,871, has an exponential transfer characteristic which is dependent on the number of its dynodes: The quantity of electrons made available by radiation received at the cathode of a photomultiplier tube increases exponentially as a function of the number of dynodes of the photomultiplier tube. Since an exponential relationship ($y=x$) resembles, to some extent, a logarithmic relationship ($y=n^x$), the raw output of the photomultiplier tube approximates a linear function of the logarithm of its input light; which is to say that such output approximately linearly varies with sample density.

Sweet, in U.S. Pat. No. 2,492,901, issued Dec. 27, 1949, provides a constant current photomultiplier tube densitometer circuit of the type indicated by Gunderson, (see above) and indicates an incremental technique for linearizing the relationship of the output of a photomultiplier tube with optical density; Journal of Scientific Instruments, Vol. 33, Feb. 1966, in an article entitled "A Wide Range, Recording, Logarithmic Photometer Circuit" by Hariharan and Bhalla indicates a nonincremental technique for linearizing such relationship. Whereas the Sweet circuit arrangement is fairly simple in construction, it is functionally less than adequate because of its use of discrete corrections: i.e., quantizing an incrementally adjusted voltage is less than adequate if such voltage is to be digitally manipulated, a fact which has been reconciled by the invention. The Hariharan and Bhalla circuit on the other hand is functionally adequate, but is comparatively complex and expensive constructionwise.

SUMMARY OF THE INVENTION

The invention provides a densitometer circuit which produces a nonincrementally adjusted output signal that varies as a linear function of optical density (e.g., x volts equals a density of 1, $2x$ volts equals a density of 2, $3x$ volts equals a density of 3, etc.), and which circuit is even more simply constructed than the Sweet circuit. To illustrate and emphasize these features, the invention—aside from being depicted in its presently preferred form—is cast herein in the environment of the circuit which is actually shown in FIG. 3 of the Sweet patent.

The invention recognizes that if the light input to a photomultiplier tube circuit varies logarithmically in accordance with some parameter, then the output of such circuit arranged as taught by Gunderson (see above) will be a signal which varies linearly with that parameter provided such signal is developed across a varistor. If the parameter in question is optical density, and if radiant flux is transmitted by a sample onto the cathode of the photomultiplier tube, the electrons so produced will be exponentially multiplied by action of the photomultiplier tube dynodes; and if the output current of the photomultiplier tube is passed through a varistor, the voltage so developed across the varistor will be linearly proportional to the optical density of the sample.

As presently preferred, the invention is embodied in a densitometer circuit which maintains constant the current through a photomultiplier tube by adjustment of the tube dynode potentials (a la Sweet), whereby the total dynode voltage change may be taken as the circuit output to reflect a change in optical density. So as not to influence adversely the performance of the photomultiplier tube, the varistor in question is preferably disposed in parallel with the photomultiplier tube dynodes, and is electrically isolated from the dynodes by means having a fairly large impedance. However the dynode voltage changes, so too does the voltage that appears across the varistor and its isolating impedance means; and that portion of the dynode voltage which appears across the varistor is linearized by the inherent characteristics of the varistor to represent the matter of optical density.

An object of the invention is to provide an improved photomultiplier tube circuit.

Another object of the invention is to use to advantage the properties of a varistor to improve the overall performance of a photomultiplier tube circuit.

Another object of the invention is to employ the complementary characteristics of a photomultiplier tube and a varistor to provide a densitometer circuit the output of which varies linearly with optical density.

The invention will be described with reference to the figures wherein:

FIG. 1 is a block diagram illustrating apparatus according to the invention;

FIG. 2 is a schematic diagram of a circuit found in the prior art, and improved by means of the invention;

FIG. 3 is a diagram useful in describing the invention; and

FIG. 4 is a schematic diagram illustrating the invention in its presently preferred form.

Reference should now be had to FIG. 1 which broadly illustrates apparatus according to the invention. A light source **10**, e.g., a transparency, illuminates the cathode of a photomultiplier tube **12** with an intensity that is logarithmically related to a parameter (d), e.g., the optical density of the transparency. The photomultiplier tube **12** produces an output current which is maintained constant by changes to the dynode voltages **13**. Such dynode voltage changes are exponentially related to the light which is received at the cathode of the photomultiplier tube **12**; which is to say that the output current of the photomultiplier tube is an approximate analogue (i.e., slightly larger) of the parameter in question ($i \cong kd$). By passing the photomultiplier tube output current through a varistor **14**, a voltage ($e=gd$) appears across the varistor **14** which is a close analogue of the parameter d; this is because the varistor **14** develops a voltage which does not increase as fast as the corresponding current passed through it.

To see how the invention may be practiced in connection with a densitometer circuit such as the above-mentioned Sweet circuit, reference should be had to FIG. 2. See also the Sweet U.S. Pat. No. 2,492,901. Light from a lamp **16** is directed through a lens **18**; thence through sample density **20** to the cathode **22** of a photomultiplier tube **24**. The current through the photomultiplier tube **24** is maintained constant, irrespective of the light intensity reaching the cathode of the photomultiplier tube, by adjustment of the potentials applied to the dynodes **26***a*—**26***i* of the tube **24**. Whether the sample density 20 is zero (100 percent transmittance), or one (10 percent transmittance), etc., the current through the photomultiplier tube **24** remains constant by adjustment of the dynode potentials in approximate proportion to the density of the sample **20**; A control signal is developed across resistor **28** by means of the anode (**30**) current of the photomultiplier tube **24**; a feedback amplifier **32** in series (across points A and B) with the source of dynode potentials—a suitably tapped resistor **34**—is driven to a higher or lower negative potential as a

function of sample density. When the density of the sample **20** goes, say, from one to zero, the potential at the grid of the amplifier **32** goes negative, causing the amplifier **32** to appear as a high impedance in series with the tapped resistor **34**; the voltage across points A and B then redistributes itself, whereby the voltage across the tapped resistor **34** decreases to some (low) value related to a sample density of zero, thereby to keep constant the photomultiplier tube current. Were the density of the sample to have increased, say from zero to one, the opposite would have occurred.

It is well known that the dynodes of a photomultiplier tube, in effect, exponentially multiply the electrons photoelectrically produced at the cathode of the photomultiplier tube. Since, however, an exponential relationship between photomultiplier tube current and dynode potential is not quite the same as the logarithmic relationship which exists between photomultiplier tube current and incident light received by the photomultiplier tube through a density, the dynode potential in a constant current photomultiplier tube densitometer circuit is only an approximate analogue of sample density. Thus, the invention proposes that the dynode voltage (actually a fraction thereof) be developed across a varistor **36** connected in parallel with the source **34** of dynode voltage. (Homogenous varistors, such as the silicon carbide type, have proven especially useful in practicing the invention.) And to assure that the varistor **36** does not adversely influence the potentials applied to the dynodes **26***a*—**26***i*, means **38** having a large impedance is connected in series with the varistor **36** to isolate the varistor from the dynodes.

Reference should now be had to FIG. **3** which indicates that as the voltage applied to the dynodes increases with sample density to maintain constant the current through the photomultiplier tube (dashed line), the impedance of the varistor **36** decreases to maintain the voltage across itself as a linear function of sample density (solid line). To be noted in FIG. **3** is that the abscissa thereof is indicated as being ordinately positionable; this is to indicate that a meter **40** employed to read the density-representative voltage that appears across the varistor **36** may be zeroable to cancel the effect of a quiescent voltage which appears across the varistor **36** when a sample density of zero obtains. Such meter zeroing, however, will be no avail if zero volts is to be quantized to a digital count (**000**) representing zero/density; this is because zero volts never actually appears across the varistor **36** when the circuit of FIG. **2** is operative.

The circuit of FIG. **4** produces a density-representative voltage output which may be directly quantized to a density-representative digital count; and since the circuit of FIG. **4** is otherwise functionally the same as the circuit of FIG. **2**, similar character notations are employed for the corresponding parts of the two figures (although primed notations are used in FIG. **4**): A transistor **32'** and a tapped dynode resistor **34'** are so serially connected to a source A'B' that when the current through a photomultiplier tube **24'** attempts to change, the impedance of the transistor **32'** adjusts to vary the voltage(s) applied to the dynodes, thereby to keep constant the photomultiplier tube current. The dynode voltage is also developed across means **38'** having a large impedance connected in series with a summing network **42**, part of which includes a varistor **36'**. The varistor **36'**, aside from being subject to a portion of the dynode voltage, via the impedance means **38'**, also sees a bias voltage applied thereto via a rheostat **44**; and which voltages algebraically add to produce a resultant voltage across the varistor. Such resultant voltage may be set to zero—to represent zero density—by adjustment of the rheostat **44**; may be taken as the circuit output for purpose of quantizing same into a digital density-representative count.

As with the circuit of FIG. **2**, the potential across the varistor **36'** may be read by a density-calibrated meter **40'**.

The invention has been described in detail with particular reference to preferred embodiments thereof, but it will be understood that variations and modifications can be effected within the spirit and scope of the invention.

I claim:

1. Circuit apparatus comprising:

a. means for producing a signal which varies logarithmically with a certain parameter;

b. means adapted to receive and exponentially amplify said signal to produce a signal that varies approximately linearly with said parameter; and

c. varistor means across which said exponentially amplified signal is developed for adjusting said exponentially amplified signal to vary substantially linearly as a function of said parameter.

2. The circuit apparatus of claim **1** wherein said means adapted to receive and exponentially amplify said signal is a photomultiplier tube.

3. The circuit apparatus of claim **2** wherein said certain parameter is optical density, and wherein said means for producing a logarithmically variable signal includes a source of radiation and means having a sample density adapted to pass said radiation to said photomultiplier tube.

4. In combination with a photomultiplier tube circuit of the type adapted to amplify exponentially signals applied thereto and means for applying radiation to the input of the photomultiplier tube thereof, which radiation varies as a logarithmic function of a certain parameter;

a varistor responsive to the output of said photomultiplier tube for adjusting said output to develop across itself a voltage which varies as a linear function of said parameter.

5. The circuit of claim **4** wherein said means for applying radiation includes a source thereof and sample means, having an optical density, for receiving and passing said source radiation to the input of said photomultiplier tube, whereby said varistor produces a voltage thereacross which is representative of the optical density of said sample means.

6. In combination with a radiation responsive photomultiplier tube:

a. voltage divider means for application of potentials to the dynodes of the photomultiplier tube;

b. variable impedance means in series with the voltage divider means responsive to the current flow through said photomultiplier tube to vary the impedance of said variable impedance means in proportion to changes in said current;

c. means for applying a potential across the serially arranged voltage divider means and variable impedance means, said potential redistributing itself in response to changes to said variable impedance means to maintain substantially constant the current through said photomultiplier tube to produce a potential across said divider means that is exponentially related to the light received by said photomultiplier tube; and

d. varistor means cooperative with said voltage divider means to develop thereacross a voltage which changes with changes to the voltage across said voltage divider means, said voltage across said varistor being substantially logarithmically related to the light received by said photomultiplier tube.

7. The apparatus of claim **6** including impedance means in series with said varistor, the said serially arranged varistor and impedance means being disposed in parallel with said voltage divider means.

8. The apparatus of claim **7** including means for applying a bias voltage across said varistor which is of such a value that when algebraically combined with the voltage produced thereacross by means of said voltage divider means there is no net resultant voltage across said varistor when the radiation received by said photomultiplier tube is at some certain maximum level.