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R. C. M. BEEH

3,268,735

PHOTOCELL MODULATORS

Filed May 24, 1962

FIG. 1

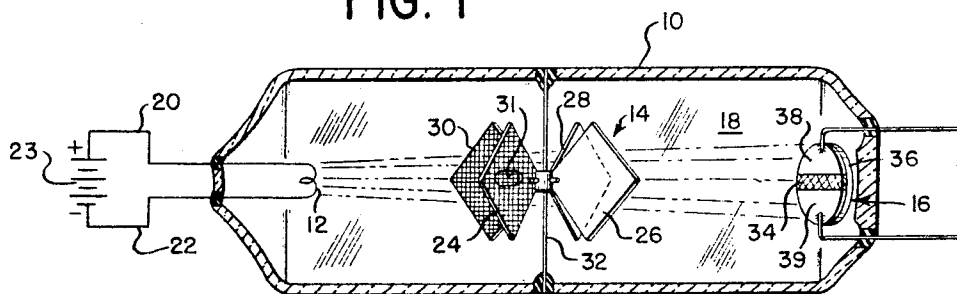


FIG. 2

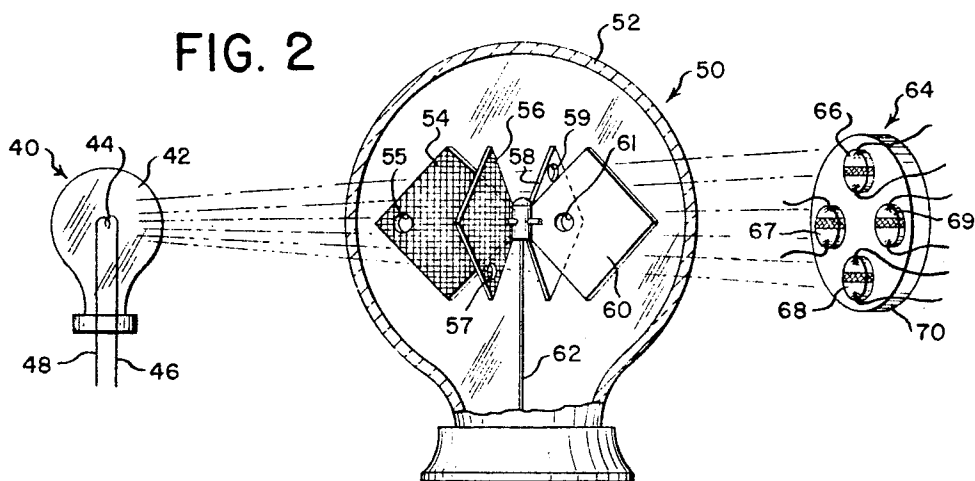


FIG. 3

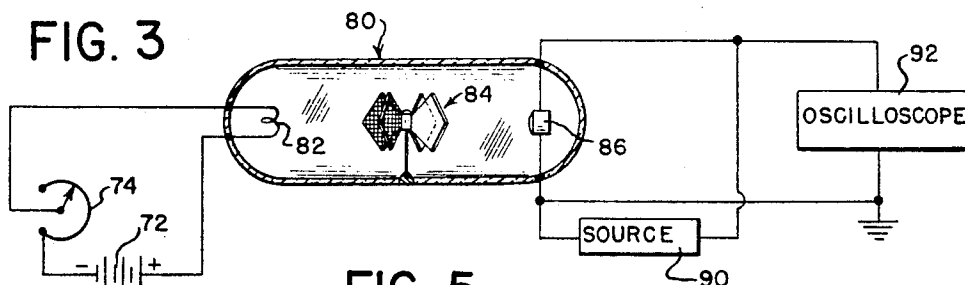


FIG. 5

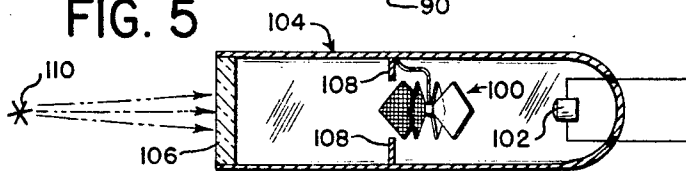
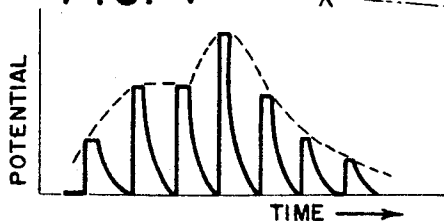


FIG. 4



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This invention relates to photocell modulators, and in particular to such apparatus in which the modulation is produced by means of a rotating vane radiometer.

Measurement of low-level direct-current voltages and currents is difficult, and D.-C. metering devices capable of making the measurements directly are limited in sensitivity, applicability, stability, reliability, etc. D.C. amplifiers have been used to provide increased sensitivity, but noise and drift present serious problems with low-level signals. Accordingly A.C. amplifiers are often employed, with a so-called "chopper" for converting the D.-C. signal to an A.-C. signal.

While various forms of choppers such as commutators, solenoid-operated switches, etc., have been used, photocell modulators have been found advantageous for many applications. In one form of photocell modulator heretofore employed, a beam of light impinging on a photocell is periodically interrupted by a mechanical shutter driven by a small motor. With a photocell of the photoconductive type, having a high impedance in the dark state and a low impedance in the illuminating state, measurement of voltages as low as 0.005 microvolt and currents as small as 10^{-10} amperes has been accomplished.

Although such photomodulators have proved to be very useful, heretofore a power supply has been required for the motor which drives the mechanical shutter, and shielding is often required to prevent interference caused by electric motors. Both have added to the basic bulk and weight of photomodulator systems.

In accordance with the present invention a vane type radiometer is employed to alternately intercept and pass radiation to a photocell. Thus, the radiation to which the photo-cell is responsive also serves to produce the modulation or chopping. For certain applications, such as in space applications where response to light from a distant source such as the sun, a star, etc., is desired, no additional source of power is required to produce the modulation. In more conventional applications, however, a local light source such as an incandescent lamp is used, and the light from this source serves both to energize the photocell and produce the modulation or chopping.

The photocell may be of any desired type suitable for the particular application. Frequently photocells of the photoconductive type will be employed, but for some applications photocells of the photo-emissive or photo-voltaic types may be used.

One or more vanes of the radiometer are adapted to alternately intercept and pass radiation to the photo-cell. This may be accomplished by providing one or more apertures in the vanes, making one or more vanes of semi-transparent material, or of polarized material which provides extinction of incident radiation when the angle of incidence of the radiation on the vane equals the angle of extinction of the polarized material, etc.

For a more complete description of the invention, reference is made to the following description of specific embodiments thereof, taken in conjunction with the drawings, in which:

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

FIG. 2 is a cross-sectional elevation of a second embodiment providing several modulation outputs

FIG. 3 is a schematic drawing of the apparatus of FIG.

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1 incorporated in a circuit which permits altering the modulation frequency;

FIG. 4 is a graph of an illustrative output signal displayed on the oscilloscope shown in FIG. 3; and

FIG. 5 is a cross-sectional view of a third embodiment of the invention.

Referring to FIG. 1, a light tight envelope 10 houses a lamp 12, a radiometer 14, and a photocell 16. Envelope 10 is elongated and is composed of a material such as glass painted internally with an opaque material, e.g., Aquadag. The space 18 within the envelope is evacuated to suitably low pressure, for example, in the range between 10 mm. and 10^{-9} mm. of mercury. The lamp 12 is shown as a filament sealed in one end of the envelope with electrical leads 20 and 22 extending through the envelope and connected across battery 23.

The radiometer 14 includes four diamond-shaped flat vanes 24, 26, 28 and 30. Each vane is painted on one side with a light absorbing material, e.g., black or the like, and the other side is painted with a light reflecting material, e.g., white or silver. One vane 24 has an aperture 31 therein. The vanes are affixed to a thin vertical axle 32 at 90° intervals, and axle 32 is rotatably mounted in envelope 10.

The photocell 16, e.g., a photoconductor, photoemitter or photo-voltaic cell, photomultiplier tube, etc., is located at the opposite end of envelope 10. The photocell as illustrated has an overall disc shape and includes a strip 34 of photoconductive material, e.g., cadmium sulfide, cadmium selenide, or the like. The photoconductive material is mounted on a substrate 36 such as a ceramic material or the like. Electrodes 38 and 39 contact opposite sides of the strip 34 and are also mounted on substrate 36. Electrical leads 42 and 44 are attached to electrodes 38 and 39 and pass through vacuum seals to the exterior of envelope 10, the leads serving as supports for the photocell 16.

The photoconductive strip 34 is positioned with respect to the vanes of the radiometer and lamp 12 so that light emitted from lamp 12 may not impinge on the strip 34 except by passing through aperture 31 when vane 24 is generally broadside to the radiation from lamp 12. To this end the axle 32 of the vane assembly is mounted to one side of the path between lamp 12 and photocell 16, and the size and position of aperture 31 selected with respect to the effective areas of source 12 and the photocell to give a response through a desired angle of rotation of vane 24.

In operation, the battery 23 supplies power to lamp 12 through leads 20 and 22 so that a beam of photons is generated and directed toward the photoconductor strip 34. The light included in those rays strikes the vanes 24, 26, 28 and 30 and produces rotation thereof in known manner.

As the vanes rotate on axle 32, they chop, i.e., modulate, the rays of light directed at the photocell so that light strikes the surface of photoconductor strip 34 once each revolution of the radiometer 14, causing the impedance of the photoconductor strip 34 to drop from its "dark state" value of, say, 200 megohms to an "illuminated state" value of as low as 500 ohms. Thus the impedance of the photoconductor strip 34 varies periodically as a direct function of the frequency of rotation of the radiometer 14. This frequency depends upon the intensity of the light source, the structure of the radiometer, and the forces opposing rotation including the friction between the fulcrum points and member 32, the inertia of the system, and the effect of residual gases within the system. In a vacuum of one micron the effect of pressure, turbulence and the like is usually negligible in comparison with friction and inertia.

The value of the impedance of the photoconductor 34 varies as a function of the intensity of the light reaching it and the characteristics of the photoconductive material.

Many variations in the structure of the photomodulator shown in FIG. 1 are possible. For instance, apertures can be similarly positioned in two or more of the vanes to increase the modulation frequency for a given speed of rotation of the radiometer. Or, with suitable arrangement of light source and photocell, a given vane may pass light to the photocell when it is on either side of axle 32, thereby passing light twice per revolution.

Referring to FIG. 2, a lamp 40, a radiometer 50 and a photocell sensing unit 64 are shown, the latter having a mosaic of photoconductors providing four different signal outputs at different times by means of using four photoconductor surfaces and using radiometer vanes with holes located appropriately to permit separate actuation of each of the photoconductors.

Lamp 40 includes an evacuated transparent envelope 42 and an incandescent type of filament 44 having electrical leads 46 and 48 connected to it. The radiometer 50 is enclosed in an evacuated transparent envelope 52 and includes four diamond-shaped vanes 54, 56, 58 and 60 painted with reflecting and absorbing paints on opposite sides as described above with reference to FIG. 1. The vanes are rotatably mounted and spaced 90° apart upon a vertical support member 62. Through each vane is a hole located in a different relative position with respect to the holes in the other vanes. Hole 55 is located adjacent the outer corner of vane 54, hole 57 is located in the lower corner of vane 56, hole 59 is in the upper corner of vane 58, and hole 61 is near the inner corner of vane 60.

The sensing unit 64 includes four photoconductors 66, 67, 68 and 69 mounted on a single disc-shaped substrate 70 and having electrodes and leads connected to them. The photoconductors are spaced in a pattern selected to give the proper sequence or reception of light by each one through a corresponding vane.

The lamp 40, radiometer 50 and sensing unit 64 are aligned with the axis of the radiometer 50 held vertically and the disc-shaped substrate 70 supported in the shadow of the vanes of radiometer 50, except for light transmitted through the holes therein.

Many variations in the basic structure are possible. These include using different radiation sources, e.g., a gas discharge lamp, an incandescent lamp, an electroluminescent lamp positioned either within or outside the envelope containing the radiometer, changing the shape and design of the vanes, and using different means for rotatably mounting the vanes.

Although radiation in the visible light range is conveniently employed for many applications, radiation outside the visible range may be employed if desired, so long as its wavelength is suitable for driving the radiometer and actuating the photocell.

Instead of holes, sem-transparent or polarizing material may be used in the vanes. In the latter case, the polarized surface of a vane may be arranged to pass light when the angle of the vane with respect to the radiation beam is less than the extinction angle of the material.

Narrow band filters may be mounted over the vane aperture so that only radiation within the narrow band will pass to the photocell. Thus, with a wide band radiation source, radiation outside the narrow band will be effective to produce rotation of the vanes at the aperture areas, so as not to reduce the efficiency appreciably. For example, a light source with a broad wavelength distribution could be used with a photoconductive material having a 5600-Angstrom peak sensitivity, and the filter material could offer a narrow band of maximum transmission centered at 5600 Angstroms.

The radiometer can be enclosed within an envelope provided with a coupling tube and a valve. By varying the pressure within the envelope, the speed of rotation of the radiometer can be varied.

Referring to FIG. 3, the circuit shown employs a photocell modulator to measure a low level D.-C. signal. The modulator 80 is like that shown in FIG. 1, and includes a lamp 82, a radiometer chopper 84, and a photoconductor 86. Lamp 82 is energized by battery 72 through a rheostat 74 which enables the intensity of radiation to be varied. The D.-C. signal source 90 may be a transducer having a low level D.-C. output, e.g., a thermocouple, a photocell, or other types of D.-C. generating devices, the output voltage of which is to be measured. Source 90 is in series with the photocell 86, so that its output is modulated, and oscilloscope 92 is connected across photocell 86 to give an indication of the modulated or chopped signal.

Thus a series of pulses are produced on the screen of the oscilloscope such as those shown in FIG. 4. The pulses are represented by solid lines, and the dotted envelope represents the original D.-C. signal.

By varying rheostat 74 to vary the intensity of radiation from lamp 82, the frequency of rotation of the radiometer 84 can be increased or decreased, so that the modulating frequency can be adjusted to desired values. Instead of manual control of the intensity of radiation, automatic control could be employed to add a desired amount of frequency modulation to the output signal.

Referring to FIG. 5, apparatus responsive to the light output from an external source of light is shown. Here a radiometer 100 and a photocell 102 are mounted in an envelope 104. The envelope 104 is elongated and opaque, except for a window 106 at one end. An apertured diaphragm 108 is provided adjacent the radiometer 100 to prevent radiation from reaching the photocell except under the control of the radiometer. The device can be used in systems for tracking light sources such as stars, satellites and the like, as indicated at 110. For applications in space systems where a high vacuum exists, the window 106 can be removed.

The invention has been described in connection with several specific embodiments thereof. It will be understood that many modifications may be made by those skilled in the art, within the spirit and scope of the invention.

I claim:

1. A photocell modulator for converting D.-C. signals to corresponding pulsating signals which comprises
 - (a) a vane-type radiometer for receiving radiation from a source thereof and being rotated thereby,
 - (b) a photocell sensitive to said radiation,
 - (c) the radiometer being positioned and adapted to alternately intercept and pass radiation to the photocell,
 - (d) and means for applying a D.-C. signal to said photocell for modulation thereby.
2. A photocell modulator for converting D.-C. signals to corresponding pulsating signals which comprises
 - (a) a vane-type radiometer for receiving radiation from a source thereof and being rotated thereby,
 - (b) the radiometer having a plurality of vanes and at least one vane being adapted to pass radiation there-through periodically as the vanes rotate,
 - (c) a photocell positioned to receive radiation periodically passing through said one vane and responsive thereto,
 - (d) and means for applying a D.-C. signal to said photocell for modulation thereby.
3. A photocell modulator in accordance with claim 2 in which said one vane has an aperture for periodically passing radiation to the photocell.
4. A photocell modulator in accordance with claim 2 in which said one vane includes filter means for passing only a relatively narrow band of radiation frequencies incident thereon, said photocell being responsive to said narrow band of radiation frequencies.

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5. A photocell modulator for converting D.-C. signals to corresponding pulsating signals which comprises

- (a) a source of radiation,
- (b) a vane-type radiometer positioned to receive radiation from said source and be rotated thereby,
- (c) the radiometer having a plurality of vanes and at least one vane being adapted to pass radiation there-through periodically as the vanes rotate,
- (d) a photocell of the photoconductive type positioned to receive radiation periodically passing through said one vane and responsive thereto,
- (e) a D.-C. signal source connected with the photocell for modulation of the D.-C. signal thereby,
- (f) and means for varying the intensity of the source of radiation to thereby alter the frequency of rotation of the radiometer and the modulation produced thereby.

6. A photocell modulator for converting D.-C. signals to corresponding pulsating signals which comprises

- (a) a source of radiation,
- (b) a vane-type radiometer positioned to receive radiation from said source and be rotated thereby,
- (c) said radiometer having a plurality of vanes and at least one vane having an aperture therein for periodically passing radiation therethrough as the vane rotates,
- (d) a photocell positioned to receive radiation passing through said aperture and responsive thereto,
- (e) and means for applying a D.-C. signal to said photocell for modulation thereby.

7. A photocell modulator in accordance with claim 6

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including a plurality of photocells, and a plurality of apertures differently positioned on a corresponding plurality of vanes for passing radiation to different photocells, different photocells having different D.-C. signals applied thereto for modulation thereby.

8. A photocell modulator for converting D.-C. signals to corresponding pulsating signals which comprises

- (a) a source of radiation,
- (b) a vane-type radiometer positioned to receive radiation from said source and be rotated thereby,
- (c) a photocell of the photoconductive type sensitive to said radiation,
- (d) the radiometer being positioned and adapted to alternately intercept and pass radiation to the photocell,
- (e) and a D.-C. signal source connected with the photocell for modulation of the D.-C. signal thereby.

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30 RALPH G. NILSON, *Primary Examiner.*

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