

Aug. 24, 1965

N. K. SHANKAR ETAL

3,202,933

NEGATIVE RESISTANCE PHOTOMULTIPLIER OSCILLATOR

Filed Aug. 10, 1961

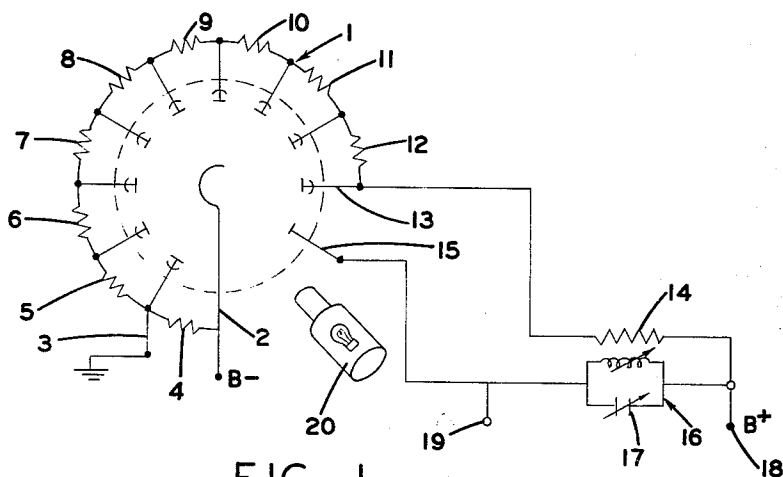
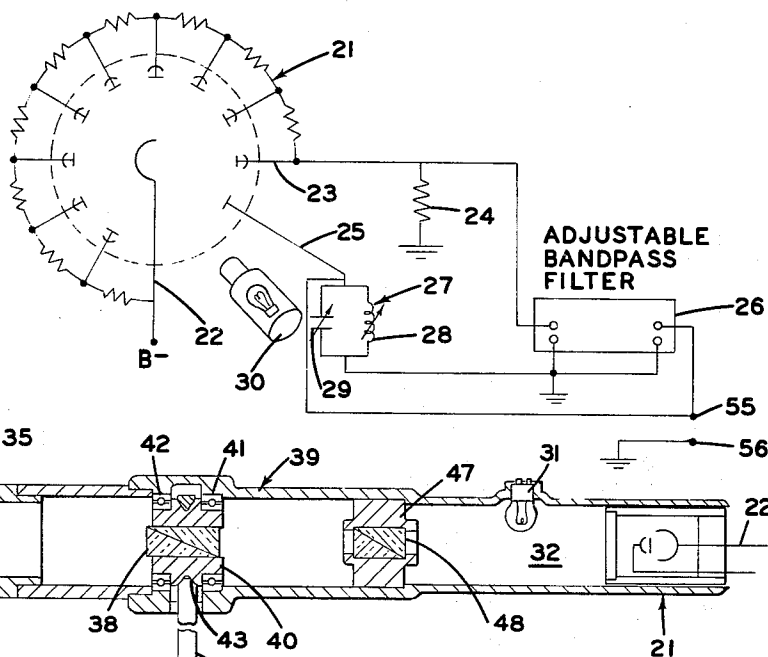
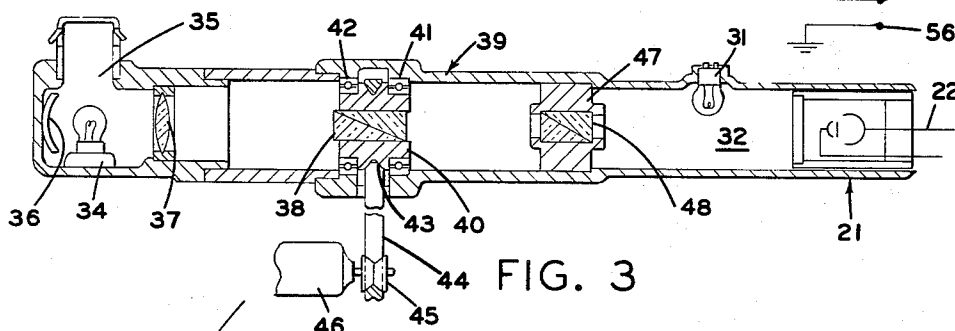
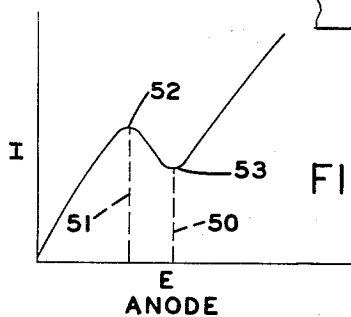


FIG. 2



NARANAPPA K. SHANKAR
ALEXANDER E. MARTENS
INVENTOR.

BY *Frank C. Parker*

ATTORNEYS

1

3,202,933
NEGATIVE RESISTANCE PHOTOMULTIPLIER
OSCILLATOR

Naranappa K. Shankar, Rochester, and Alexander E. Martens, Greece, N.Y., assignors to Bausch & Lomb Incorporated, Rochester, N.Y., a corporation of New York
Filed Aug. 10, 1961, Ser. No. 130,591
9 Claims. (Cl. 331-66)

This invention relates to a photomultiplier tube oscillator and more particularly to a photomodulator in combination with a photomultiplier tube oscillator.

The linear characteristics of the photomultiplier tube have been quite thoroughly investigated, however, very little is known of the non-linear characteristics of the photomultiplier tube. The photomultiplier tube has a linear response characteristic under normal operating condition of the tube. A negative resistance characteristic is indicated for higher voltage application on the anode. This negative resistance is shown in a curve where the anode current is a function of the anode voltage. With an increase in anode voltage the anode current decreases thereby exhibiting the negative resistance property. It is this portion of the voltage current characteristic which indicates that the photomultiplier curve may be used to produce oscillations.

The photomultiplier tube is energized in response to a luminous flux. The intensity of the luminous flux may be varied to modulate the output of the photomultiplier tube. Accordingly, this invention is intended to provide an oscillator circuit in combination with photomultiplier tube for producing a carrier wave. The intensity of the light is varied in a sinusoidal manner to impress a modulating signal on the carrier and thereby produce a photomodulating oscillator circuit.

It is an object of this invention to provide an oscillator circuit in combination with a photomultiplier tube capable of producing a wide frequency spectrum, including audio frequencies.

It is another object of this invention to provide an oscillator using a photomultiplier tube and a tuned circuit for generating a modulated or unmodulated carrier.

It is a further object of this invention to employ a photomultiplier tube and a tuned circuit to provide a carrier and vary the intensity of the light source to impress a modulating signal on the carrier signal and thereby provide a photomodulated oscillator circuit.

The objects of this invention are accomplished by connecting a photomultiplier tube through a series of resistors between the dynodes and the anode of the tube. The illuminating source activating the cathode of the photomultiplier tube is modified in its intensity by a polarizing means. A polarizing means provides substantially a sinusoidal photomodulation of the cathode emission of the photomodulator tube. A resistance is placed between the last dynode and the high positive voltage. A tuned LC circuit is connected between the anode and the high positive voltage. The photomultiplier tube is operated on the portion of the voltage-current curve indicating a negative resistance to create an unstable condition which initiates oscillation. The last dynode is connected through an adjustable band pass filter to the tuned anode tank circuit to provide additional regeneration. In this manner a carrier wave is generated and the photomultiplier tube is modulated in response to the illuminating source. The output of this tube is a modulated carrier signal.

FIG. 1 is a simplified oscillator circuit using a photomultiplier tube.

FIG. 2 is an improved circuit over that disclosed in FIG. 1 which employs an adjustable band pass filter between the last dynode and the anode.

2

FIG. 3 is a mechanical polarizing means for modulating the luminous flux which excites the cathode of the photomultiplier tube.

FIG. 4 is a graph illustrating the negative resistance of the photomultiplier tube where the current in the anode is a function of the voltage.

Referring to the drawings, FIG. 1 illustrates the photomultiplier tube connected to a tank circuit to provide oscillation. The photomultiplier tube 1 has the cathode 2 connected to a negative potential. The first dynode 3 is connected to ground, and a resistor 4 is connected between the cathode 2 and the first dynode 3. The resistors 5, 6, 7, 8, 9, 10, 11 and 12 are of similar value to the resistance 4. The resistances are serially connected with each other having intermediate connecting points connected to a dynode. The last dynode 13 is connected to a resistor 14 which in turn is connected to a high positive potential. The anode 15 is connected through a tank circuit 16 to the high positive potential. The tank circuit 16 includes a variable capacitor 17 and a variable inductor 18. The tank circuit 16 is tuned to the frequency of output desired for the circuit. The output terminals 18 and 19 are connected across the tank circuit 16. The source of illumination 20 provides the luminous flux for exciting the cathode of the photomultiplier tube 1. The frequency of oscillation is controlled by the tank circuit 16 in the anode circuit.

FIG. 2 discloses a photomultiplier tube 21 connected in a slightly different manner from that illustrated in FIG. 1. A negative potential is connected to the cathode 22. A plurality of resistors are serially connected between the cathode and the dynodes including the last dynode 23. The values of the resistors are the same as in the circuit illustrated in FIG. 1, however, the applicants do not wish to limit the circuit to a circuit of resistors of equal value. The last dynode 23 is connected to ground through the resistor 24. The anode 25 is connected through an adjustable band pass filter 26 to the last dynode. The tank circuit 27 is connected to the anode 25 and ground. The tank circuit 27 comprises an inductor 28 and a capacitor 29. The tank circuit 27 may be tuned to the desired frequency of output. The light source 30 excites the cathode 22 of the tube 21. The light source may be a tungsten lamp having a constant direct current voltage to provide illumination of the constant intensity. The intensity impinging on the cathode 22 however, may be modulated in any desired manner. This may be controlled by a mechanical arrangement as illustrated in FIG. 3.

Referring to FIG. 3, the cathode 22 is shown schematically in the photomultiplier tube 21. A lamp 31 illuminates the chamber 32. The light from the lamp 31 is permitted to impinge directly on the cathode 22 maintaining a low current in the photomultiplier tube to provide for carrier excitation and control of envelope.

A second lamp 34 is positioned in the chamber 35 in the opposite end of the housing 39. A reflector 36 intensifies the source of illumination. The lens 37 collimates the rays of light in the luminous flux and directs them on the polarizing screen 38. The polarizing screen 38 is rotatably mounted relative to the housing 39. The rotatable mount comprises the lens mount 40 mounted in the bearings 41 and 42. The lens mount 40 is formed with a V slot 43 about its outer periphery for reception of a V belt 44. The V belt 44 is received within a V belt pulley 45. The V belt drive pulley 45 is connected to the motor 46 and is rotated at the desired speed of rotation. The V belt drive 45 drives the V belt 44 which in turn drives the polarizing screen mount 40.

A stationary polarizing screen 48 is centrally mounted within the screen mounting 47 and axially in line with the rotating polarizing screen 38.

As the rotating polarizing screen 38 is rotated the polarizing axis of the screen 38 changes relative to the polarizing axis of the screen 43. The intensity of the luminous flux permitted to pass through the polarizing screens is controlled by relationship of their polarizing axis. The light transmitted through the polarizing screens during rotation of the rotating polarizing screen 38 is substantially equal to a sine wave. The variance of the luminous flux cannot be varied to a negative value. However, the lamp 31 provides a constant illumination and the luminous flux is not modulated in any manner. The modulated light of the polarizing screens from the lamp 34 is added to the light flux from lamp 31 and thereby produces a modulated source of illumination impinging on the cathode 22.

Referring to FIG. 4, the anode voltage is plotted on a horizontal axis. The anode current is plotted on a vertical axis as a function of the anode voltage. The characteristic of the curve as illustrated has a linear function of the low voltage portion of the curve. As the voltage increases the secondary emission on the dynodes creates a reduction in current on the last dynode with an increase in dynode voltage. This characteristic gives an effective negative resistance in the anode circuit. It is this negative resistance characteristic of the photomultiplier with which the applicant employs to provide an oscillator in the last dynode and the anode circuits.

The mechanical device illustrated in FIG. 3 modulates the output of the photomultiplier tube. As previously described, this is accomplished through a stationary and a rotating polaroid screen. The lamp 31 transmits a constant intensity for energizing the photomultiplier tube and controlling the signal envelope. The emission of the cathode is relative to the intensity of the light impinging on the cathode. The lamp 34 is a source of constant illumination, however, the polarizing screens modulate the intensity being transmitted to the cathode 22. The frequency of modulation through a mechanical device of this nature is controlled by the frequency of rotation of the rotating screen 38. This type of a modulating means has a distinct advantage in extremely low frequencies where an electrical circuit of a charging and discharging capacitor is not readily adaptable. Frequencies of one cycle per second are very easily handled through a mechanism of this type.

The inventor does not wish to limit modulating the carrier to the polarizing means disclosed. Any suitable means of varying the light intensity would be adequate.

Referring to FIG. 2, a modification of the oscillator circuit is illustrated. The source of illumination 30 is a device as illustrated in FIG. 3 wherein a modulating mechanism is provided. The mechanism is schematically illustrated in the element 30. The emission of the cathode 22 is responsive to the luminous flux from the source of illumination 30. A negative potential being impressed on the cathode 22, and the high positive potential relative to the cathode is the ground potential. The ground potential is connected through the tuned circuit to the anode 25, and through the resistance 24 to the last dynode 23. As the tube conducts a voltage is created across the resistor 24.

Referring to FIG. 4, the operating potential for the tube is substantially between the points 52 and 53 on the curve. The tube 21 oscillates when operating between the voltage potentials 50 and 51 as illustrated. Initially, when no current is conducted the voltage on the last dynode 23 is approximately indicated by the line 50. As the photomultiplier tube 21 conducts a voltage is established across the resistor 24. With the decrease in voltage on the dynode 23, an increase in dynode current is also realized as indicated on the graph in FIG. 4. The greater the current the greater the voltage drop is across the resistor 24. The current increases until the voltage indicated by the line 51 is impressed on the last dynode 23. The negative slope of the curve illustrates an effect which may be termed negative resistance. As the voltage impressed on the dynode 23 swings by the high point 52 on the curve, the current rapidly decreases. As the current decreases

through the resistor 24, the voltage across resistor 24 decreases thereby raising the voltage on the last dynode 23. The voltage on the last dynode then swings upwardly. As the voltage on the dynode becomes more positive less current is conducted by resistor 24 and the voltage continues to become more positive. This cycle continues until the voltage on the dynode swings by the low point 53 on the curve illustrated in FIG. 4. Beyond this point an increase in voltage creates an increase in current and the oscillating cycle begins again.

The adjustable band pass filter may be adjusted to pass a frequency to the tank circuit 27. This frequency is the tuned frequency of the tank circuit. In this manner a regenerative voltage is transmitted through the band pass filter to the tank circuit. The tank circuit and the band pass filter control the frequency of oscillation. The frequency of output is taken across the tank circuit, on the terminals 55 and 56.

The frequency of the tank circuit may be called the frequency of the carrier signal. The carrier signal is modulated as previously described by the illuminating source. The frequency of the carrier signal is dependent on the tank circuit. Tank circuits of various values may be substituted to give the desired frequency of output for the carrier signal. The modulation impressed on the carrier may also be varied through a wide range of frequencies. In this manner the device as illustrated adapts itself to any type of photomodulating device.

The invention has been illustrated and described in the preceding paragraphs. The following claims define the scope of the invention.

We claim:

1. An oscillator circuit comprising, a photomultiplier tube operating within its negative resistance characteristic, resistance means connected between the cathode and the first dynode of said photomultiplier tube, a source of negative potential connected to said cathode, a plurality of serially connected resistance elements each successive one connected between successive dynodes of said photomultiplier tube, a resistance element connected to the last dynode of said photomultiplier tube and adapted for connection with a positive potential, a tank circuit connected to the anode of said photomultiplier tube and adapted for connection to the positive potential, a band pass filter connected between the last dynode and the anode providing regenerative feedback to the tank circuit in said anode circuit thereby providing oscillatory output.

2. A photomodulated circuit comprising, a photomultiplier tube operating as an oscillator, resistance means connected between the first dynode and the cathode and each of the dynodes of said photomultiplier tube, a source of negative potential connected to said cathode, a modulated source of light directing light on the cathode of said photomultiplier tube for amplitude modulating the tube oscillations, a resistance element connected to the last dynode of said photomultiplier tube for connection to a high positive potential, a tank circuit connected to the anode and the high positive potential and controlling the frequency of oscillation of said photomultiplier tube.

3. A photomodulated oscillator comprising, a photomultiplier tube operating as a negative resistance oscillator, a cathode element of said photomultiplier tube for connection to a negative potential, a resistive element connected between the first dynode and said cathode, a plurality of serially connected resistive elements of equal value each successive one connected between successive dynodes of said photomultiplier tube, a resistive element connected to the last dynode for connection with the high positive potential, a tank circuit connected to the anode and for connection to the high positive potential and controlling the oscillator frequency, a band pass filter connected between the last dynode and the anode, and providing regenerative feedback, a modulated source of illumination exciting said cathode of said photomultiplier tube for amplitude modulating the tube oscillations.

5

4. A frequency generator comprising a photomultiplier tube operating as a negative resistance oscillator, a cathode element on said photomultiplier tube connected to a negative potential, a plurality of dynode elements on said photomultiplier tube, an anode on said photomultiplier tube, a resistor connecting said cathode to the first of said dynodes, a plurality of resistors serially connected each positioned between adjacent of said dynodes, a resistor and tuned circuit controlling oscillator frequency connected between said anode and the last of said dynodes, a source of high positive potential connected at the junction of said resistor and said tuned circuit, an adjustable band pass filter connected between said last dynode and said anode providing regenerative feedback of the frequency of the tuned circuit to sustain oscillations of said multiplier tube.

5. A photomodulating circuit comprising, a photomultiplier tube operating as an oscillator, a cathode element on said photomultiplier tube, a plurality of serially connected resistors connected between the first and last dynodes on said tube and each successive intermediate dynode connected intermediate each successive junction of said plurality of serially connected resistors, a resistor element connecting said cathode to the first of said dynodes, a resistor element connected to the last dynode, a source of negative potential connected to said cathode, a source of high positive potential connected to said resistor connected to said last dynode, a tuned LC circuit connected to the anode of said photomultiplier tube and tuned to the frequency of oscillation, a high positive potential connected to said LC circuit, a band pass filter connecting the last dynode with said anode of said photomultiplier tube and providing regenerative feedback, a light source exciting emission from said cathode, and controlling the amplitude of tube oscillations, a source of illumination in said light source having constant intensity impinging upon said cathode, a second source of illumination having means for modulating the luminous flux impinging upon said cathode thereby modulating the output of said photomultiplier tube to provide a modulated carrier frequency output from said photomultiplier tube.

6. A photomodulated oscillator comprising, a photomultiplier tube operating as a negative resistance oscillator, a plurality of serially connected resistors each successive resistor singly connected between successive elements including the cathode and dynodes, a source of negative potential connected to said cathode, resistance means connecting the last dynode with a source of high potential, a tuned circuit coupling the anode to the source of high potential, a modulated source of light controlling the amplitude of tube oscillations comprising a lamp of constant intensity illuminating the cathode of said photomultiplier tube, polarizing means modulating the intensity of a second lamp to modulate the output of said photomultiplier tube.

7. A photomodulated oscillator comprising, a photomultiplier tube operating as a negative resistance oscillator, a plurality of serially connected resistors each successive resistor connected between successive elements including the cathode and dynodes of said photomultiplier

6

tube, a source of negative potential connected to said cathode, a source of positive potential, resistance means connected to said source of positive potential and the last dynode of said photomultiplier tube, a tuned circuit connecting the anode of said photomultiplier tube with said positive potential and controlling oscillator frequency a source of light including a lamp with constant intensity directing light on said cathode, a modulating means modulating the light directed on said cathode to provide amplitude modulation of the output of said oscillator.

8. A photomodulated oscillator comprising, a photomultiplier tube having a negative response characteristic, a plurality of serially connected resistors connected between the cathode and the last dynode of said multiplier tube, a plurality of intermediate connections of said resistors connected to each of the remaining dynodes of said multiplier tube, a source of negative potential connected to said cathode, a resistor and a tuned circuit serially connected between the anode and the last dynode and controlling the oscillator frequency, a source of high positive potential connected intermediate said resistor and said tuned circuit, a band pass filter connected between the last dynode and the anode and providing regenerative feedback to the anode, a photomodulating light source exciting the cathode of said multiplier tube for amplitude modulating the output of the oscillator.

9. An electrical circuit for generating an oscillating frequency comprising, a photomultiplier tube operating as a negative resistance oscillator, a plurality of serially connected resistors connected between the cathode and the last dynode with the junction points intermediate successive resistors connected to successive dynodes of said photomultiplier tube, a negative potential connected to the cathode, resistance means and a tank circuit connected intermediate the last dynode and the anode, a bandpass filter connected to the last dynode and said anode for applying a regenerative signal to the tank circuit for sustaining oscillations of said photomultiplier tube, a source of high positive potential connected to said anode through said tank circuit, a source of illumination of a predetermined modulating frequency directing illumination on the cathode of said photomultiplier tube to excite the tube and vary the amplitude of oscillation with the modulating frequency thereby providing amplitude modulated oscillator output.

References Cited by the Examiner

UNITED STATES PATENTS

2,254,022	8/41	Whitaker	250—225
2,807,723	9/57	Singer et al.	331—66 X
2,911,881	11/59	Franklin	250—233 X
2,958,785	11/60	Camp	250—207 X

OTHER REFERENCES

"Secondary Emission Electron Multipliers," *Electronics*, November 1935, pages 10—13.

ROY LAKE, *Primary Examiner*.

JOHN KOMINSKI, *Examiner*.