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2,430,095

PHOTOCELL MODULATOR

Filed July 25, 1944

2 Sheets-Sheet 1

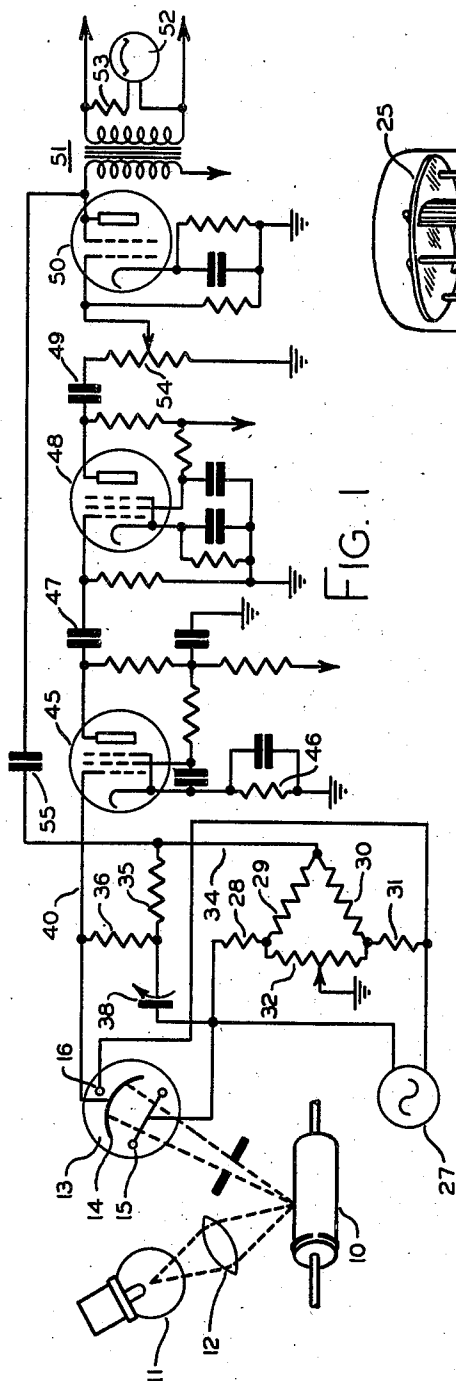


FIG. 1

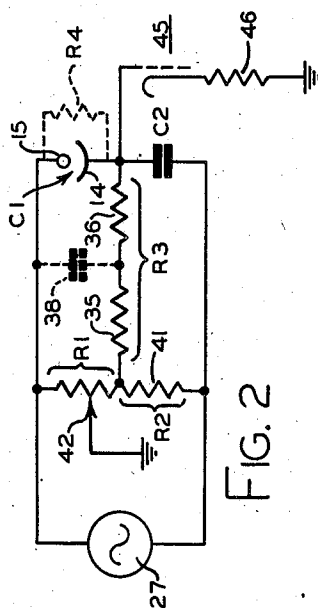


FIG. 2

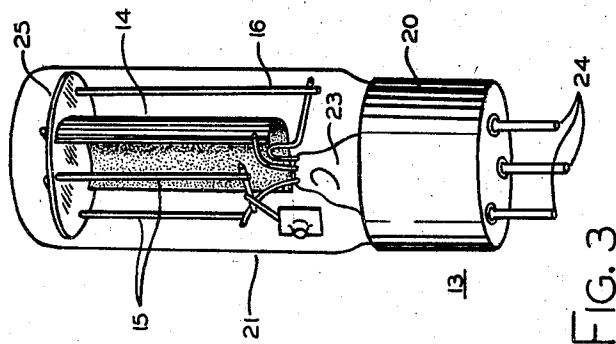


FIG. 3

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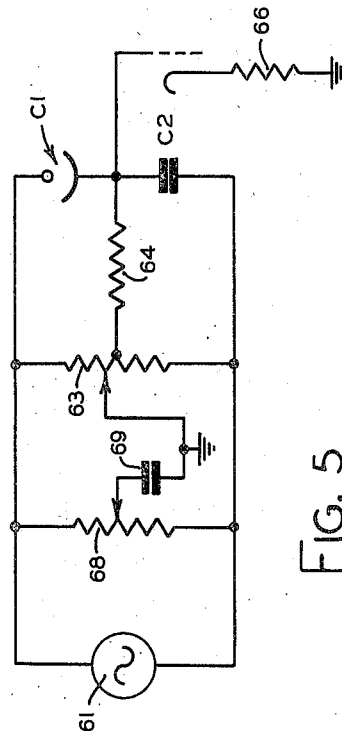
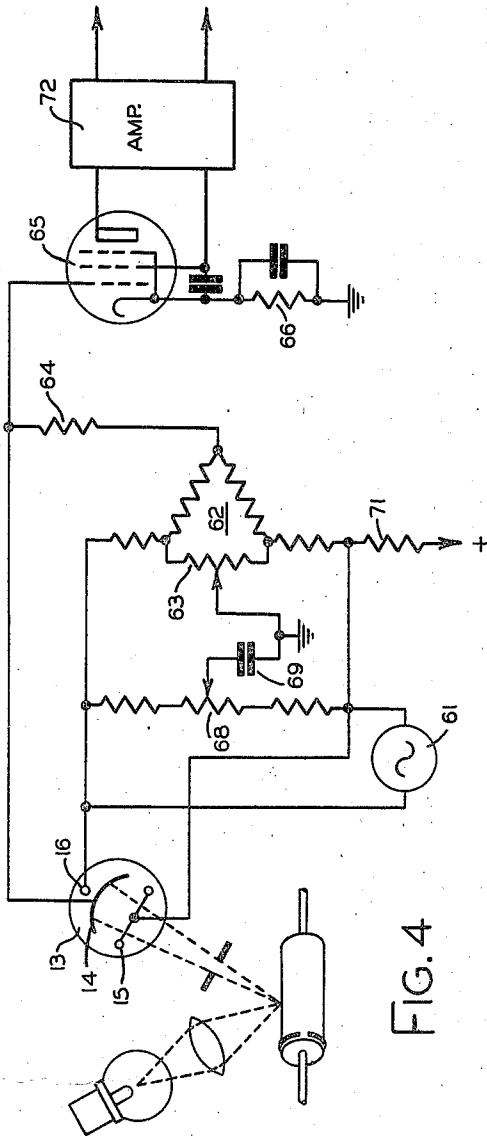
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2 Sheets-Sheet 2



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PHOTOCELL MODULATOR

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Application July 25, 1944, Serial No. 546,518

9 Claims. (Cl. 179—171.5)

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This invention relates to a photocell modulator useful in telefacsimile transmission and related arts.

In general terms, the object of the invention is to provide an improved scanning arrangement for facsimile systems and the like.

Another object of the invention is to provide a photocell modulator which is stable in adjustment, and which is not affected by atmospheric conditions encountered in actual service.

A further object of the invention is to improve the operation and simplify the construction of photocell modulators of the type which are designed to transmit both positive and negative modulated signals.

In a preferred form of optical scanning apparatus for the transmitter of a telefacsimile system, a balancing bridge arrangement is employed by means of which an alternating-current carrier can be impressed upon the photocell or cells in such a manner that the output current from the scanning system is a constant frequency carrier, the amplitude of which is a function of the illumination of the light-sensitive cell. The most effective modulator arrangement of this character in general use, described in the prior patent of Austin G. Cooley, No. 2,298,466, dated October 13, 1942, employs a capacity-resistance bridge (which includes the inherent capacity between the electrodes of the photocell or cells) to translate light signals into current variations of an applied carrier current. In operation the inter-electrode capacity of the cell is balanced by a trimmer condenser, the capacity of which must be adjusted and maintained very closely for optimum results. In the modulator system described in said prior patent, the trimmer condenser is connected directly to the output circuit of the cell. In practice, with this arrangement, it has been found difficult to adjust and maintain the constants of the modulator system with the necessary precision. This is partly due to the extreme sensitivity of the photocell and associated amplifier to changes in the capacity or leakage of the cell cathode circuits, which are directly connected to the input circuit of the amplifier. In addition, laboratory tests have now shown that another effect is present, i. e., a phase shift in the equivalent impedances of the space paths between the cathode and anodes of the cell (both anodes in the case of a double-anode cell) when the illumination of the cell is changed. Improved results are obtained, in accordance with the invention, by a novel compensative circuit which maintains a balanced bridge in spite of the phase-

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shift phenomena referred to. Still another advantage of the modulator according to the invention is that the trimmer condenser and other elements of the compensating circuit are not directly connected to the photocell cathode, which is only connected to the grid-bias resistor and the control grid of the pre-amplifier stage. This renders the cell circuit less sensitive to atmospheric changes and the like, which have heretofore hampered the use of efficient cells in certain applications.

Other objects and advantages of the invention will appear from the following description of the preferred embodiments thereof shown on the accompanying drawings, wherein

Fig. 1 is a circuit diagram of a photocell modulator embodying the invention and including elements of a telefacsimile transmitter;

Fig. 2 is a simplified diagram of the photocell modulator shown in Fig. 1;

Fig. 3 is a detailed view illustrating the construction of the photocell shown in Fig. 1;

Fig. 4 is a circuit diagram of a modification; and

Fig. 5 is a simplified diagram of the bridge and compensating circuits shown in Fig. 4.

Referring to Fig. 1, there is shown in schematic form the photoelectric components of a telefacsimile transmitter comprising a conventional rotating drum 10 carrying the picture or copy to be transmitted; an exciter lamp 11 and condenser lens 12 for illuminating the copy being scanned; and a photocell 13 for generating a signaling current modulated in accordance with the variations in shading of the successive elemental areas of the copy wrapped around the drum 10. The drum 10 is rotated at a uniform speed and at the same time moved in an axial direction so that elemental areas of the copy are scanned successively from one side to the other. It will be understood that the invention is not limited to such applications as that illustrated but may be used in electro-optical systems generally where a modulated carrier is generated.

The light-sensitive cell 13 is provided with a cathode 14 having an emissive coating on one side thereof and two anodes 15, 16 on opposite sides of said cathode. The photocell 13 may be the RCA type 1645 photocell as illustrated in Fig. 3. This cell is a highly-evacuated rubidium cell but any other suitable cell may be employed, depending upon the spectral response or other characteristic desired.

As shown in Fig. 3, the preferred construction of cell is provided with the usual base 20 and

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glass envelope 21 in which the electrodes are sealed. The cathode 14 and anodes 15 and 16 are mounted in a re-entrant press 23 in which lead-in wires connected to the socket pins 24 are sealed. As shown the anode 15 comprises a loop of wire, the sides of which are disposed adjacent the outer edges of the cathode 14 so that they do not obstruct the passage of light to the coated surface of the cathode. The upper ends of the electrodes are anchored in an insulating disc 25 of mica or other suitable insulating material. The size and spacing of the anodes 15 and 16 with respect to the cathode 14 are such that the cathode-anode capacities are approximately equal. The construction shown however is merely illustrative of a suitable cell which may be employed in carrying out the invention and may be modified if desired.

Referring again to Fig. 1 the photocell modulator embodying the invention incorporates the general principles of that shown in the above-mentioned Cooley patent but differs therefrom in detailed construction. As shown the modulator arrangement includes a source 27 of alternating electromotive force which is connected to the anodes 15 and 16 of the photocell 13. The modulator thus comprises a bridge network including as two arms thereof the cathode-anode capacities of the cell. The bridge network further comprises two series resistance arms paralleling the capacity arms referred to and also connected across the terminals of the source 27, said series resistance arms including resistors 28, 29, 30 and 31 in series relation and a potentiometer 32 in parallel with the resistors 29 and 30. The common terminal of resistors 29 and 30 provides a mid-point connection for the resistance arms of the bridge while the potentiometer 32 having its adjustable tap connection grounded permits the biasing of the cell so that the picture or copy may be transmitted as either a positive or a negative as desired (zero output for either maximum or minimum light intensity).

The mid-point of the resistance arms of the bridge is connected through conductor 34 and resistors 35 and 36 to the cathode 14 of the photocell. A trimmer condenser 38 is connected between the anode 15 and the common terminal of the resistors 35 and 36 in order to permit the precise matching of the cathode-anode capacities of the photocell. In actual service the condenser 38 is properly adjusted during the initial wiring and line-up of the photoelectric equipment for not only the capacities between the cathode and anodes of the cell but also the capacity between the wires or conductors leading to the electrodes of the photocell. However, once the trimmer condenser 38 is properly adjusted it is not necessary to change it unless the photocell has to be replaced or some other change occurs which affects the capacity balance of the bridge; i. e., it is not altered during normal operation.

In order to simplify the explanation of the bridge circuit employed, it has been redrawn in simplified form in Fig. 2. In this diagram, C1 and C2 represent the cathode-anode capacities between the cathode and the front or operative anode and the back anode respectively. The resistors 28, 29, 30, 31 and 32 have been replaced by a potentiometer 41 having a mid-point tap connection to the resistor 35 and an adjustable tap 42 connected to ground. The size of the trimmer condenser 38 depends upon the amount of capacity unbalance in the cell and its connection in the bridge obviously depends upon whether

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C1 or C2 is greater. The trimmer condenser 38 is shown in dotted lines because it is only required when the capacities C1 and C2 are unequal and for purposes of explanation we can assume that they are equal. It will be obvious that when the cell is dark, if the cathode-anode capacities C1 and C2 are equal and the adjustable tap 42 is at the mid-point of the potentiometer 41, the bridge is symmetrical and there will be no output voltage applied to the control grid of the tube 45 in the amplifier.

The adjustment of the tap 42 (or potentiometer 32, Fig. 1) until the output carrier is a minimum when the illumination of the cell is a minimum is employed in negative transmission. With this adjustment, during the scanning of the copy the light reflected from the white or gray portions changes the equivalent impedance of the space path between the cathode 14 and front anode 15. A smaller change in impedance occurs in the space path between the cathode 14 and back anode 16 (represented in Fig. 2 by the fixed condenser C2). Since R1 and R2 remain unchanged the bridge becomes unbalanced when light impinges on the cell cathode and a modulated carrier of the frequency of the source 27 is impressed upon the grid of the amplifier 45. The magnitude of the output carrier is directly proportional to the level of illumination of the cell at any instant. In this manner, a modulated carrier is obtained which can be employed at the receiver to produce a negative facsimile of the copy being scanned at the transmitter.

In positive transmission, the modulation of the carrier is reversed, i. e., the amplitude of the carrier decreases as the lighter portions of the copy are scanned. Thus if the bridge modulator is to be used for both positive and negative transmission, it must be possible to balance the bridge (by adjustment of the tap 42) for various levels of illumination of the photocell corresponding to the light reflected from either the lightest or the darkest portion of the copy to be transmitted. This would involve no difficulty if the illumination of the cell only altered the capacity of C1 with respect to C2, as compared to the dark-cell condition. However it is found that when light strikes the photocell cathode, there is a slight phase shift in the equivalent impedances of the space paths between the cathode 14 and the anodes 15 and 16. Since the predominant change occurs in the space path between the cathode and the front anode 15, the effect is represented by a resistor R4 (shown in dotted lines in shunt relation to the photocell capacitance C1). The phase shift referred to varies depending upon the amount of light striking the cathode.

On account of the unequal phase shift in the potential drops across C1 and C2, it is apparent that the bridge cannot be exactly balanced by adjusting tap 42, which is arranged to impress a bias potential on the grid of amplifier 45, since this potential will not be exactly 180° out of phase with that appearing on the cathode 14. Therefore, in accordance with the invention, the trimmer condenser 38 is so adjusted with respect to the relative magnitudes and phase relation of C1 and C2, under both dark-cell and illuminated cell conditions, as to effect an approximate balance of the bridge at any level of illumination of the cell. In this manner, a compromise can be made so that while the bridge cannot be perfectly balanced, it can be balanced by means of the potentiometer 32 to a point where the minimum carrier

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output is sufficiently low for both positive and negative transmission.

The size of the trimmer condenser 38 is determined by the capacity unbalance of the photocell structure and by the values of resistors 35 and 36, which may be 10,000 ohms and 2 megohms, respectively, if an ordinary ceramic trimmer condenser of 6.5 to 35 mmf. capacity is used. As the ratio of resistor 36 to resistor 35 increases for a total series resistance R3 of two or three megohms, the size of the trimmer condenser required to balance different cells increases. It is evident therefore that the values given are only exemplary. The arrangement described has the advantage that a larger trimmer condenser is used than would be employed if connected directly to the cathode of the cell, and the unavoidable minute variations of the capacity of such condenser resulting from condensation of moisture or other causes do not affect the constants of the bridge sufficiently to upset the operation in normal service over a prolonged period. The values of R1 and R2 are not critical and may be for example, a few hundred ohms. A conventional two-electrode cell may also be employed in the modulator shown, with the capacitance C2 between the cathode 14 and anode 16 of the photocell shown replaced by an external condenser.

Referring again to Fig. 1, a conventional multi-stage amplifier is shown of which the first stage is the tube 45 having the usual cathode-bias resistor 46. The tube 45 may be a high-gain pentode tube such as the type 7C7 or 7L7. The anode of this tube is connected through a condenser 47 to the control grid of a second pentode tube 48 of the same type. The coupling condenser 47 is selected to provide desired amplification of a carrier of the frequency of a source 27, for example .0025 mfd. capacity in the case of a carrier of, say, 1800 cycles per second. The anode of the amplifier tube 48 is connected through a condenser 49, for example of .0005 mfd. capacity to the control grid of the third vacuum tube 50. This tube may be of the type 7C5 connected as a triode and operating as a class A output amplifier. The output circuit of the vacuum tube 50 is connected through a transformer 51 to the line output circuit. A meter 52 connected in series with a resistor 53 across the output circuit is provided to indicate the output level. A potentiometer 54 may be arranged to function as a gain control. This amplifier is shown by way of example and may be modified without departing from the scope of the invention.

A feedback coupling condenser 55 is preferably connected between the output circuit of the first or third stage of the amplifier to the mid-point of the resistors 29 and 30. This affects degenerative coupling which serves to reduce the residual unbalance current, principally second harmonic, when the bridge is brought to the balance condition, without materially affecting the output of the bridge under unbalance conditions. The effect is to improve the balance of the bridge obtainable by adjustment of the potentiometer 32 under all conditions of illumination of the cell since it must be realized that the problem involved in a modulator of the class described is to obtain an approximately exact balance with the use of a single manual control under either the dark-cell or illuminated-cell condition.

The described modulator system generates picture signals adapted to operate conventional facsimile receiving apparatus to reproduce a facsimile of the picture or copy on the transmitting drum

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10. Examples of a suitable facsimile receiver are shown in the patent to A. G. Cooley, No. 1,702,595, granted February 19, 1929, and the patent to H. E. Ives, No. 1,695,048 granted December 11, 1928.

A modified form of the invention embodying further advantages is illustrated in Fig. 4. Referring to this figure, a bridge modulator is shown associated with the optical scanning mechanism of a telefacsimile transmitter similar to that shown in Fig. 1. A source 61 of alternating electromotive force is connected to the anodes 15 and 16 of the photocell 13 and to the terminals of the resistor network 62. The network 62 forms two resistance arms of the modulator bridge corresponding to the resistance arms of the bridge shown in Fig. 1, and includes a potentiometer 63 corresponding to the potentiometer 32 of Fig. 1. The mid-point of the bridge arms of the network 62 is connected through a grid-bias resistor 64 to the cathode 14 of the photocell and to the control grid of the amplifier 65. The cathode of the amplifier 65 is connected through the cathode-bias resistor 66 to ground.

In this modification an improved compensating circuit is provided which enables the bridge to be balanced more precisely for zero output for either positive or negative modulation without rendering the cell or amplifier sensitive to atmospheric changes, or unavoidable leakage or capacity variations of any character. This compensating circuit comprises a shunt resistor 68 bridged across the terminals of the source 61 and the anodes of the photocell 13, together with a condenser 69 connected between an intermediate point of the resistor 68 and ground.

The bridge modulator circuit of Fig. 4 has been redrawn in simplified form in Fig. 5, with C1 and C2 representing the equivalent impedances of the space paths between the cathode and the respective anodes 15 and 16 of the photocell 13. The adjustable tap on the resistor 68 is set during initial adjustment of the circuit to a point where the bridge may be balanced to zero for any level of illumination of the cell 13 (the potentiometer 63 being adjusted to different points for the different levels while the connection of the condenser 69 to the resistor 68 remains fixed after it has been properly adjusted). The size of the condenser 69 is not critical and may, for example, be of approximately 0.5 mf. for the RCA No. 1645 photocell. The resistance of the resistor 68 is sufficiently high to limit the loading of the source 61 to the desired extent.

When the tap connection of the condenser 69 to the resistor 68 has been properly adjusted, positive or negative transmission may be effected at any level by suitable adjustment of the potentiometer 63. This means that the potentiometer 63 may be adjusted so that there is no potential developed on the grid of the amplifier at any level of illumination of the photocell. Thus the potential difference developed across the resistor 64 by the photocell, at different levels of illumination, must be exactly balanced by the potential difference across the section of the potentiometer 63 between the left hand terminal of resistor 64 and the grounded tap on the potentiometer. The compensating circuit including the condenser 69 therefore corrects both for inequality between C1 and C2 resulting from lack of symmetry in the cell construction and for the phase shift in the equivalent impedances of the space paths in the cell when the cell is illuminated.

The compensating circuit shown has been found

to work satisfactorily with almost any cell of the type referred to, in spite of the wide variation in sensitivity encountered in such cells and the differences in spacing between the electrodes of different cells. In addition to compensating for such variations in individual cells, when the photocell is dark, the connection of the resistor 68 and condenser 69 to the carrier source 61 and to the tap on the potentiometer 63 enables the bridge to be balanced for any level of illumination of the cell solely by adjustment of the potentiometer 63, i. e., when the tap on the variable resistor 68 is set correctly for the particular cell, the phase shift in the equivalent impedances of the space paths in the photocell, when illuminated, is matched by the compensating circuit so closely that the residual unbalance current for the null adjustment is extremely small. In some instances, further compensation to improve the balance can be obtained by connecting a bias potential of the order of 0.5 volt through a resistor 71 to either anode 15 or anode 16 of the photocell, as explained in the copending application of John R. Shonard, Ser. No. 517,603, filed January 8, 1944. This bias can be omitted if desired.

Modulated carrier output corresponding to the picture or copy being scanned by the photocell is impressed upon the control grid of the amplifier 65 and may be further amplified by the amplifier 72 before it is impressed upon the line circuit. The amplifier 72 may be similar to the second or third stages of the amplifier shown in Fig. 1, or any other suitable amplifier of the same general type may be employed as well known to those skilled in the art.

Various modifications in the modulator circuits shown and described above for the purpose of explaining the invention may be made without departing from the scope thereof.

I claim:

1. In a photocell modulator, in combination, a photocell provided with a cathode and two anodes, an output circuit for said cell connected to said cathode, a source of alternating electromotive force, a capacity-resistance network connected between said source and the output circuit of said cell, said network comprising a bridge two arms of which are constituted by the space paths between the cathode and anodes of the photocell, resistors constituting the opposite arms of said bridge, a resistor connected between the two terminals of the bridge formed by the photocell cathode and the midpoint of the opposite arms of the bridge, connections between the terminals of said alternating source and the other terminals of said bridge, an adjustable ground connection for the resistance arms of said bridge to permit the adjustment of the modulator to obtain minimum output current for any predetermined illumination of the cell and means including a condenser additional to the above-mentioned arms of said bridge for compensating for the characteristics of the photocell whereby said minimum output for the balanced adjustment of the bridge is substantially zero.

2. In a photocell modulator, in combination, a photocell provided with a cathode and two anodes, an output circuit for said cell connected to said cathode, a source of alternating electromotive force, a capacity-resistance network connected between said source and the output circuit of said cell, said network comprising a bridge two arms of which are constituted by the space paths between the cathode and anodes of the photocell, resistors constituting the opposite arms

of said bridge, a resistor connected between the two terminals of the bridge formed by the photocell cathode and the midpoint of the opposite arms of the bridge, connections between the terminals of said alternating source and the other terminals of said bridge, an adjustable ground connection for the resistance arms of said bridge to permit the adjustment of the modulator to obtain minimum output current for any predetermined illumination of the cell, a shunt resistor connected across the terminals of said alternating source and capacitance connected between an intermediate point on said last-mentioned resistor and ground to provide a more exact balance of the bridge for any desired setting of the adjustable ground connection.

3. In a photocell modulator, in combination, a photocell provided with a cathode and two anodes, an output circuit for said cell connected to said cathode, a source of alternating electromotive force, a capacity-resistance network connected between said source and the output circuit of said cell, said network comprising a bridge two arms of which are constituted by the space paths between the cathode and anodes of the photocell, resistors constituting the opposite arms of said bridge, a resistor connected between the two terminals of the bridge formed by the photocell cathode and the midpoint of the opposite arms of the bridge, connections between the terminals of said alternating source and the other terminals of said bridge, an adjustable ground connection for the resistance arms of said bridge to permit the adjustment of the modulator to obtain minimum output current for any predetermined illumination of the cell and means to compensate for the phase shift of the equivalent impedances of the space paths in the photocell as the illumination of the cell varies whereby a more exact balance of the bridge is obtainable at any desired level of illumination, said means comprising resistance in shunt to the anode terminals of the photocell and capacitance connected between a point on said shunt resistance and ground.

4. In a photocell modulator, in combination, a photocell provided with spaced electrodes including a cathode, an output circuit for said cell, a source of alternating electromotive force, a bridge including said photocell and connected to said alternating source to produce a carrier in said output circuit varying in amplitude with changes in the illumination of said photocell, said bridge comprising a resistance provided with an adjustable tap to enable the bridge to be adjusted for minimum carrier output for either dark or illuminated cell conditions as desired, and means to compensate for the phase shift of the equivalent impedance of the cell as the illumination of the cell varies whereby a more exact balance of the bridge is obtainable at any desired level of illumination, said means comprising an impedance in shunt relation to said cell and capacitance connected between said tap and an intermediate point on said shunt impedance.

5. A photocell modulator according to claim 4, in which said shunt impedance consists of non-inductive resistance connected across the terminals of said alternating source.

6. In a photocell modulator, in combination, a photocell provided with spaced electrodes including a cathode, an output circuit for said cell, a bridge network including said cell, means to apply an alternating electromotive force to said network and cell whereby a modulated carrier cur-

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rent is produced in said output circuit as the illumination of the cell varies, said bridge network comprising manually adjustable means for null adjustment at which the carrier output is a minimum at any predetermined level of illumination of the cell, and compensating means for correcting for the phase shift in the equivalent impedance of the cell as the level of illumination varies to provide a more precise balance of the bridge at the null adjustment, said compensating means including resistance and capacitance connected to an electrode of the photocell.

7. In a photocell modulator, in combination, a photocell provided with spaced electrodes including a cathode, an output circuit for said cell, a plurality of impedances connected to form a bridge with said cell, means to apply an alternating electromotive force to said bridge whereby a modulated carrier current is produced in said output circuit as the illumination of said cell varies, means including a potentiometer for null adjustment of said bridge at which the carrier current is a minimum at any predetermined level of illumination of said cell and compensating means for correcting for the phase shift in the equivalent impedance of the cell as the level of illumination varies to provide a more perfect balance of the bridge at the null adjustment, said compensating means including capacitance connected between an electrode of the photocell and the adjustable tap of said potentiometer.

8. In a photocell modulator, in combination, a photocell provided with spaced electrodes including a cathode, an output circuit for said cell, a plurality of impedances connected to form a bridge with said cell, means to apply an alternating electromotive force to said bridge whereby a modulated carrier current is produced in said output circuit as the illumination of said cell varies, manually operable means for null adjustment of said bridge to reduce the carrier current to a minimum at any predetermined level of illumination of said cell and means including a compensating circuit connected to said bridge for correcting for the variations in the characteristics of different cells that are used in the modulator and also for correcting for the phase shift in the equivalent impedance of the particular cell in use as the level of the illumination varies to provide a more perfect balance of the bridge at the null adjustment.

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9. In a photocell modulator, in combination, a photocell provided with a cathode and two anodes, an output circuit for said cell connected to said cathode, a plurality of impedances connected to said cell to form a bridge, two adjacent arms of which are constituted by the space paths between said cathode and the respective anodes, means to apply an alternating electromotive force to said bridge whereby a modulated carrier current is produced in said output circuit as the illumination of said cell varies, and means providing for null adjustment of the bridge at any predetermined level of illumination of the cell, said last-mentioned means including a resistor connected across the two anodes of the cell and capacitance connected between said resistor and one arm of said bridge.

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