Dec. 3, 1929. R. H. RANGER 1,738,315

PHOTO AMPLIFYING SYSTEM

Filed Nov. 18, 1924 2 Sheets-Sheet 1

Fig. 1

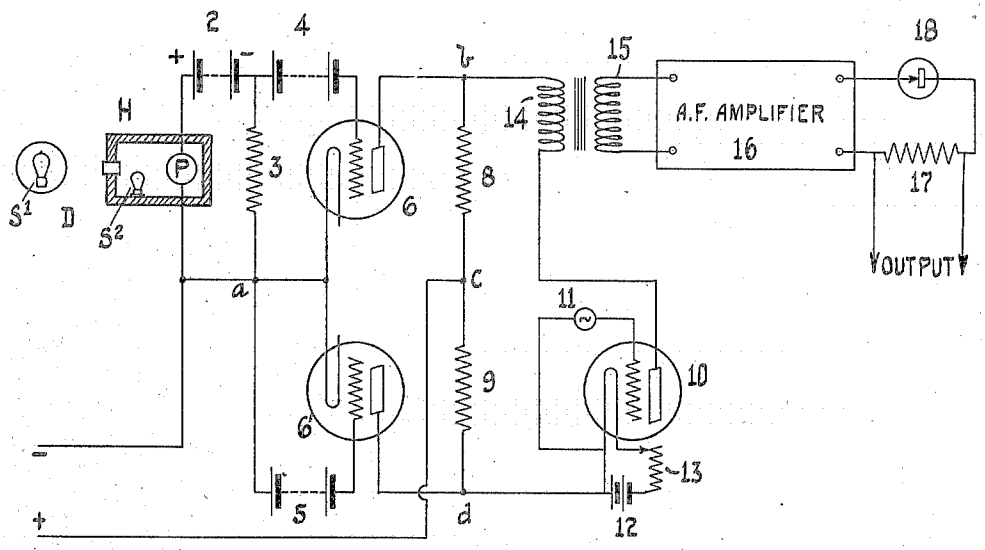
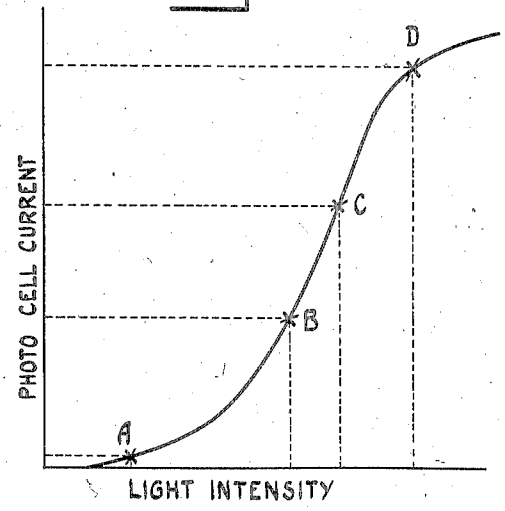


Fig. 2



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Filed Nov. 18, 1924 2 Sheets-Sheet 2

Fig. 3

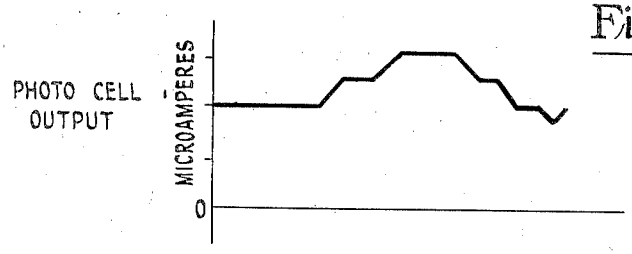


Fig. 4

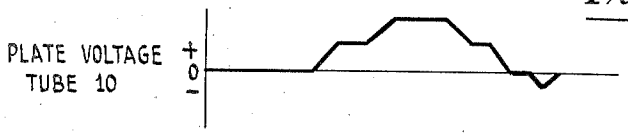


Fig. 5

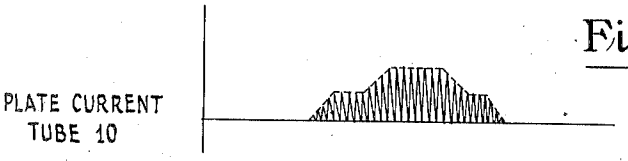


Fig. 6

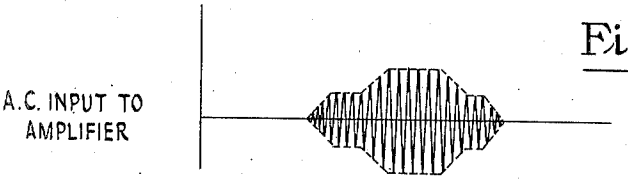
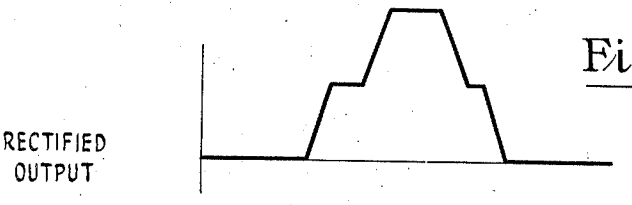


Fig. 7



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UNITED STATES PATENT OFFICE

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PHOTO-AMPLIFYING SYSTEM

Application filed November 18, 1924. Serial No. 750,514.

This invention relates to systems for converting fluctuations of light intensity into fluctuations of electric potential or current, and while it is apparent that it will be found useful for many purposes, it is of particular value in connection with facsimile telegraph systems, whether the telegraphing is done over wire lines, composite lines, or by radio, for the purpose of deriving an electromotive force of suitable value for controlling, modulating or otherwise affecting the transmission of waves, impulses or other effects in a manner so that the same may readily be converted back into variations of light after reception, and is particularly applicable to the systems shown in copending application of E. F. W. Alexanderson, and R. H. Ranger, Serial No. 669,688, application of R. H. Ranger, Serial No. 695,175, and application of R. H. Ranger, Serial No. 726,235.

It is an object of this invention to provide a photo amplifying system of greater effective sensitivity; that is to say, one which is responsive to smaller values of light intensity and also to smaller variations of light intensity, and conversely one capable of greater effective amplification.

It is a further object of this invention to produce a photo amplifying system in which the potentials or currents produced are truly proportional to light intensity.

It is a further object of this invention to produce a system which when used in picture transmission systems and the like will provide a more accurate reproduction of the original and more fidelity of detail.

It is a further object of this invention to produce a photo amplifying system of sufficient sensitivity and sufficient amplifying power to be capable of practical working by light reflected from an opaque object if desired.

Generally, it is an object of this invention to produce a photo amplifying system capable when utilized in existing picture transmission systems of improving the quality of the received picture.

Still other and ancillary objects of my invention will be apparent from the specification.

The novel features which I believe to be characteristic of my invention are particularly set forth in the appended claims. The invention itself however, both as to its construction and mode of operation, together with further objects and advantages thereof, will best be understood by reference to the following description taken in connection with the accompanying drawings, in which:

Fig. 1 is a diagrammatic illustration of apparatus utilized in carrying out my invention; and

Figs. 2 to 7 inclusive are curves explaining the principles thereof.

Many attempts have been made to devise methods and apparatus for the transmission by wire or radio of pictures and the like. As in these systems the transmission must be effected by means of variations or changes in electrical effects, it is always necessary to provide some arrangements for translating the varying light values in a logical way into electrical effects differing from each other according to a preconceived plan so that upon reception of the transmitted effects, the picture desired to be transmitted may be reconstructed.

From many standpoints, the most satisfactory manner of converting the varying light values of the picture to be transmitted into varying electrical effects is to project light from all parts of the picture successively upon a photo electric cell. The variations in light intensity act to produce variations in resistance of the cell, resulting in a varying flow of current therethru.

It has been suggested that this varying flow of current may be converted into variations of potential and amplified to a value sufficient to control, modulate or any other way affect the transmission so that that there may be produced for transmission electrical effects dependent at any instant upon the intensity of illumination of the photo electric cell.

In carrying out such methods, however, many difficulties have been met with. In the first place, the current flowing through the photo cell, due to the extremely high resistance of such cell, is extremely minute. The variations thereof are likewise very minute,

and it has been found that amplification of a very high order is necessary to convert the small fluctuations in potential or current in the photo cell into fluctuations of sufficient magnitude to be easily utilized in practice.

However, such high values of amplification are, I have found, very difficult to obtain with the types of amplifying systems known in the art for such purposes. As such variations are direct current or potential variations, it has been considered necessary to utilize a direct current or potential amplifying system generally consisting of a series of vacuum tube amplifiers in cascade coupled by what is known in the art as resistance coupling.

However, when such systems are attempted to be utilized for the extremely high values of amplification necessary to convert the photo cell variations into variations suitable for practical working, the amplifying system becomes extremely unstable and otherwise unsatisfactory, and not only tends to break into spontaneous oscillation, but even when not oscillating spontaneously tends to pick up extraneous disturbances, and furthermore amplifies variations within the system itself, such as battery noises, small fluctuations in plate current due to disturbances within the battery and the like; and these difficulties cannot be avoided by any means known in the art.

The difficulties above pointed out have made it necessary to work in picture transmission systems with light projected through the picture to be transmitted on to the photo cell, which require the preparation of a special transparent print of the picture to be transmitted. Attempts to work by reflected light have not up to the present met with success because of the fact that no system was available capable of translating the small values of light intensity or the small variations of light intensity, obtained under such conditions, into variations of potential of sufficient strength to control the transmission.

Another difficulty in the transmission of pictures and the like by the method outlined above resides in the fact that it is difficult to produce the degree of detail in the received picture which is present in the picture to be transmitted. There are several reasons for this with which I do not concern myself in this application, but it may be noted that in the systems now in use, the fluctuations produced by the photo electric cell are not strictly proportional to the light intensity, which in itself would give rise to distortion in the received picture, even if no other causes existed.

This difficulty may be understood by referring to Fig. 2, wherein the curve A B C D represents a typical characteristic for the photo cell in which photo cell current is plotted as ordinates against light intensity as abscissae. It will be noted that the curve has the shape of a somewhat distorted letter "S", similar to the characteristic curve of a thermionic vacuum tube and that only a relatively small part of the curve between the ends is substantially straight.

It follows therefore that unless the photo cell is worked at such point on its characteristic that the light fluctuates only between points on the abscissa where the curve is straight, the relation between the light intensity and the photo cell current will be constantly changing with changes of light intensity and the photo cell current will not be truly proportional to the light intensity.

This will give rise in the received picture to false light values and will distort the picture generally to a certain extent. In the past, however, it has not been possible to avoid such distortion by working on the straight line portion of the curve for the reason not only that the variations so obtained would be much smaller than when the light intensity fluctuated between points corresponding to points A and D on the abscissa, but also the photo cell current then varied only in a minor part; that is to say, if the light intensity varied between points on the abscissa corresponding to B and C, the current then varied between points on the ordinate corresponding to points B and C and the increase in current corresponding to the greatest possible increase in light intensity might not exceed a small fraction of the photo cell current for the lowest intensity of light.

The net result of this would be to require not only an amplifying system responding only to variations, but one of considerably greater amplifying power than any known in the art.

However, the distortion introduced by other causes has in the past been so much greater than the distortion due to this cause that it has been customary to neglect this source of distortion and to utilize the photo cell to obtain the greatest amount of variation. In other words, the photo cell is used in such a way that for the lowest value of light it gives zero current, and for the greatest value of light, maximum current; that is to say, the light is caused to vary between points on the abscissa corresponding to A and D. However, improved systems for the transmission of pictures and the like have reduced distortion resulting from other causes to a point where in order to obtain better quality it is advisable to eliminate distortion in the photo cell itself.

Referring generally to my invention, I attain the results desired by a number of features, utilized for the purpose, to wit:

First, I provide that the fluctuations of light intensity corresponding to the picture desired to be transmitted occur only within such a range that the photo cell characteristic is substantially a straight line, and this I do

by exposing the photo electric cell to light of a substantially constant intensity which is just sufficient to bias the photo cell to the lowest part of the straight line portion of its characteristic and I then impress the variations of light in such an amount that the greatest intensity of light does not carry the cell substantially off the upper end of the straight line portion.

Secondly, I provide means whereby the amplifier amplifies only the variations in the photo cell current or potential, or in other words, I convert the variations in the minor part, thus obtained, into variations in the major part. This I do by providing a bridge arrangement which is normally in balance when what I term the bias or auxiliary light only is playing on the cell, and by amplifying the potential difference across two symmetrical points of this bridge, which is so arranged as to become unbalanced when further light is thrown upon the cell.

Thirdly, I provide an amplifying system which is capable of much greater effective amplification before it becomes unstable than amplifiers for this purpose heretofore known. I obtain such an amplifying system by in effect converting the direct potential to be amplified into an alterating wave of readily amplifiable frequency, preferably an audio frequency of about 1,000 cycles, which may then be amplified without difficulty practically to as great an extent as desired. I then rectify this amplified alternating wave to produce an uni-directional voltage across the final output of the amplifier, which uni-directional voltage may be utilized in any suitable way to control, modulate or affect the transmission of suitable signals.

Referring particularly to Fig. 1, P represents a photo electric cell of a type well known in the art and described in the copending applications referred to above. This may be surrounded by light tight housing H provided, if desired, with a lens L or any suitable opening for the purpose of admitting light upon the cell. The picture or other object to be reproduced is arranged in such a way that light from all parts of it is progressively thrown upon the photo cell, as more fully explained in the applications referred to.

Briefly, it may be stated that a suitable arrangement is to provide a drum D and a suitable source of light S′, these being so arranged that light from the source S′ is varied in intensity according to successive portions of the picture, and eventually falls upon photo cell P.

In accordance with this invention, I provide an additional source of light S_2, shown diagrammatically as a lamp located within the housing H in such a way that it illuminates the photo electric cell, but obviously I do not intend to limit myself to such an arrangement, as the same result may be obtained in other ways, for example, by omitting a portion or all of the light tight housing H in such a way that additional light falls upon the photo cell.

Connected to the terminals of the cell and forming the cell circuit, I provide a suitable source of potential, such for instance as battery 2, which may conveniently have a value of 400 volts and in series therewith a resistance 3 of extremely high value, such as 20 megohms. The battery 2 therefore tends to force a current through resistance 3 and through the photo cell, giving rise to a potential drop across resistance 3. I then provide a pair of thermionic amplifier tubes 6 and 6′, preferably duplicates of each other, although this is not essential. The filaments of these vacuum tubes are connected together and to one end of resistance 3. The other end of resistance 3 is connected through a suitable bias battery 4 to the grid of the tube 6 in such a manner that the potential drop through resistance 3 is impressed on the grid of the tube in a way to make the grid more negative than it otherwise would be.

The grid of tube 6′ is connected through a suitable bias battery 5 to the common filament lead. The plate of tube 6′ is connected through a suitable resistance 9, which may conveniently have the value of 10,000 ohms, to the positive terminal of the plate supply, the negative terminal of which is connected to the common filament lead. This plate supply may be any convenient value for the purpose, such, for example, as 220 volts.

The plate of tube 6 is connected in a similar manner through a resistance 8, which may conveniently also have a value of 10,000 ohms, and to the positive terminal of the plate supply. The plate of tube 6 is connected to the filament of an additional thermionic vacuum tube 10 and it should be here noted that this tube 10 should be provided with a separate source for energizing the filament, herein shown as battery 12, having resistance 13 in series therewith for the purpose of controlling the filament temperature. The plate of tube 6 is connected through primary 14 of an audio frequency transformer directly to the plate of tube 10. Interposed in the grid-filament circuit of tube 10 I provide a suitable oscillator 11 capable of working at a readily amplifiable frequency, preferably an audio frequency of about 1,000 cycles.

The secondary 15 of the audio frequency transformer is connected across an audio frequency amplifier designated as 16 and shown diagrammatically. As this amplifier per se is well known in the art and forms in itself no part of my invention, it is not described in detail. It is sufficient to say that it may be of one or as many stages as may be found desirable to obtain the amplification required.

The output of this amplifier is connected through a suitable rectifier 18 and resistance 17 in series.

Turning now to the operation of my invention, it will be seen that this arrangement constitutes a bridge, the plate filament circuit of tube 6 between points *a* and *b* being one arm of the bridge, plate filament of tube 6′ between points *a* and *d* being an adjacent arm of the bridge, resistance 8 between points *b* and *c* being a third arm of the bridge and resistance 9 between points *c* and *d* being a fourth arm. Obviously, when the bridge is balanced, a voltage between points *a* and *c* (plate voltage) will not appear between points *b* and *d*.

It will be apparent that when the auxiliary source S_2 is adjusted so that the photo cell is on the lowest part of the straight line portion of its characteristic, a certain current will flow through resistance 3, giving rise to a difference of potential across the ends of resistance 3 in such a manner as to swing the grid of tube 6 negative. A certain amount of plate current will flow in tube 6, but in any event, bias batteries 4 and 5 are adjusted to such values that the plate currents flowing in tubes 6 and 6′ are equal under these conditions.

The drop through resistances 8 and 9 will likewise be equal or, in other words, the bridge is in balance, and the plates 6 and 6′ of the two tubes will be at the same potential. Under these circumstances, no current will tend to flow from the plate of tube 6 through primary 14 across the steps of tube 10 and through the filament of the same, thence to plate 6′.

However, if additional light is thrown on the photo cell at this point, the current therethrough will increase, which in turn will swing the grid of tube 6 to a more negative potential. This cuts down the current flowing between the filament and plate of tube 6 and the plate of tube 6 will rise in potential, as is well known to those skilled in the art, due to the decrease in the drop across the tube 6.

No change in the potential of the grid of tube 6′ however has taken place and therefore there now appears a difference of potential between the plates of tubes 6 and 6′ in such direction as to tend to force a current through tube 10 from the plate of tube 6 to the plate of tube 6′.

It will be noted that this supplies a plate voltage to tube 10, the grid of which is swinging at an audio frequency due to the action of oscillator 11. Under these circumstances, a unidirectional pulsating current will flow in the primary 14 and across tube 10, the magnitude or envelope of which is dependent on the difference of potential between the plate of tube 6 and the plate of tube 6′.

This will be more readily understood by reference to Fig. 3 of the drawing which shows the variation of current through the photo cell and likewise the variation of potential across resistance 3. It is clearly seen from these figures, all having a common time abscissa, that when the bridge is in balance, there is no plate voltage impressed on tube 10. However, as the bridge comes out of balance due to fluctuations of light on the photo cell, the plate voltage appears across tube 10 as shown in Fig. 4.

It is to be noted that if for any reason a voltage appears in the opposite direction, such as shown in Fig. 4, no current will flow across tube 10 due to its rectifying action. This is clearly shown in Fig. 5, which shows the current flowing through primary 14 of the audio frequency transformer, and it will be noted that the envelope of this current curve is similar to the positive part of the curve shown in Fig. 4. This gives rise in the secondary to an audio frequency voltage, or current, or both, as shown in Fig. 6, whose envelope is like that shown in Fig. 5. This audio frequency wave is amplified by amplifier 16 as far as may be desired and is then passed through the rectifier 18, the action of which is sufficient to give a direct potential across resistance 17 corresponding to the curve in Fig. 7.

While I have shown and described the preferred form of my invention, it is apparent that various modifications and changes may be made, as will be readily understood by those skilled in the art without departing from the scope and spirit of my invention.

Having described my invention, what I claim is:

1. A method of converting fluctuations of light intensity into fluctuations of potential by means of a photo electric cell which comprises projecting, upon said cell, light of a substantially constant intensity such as to cause said cell to operate at a predetermined point on its characteristic, and projecting thereon in addition light of varying intensity desired to be converted into fluctuations of potential.

2. A method of converting variations of light intensity into variations of potential by means of a photo electric cell which comprises exposing said cell to the fluctuations of light intensity desired to be so converted into potential fluctuations, and simultaneously exposing said cell to a light of such predetermined and substantially constant intensity as to bias said cell to a predetermined point on its characteristic.

3. In a photo electric cell, the combination with means for projecting thereon variations of light intensity to be converted into variations of potential of means for simultaneously projecting thereon light of such a substantially unvarying intensity as to maintain the

mean of the variations of light above a predetermined point on the characteristic.

4. In a photo-amplifier, the combination of a photo electric cell with means for projecting, upon said cell, light of varying intensity to be converted into variations of potential, and means for impressing substantially constant intensity light upon said cell for biasing said cell to a predetermined point on its characteristic so as to produce linear changes in potential due to varying light intensities impressed thereon.

5. In a photo-amplifier, the combination of a photo electric cell, a bridge, means for impressing across one of the arms of said bridge a potential derived from current through said cell, means for balancing said bridge for a predetermined photo cell current and means connected across diagonal points of said bridge for amplifying differences of potential therebetween, said last named means comprising a rectifier.

6. In a photo-amplifier, the combination of a bridge, a photo electric cell, means for impressing potential derived from said cell current upon one of the arms of said bridge, a circuit connected across one diagonal of said bridge, comprising a rectifier and an interrupter and means for amplifying current flowing through said circuit.

7. In a photo-amplifier, in combination, a photo cell, a pair of thermionic vacuum tube amplifiers, each having filament, plate and control electrodes and having their filaments connected together, a resistance having its ends respectively connected to the plates of said tubes and its midpoint connected to a source of plate potential, said tubes and said resistances forming a bridge, means for impressing photo cell potential between the filament and control electrode of one of said tubes, a rectifier connected across one diagonal of said bridge and comprising means for interrupting current therethrough at a readily amplifiable frequency, and means associated therewith for amplifying currents of the frequency so produced.

8. In a photo amplifier, the combination of a photo electric cell, a bridge, means for impressing across one of the arms of said bridge a potential derived from current passing through said cell, means for balancing said bridge for a predetermined photo cell current, means connected across one diagonal of said bridge for amplifying potential differences therebetween, said last named means including a thermionic tube adapted to have its plate circuit energized by said potential differences for causing anode current to flow, means associated with said thermionic tube for continuously impressing upon the grid electrode low frequency oscillations, means associated with the output of said thermionic tube for amplifying the fluctuating waves produced in the output circuit of said amplifier and means for converting said amplified fluctuations into a uni-directional potential corresponding to the fluctuations in the current flowing from said photo cell.

9. In a photo amplifying device the combination of a photo electric cell, a bridge, means for impressing across one of the arms of said bridge a potential derived from current flowing through said cell due to varying changes in light intensity impressed thereon, means for balancing said bridge for a predetermined photo cell current, means connected across one diagonal of said bridge for producing a fluctuating wave having an envelope corresponding to the fluctuations in current flowing through said photo cell, said last named means including a thermionic tube having its grid circuit continuously energized at a low frequency and its plate circuit under a varying potential to cause a current to flow through said tube, said varying plate potential being produced by potential differences in said bridge structure, means for amplifying said fluctuating wave, and means for converting said amplified fluctuating wave into uni-directional potentials corresponding in the current fluctuations in said photo cell.

10. The method of operating a photoelectric cell having a response curve of linear characteristics for light values beyond predetermined intensities falling upon the cell, which includes, illuminating the cell by a light value of uniform intensity sufficient to bring the average light intensity impressed upon said cell to the linear portion of the characteristic, and superimposing thereon light values of variable intensity varied in in accordance with the changes in intensity of light and shadow from elemental areas of a transmitted picture element for producing output energy of a linear characteristic from the photoelectric cell irrespective of fluctuations in the superimposed light.

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