Nov. 13, 1928. 1,691,147

A. B. CLARK ET AL

ELECTRICAL PICTURE TRANSMITTING SYSTEM

Filed June 6, 1925 3 Sheets-Sheet 1

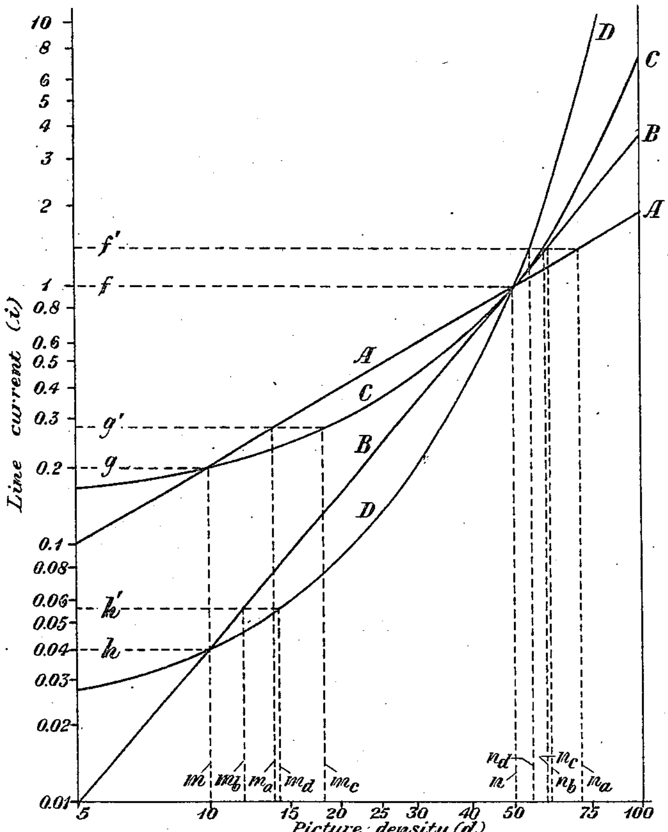

Fig. 1

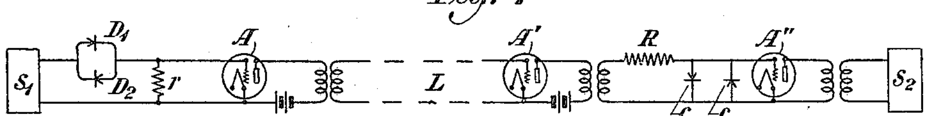

Fig. 2

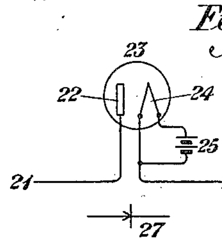

Fig. 3

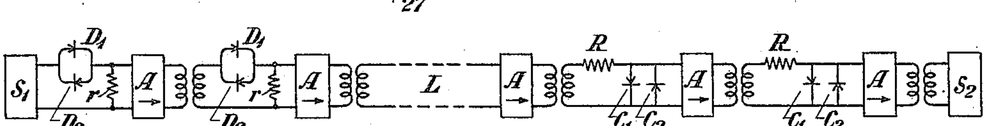

Fig. 4

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ELECTRICAL PICTURE TRANSMITTING SYSTEM

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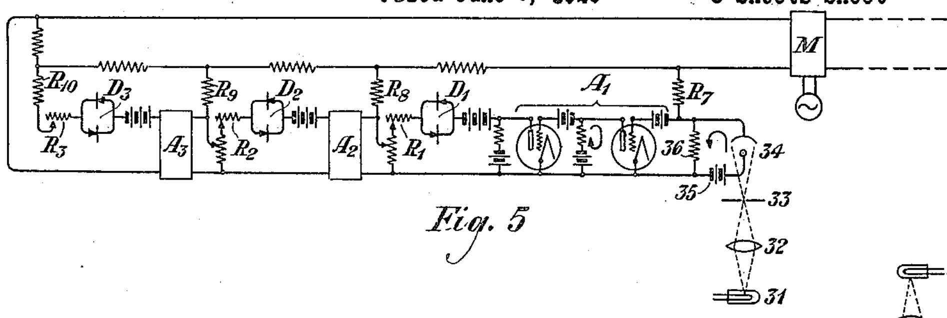

Fig. 5

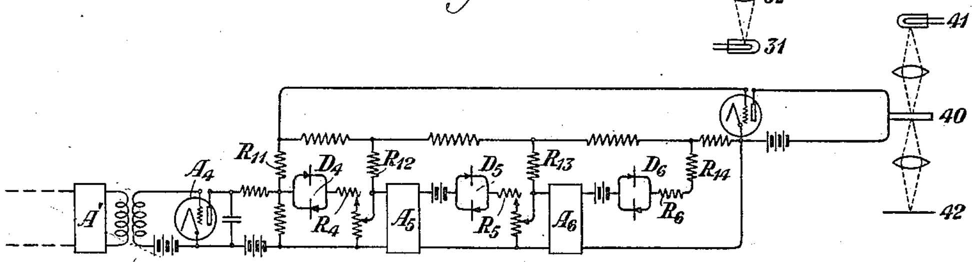

Fig. 6

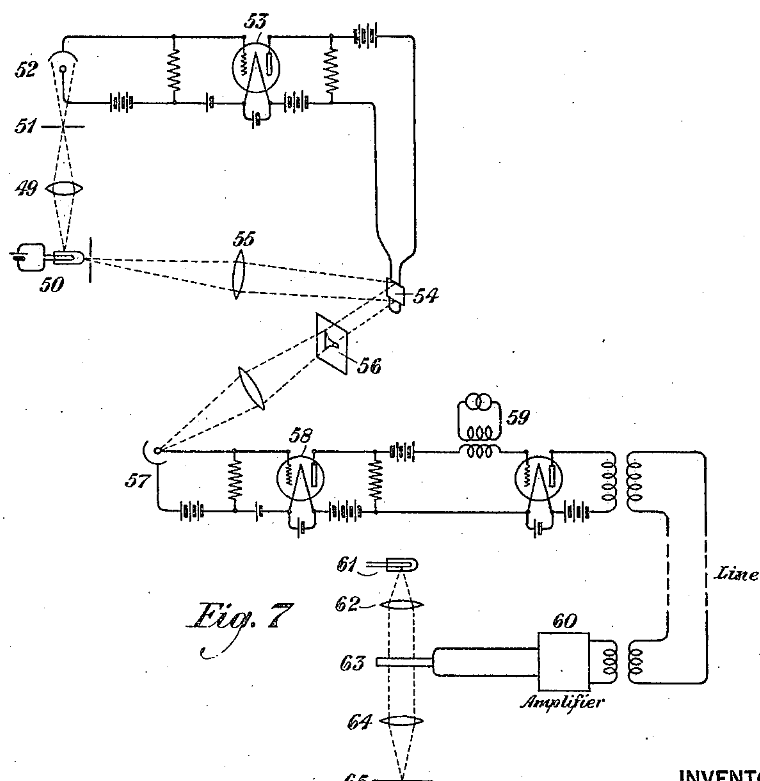

Fig. 7

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ELECTRICAL PICTURE TRANSMITTING SYSTEM

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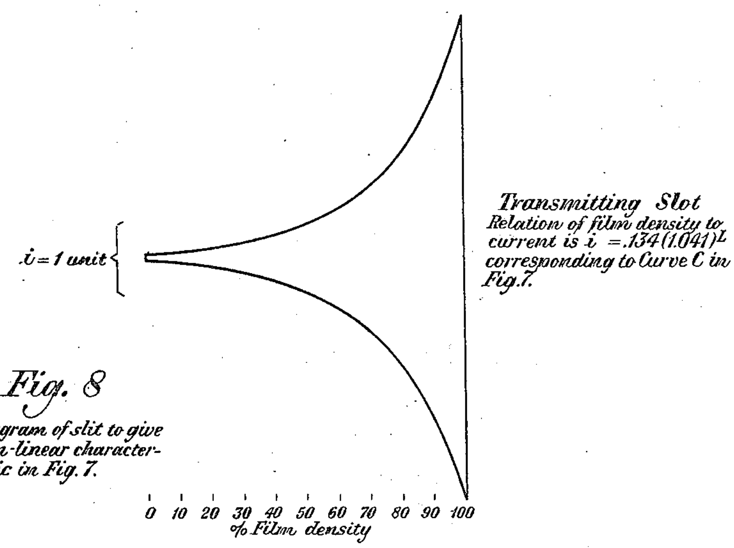

Fig. 8

Diagram of slit to give non-linear characteristic in Fig. 7.

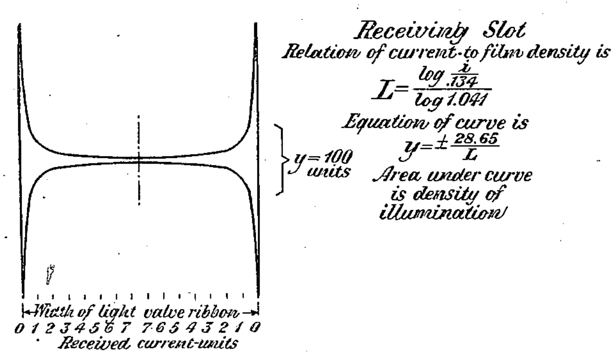

Fig. 9

Diagram of slit to restore linear characteristic in Fig. 7.

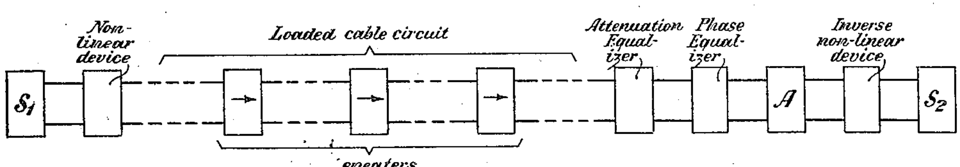

Fig. 10

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Patented Nov. 13, 1928. **1,691,147**

UNITED STATES PATENT OFFICE.

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ELECTRICAL PICTURE-TRANSMITTING SYSTEM.

Application filed June 6, 1925. Serial No. 35,323.

An object of our invention is to provide a new and improved system for electro-optically transmitting images of pictures and other objects which is adapted to give a well defined image or picture at the receiving end corresponding closely in its tone values to the picture or object from which transmission is made at the sending end. Another object of our invention is to provide such a system with the transmitted current controlled as such a function of the light of the successive elements of the picture or object, that incidental changes in the transmission equivalent value of the line will be of negligible effect. Still another object of our invention is to provide against any blurring of the received image or picture due to transmission of the different component frequencies of the current at different rates of speed. These and various other objects of our invention will become apparent on consideration of a limited number of specific examples of practice in accordance with the principle of the invention which we have chosen to disclose in the following specification, taken with the accompanying drawings. It will be understood that the following description relates more particularly to these examples of the practice of the invention and that the invention will be defined in the appended claims.

Referring to the drawings, Figure 1 is a curve sheet showing a line current as a function of picture density in several different relations that will be discussed hereinafter; Fig. 2 is a symbolic diagram of a transmitting system embodying our invention in a certain form; Fig. 3 is a detail diagram showing symbols for a vacuum tube valve; Fig. 4 is a diagram of a modification as compared with Fig. 2; Fig. 5 is a diagram for a transmitting station embodying a further modified embodiment of our invention; Fig. 6 is a diagram for the receiving station corresponding to the transmitting station of Fig. 5; Fig. 7 is a diagram of a complete system embodying still another modification; Figs. 8 and 9 are diagrams of certain light orifices disclosed in Fig. 7 and Fig. 10 is a diagram of a complete system embodying an attenuation equalizer and a phase equalizer.

In the transmission of pictures by electricity it is a well known practice to cause an electric current to vary in accordance with the light values of successive elemental areas of the picture to be transmitted. This current or a current corresponding thereto is transmitted from the sending station to the receiving station and it may be applied at the receiving station to control the application of a light to the successive elements of a sensitive surface so as to develop in that surface shades corresponding to the picture from which the transmission is made.

In the transmission of such electric currents it may happen that the transmission equivalent value of the system will change irregularly from time to time. Such changes occur in long distance telephony but are little noticed because to the person at the receiving end they are noticed merely as moderate changes in volume of sound. But in a picture transmission system such changes are rather serious because they cause the received picture to exhibit differences of shading, usually in a somewhat streaked manner and quite obviously not natural to the picture as it is intended.

Referring to Fig. 1, this is a logarithmic diagram exhibiting line current in various functional relations to picture density. The scale of picture density in Fig. 1 is a percentage scale and we define the picture density of a small elemental area of the picture expressed in per cent to be 100 minus the percentage of transmission of light through that spot of the film as compared with complete transparency at that spot.

Assume that the picture density for a picture to be transmitted varies over the range from m to n, corresponding to the lightest and darkest portions of the picture respectively. The range from m to n corresponds to about 14 TU (transmission units, defined by the equation $N_{TU}=20 \log_{10} i_1/i_2$ where i_1 and i_2 are direct measures of the intensity at the two places compared). In the case of the linear relation shown by the curve A, the corresponding variation of the line current will be from g to f. The equation of curve A is $i=0.02d$. Now, assume that the attenuation on the line is suddenly reduced by the conveniently assumed arbitrary amount 2.9 TU; this will increase the received line current from g to g' and from f to f' and will cause a corresponding increase in the film density at the receiving end from m to m_a and from n to n_a. The effect of this change on shades in the neighborhood of n is much more severe than on shades in the neighborhood of m. It will readily be seen that the change from n to n_a goes nearly halfway to 100 per cent picture density, whereas the change from m to m_a goes only a small fraction of the way to 100 per cent picture density. The change at the upper part of the picture density range will seem very pronounced to the eye of an observer, while the change at the lower part of that range will be much less noticeable, for the reason that the eye is sensitive to the amount of light reflected to it from the surface of the picture rather than the amount of light absorbed by the picture.

Curve B shows the relation such that the line current is the square of the value of the picture density; its equation is $i=0.0004d^2$. In this case a range of density from m to n will correspond to a range in line current from h to f, which is twice as great a range of line current as compared with curve A, when expressed in transmission units. The same change in transmission as was considered for curve A, namely a reduction of attenuation by 2.9 TU, produces a change in the line current from the range h, f to the range h' f' and changes the picture density from the range m, n to m_b, n_b. It will be noticed that in this case the range of picture density is shifted only half as far as was the case for curve A. Thus, the use of the square relation of curve B instead of the linear relation of curve A for line current as a function of picture density leads to the result that changes of attenuation on the line produce only half as great changes in picture density. It is obvious that higher powers than the second power would cause corresponding further increase in the range of line current required and a corresponding decrease in the effect of a transmission change in the circuit on the density of the received picture. However, it will be seen that the change from the curve A to the curve B has not equalized the effect of a transmission change in the light and dark parts of the picture, since the ratio of m_b to m is the same as of n_b to n.

Now, consider the curve C, which is an exponential curve drawn to intersect curve A at the points corresponding to the abscissas m and n; its equation is $i=0.134\ (1.041)^d$. In this case the same assumed change in transmission, namely a decrease of attenuation by 2.9 TU increases the picture density from the range m, n to the range m_c, n_c. This is a less change at the upper end of the range than before, decidedly less than for curve A, although it is somewhat greater at the lower end of the range than before. However, as has been pointed out, the change at the lower end of the range is much less serious than at the upper end of the range, so that on the whole the curve C gives a further improvement over the curves A and B.

The fourth curve D is another exponential curve drawn to intersect the curve B at the points corresponding to the abscissas m and n; its equation is $i=0.179\ (1.084)^d$. A system having this relation of line current to picture density would require as great a power range on the line as required by the curve B. The assumed transmission change of 2.9 TU decrease of attentuation causes only a small change from n to n_d, and at the lower end the change is from m to m_d, much less than for the curve C and nearly as small as for the curve A. The shift at both the light and the dark ends of the picture density range is little more than half as much for curve D as for curve C.

Referring to Fig. 2, this illustrates a system for practising the relationship shown by curve B in Fig. 1. S_1 is a picture transmitting equipment which applies to the line extending therefrom an electromotive force varying in magnitude according to the shade of successive elements of area of a picture to be transmitted; that is, the darker the picture element the greater the electromotive force. The current due to this electromotive force is a modulated carrier current and from the apparatus S_1 it goes to the oppositely connected valves D_1 and D_2. Each of these valves is represented by a simple symbol here and elsewhere in the drawings and as shown at 27 in Fig. 3; with more detail such a valve is shown in the upper part of Fig. 3. It consists of a plate 22 and a hot cathode 24 in a vacuous container 23. The cathode 24 is in the form of a filament kept hot by current from the battery 25. This device is a valve or rectifier between the terminals 21 and 26, permitting current to flow only in the conventional direction from 21 to 26. Since the two valves D_1 and D_2 are oppositely connected in Fig. 2, they permit both half waves of current to pass.

It is a well known property of a properly designed thermionic valve such as that shown in Fig. 3, that for magnitudes of current in the effective direction, the output current varies approximately as the square of the input electromotive force. Hence, the electromotive force across the low resistance r varies as the square of the electromotive force output from the apparatus S_1. This electromotive force across r is applied to the grid of the amplifier A and determines the magnitude of the current put on the line L. The result is that the current on the line varies as the square of the electromotive force from the apparatus S_1, that is, the current on the line varies as the square of the picture density within the apparatus S_1, which determines the output electromotive force therefrom.

At the receiving end the line current goes to an amplifier A′ and thence through a high resistance R and across the two opposite valves in parallel C_1 and C_2. Since the current through these valves varies as the square of the electromotive force across them it follows that the electromotive force applied to the input of the amplifier A″ varies as the square root of the current through the resistance R. Thus, the inverse relation is established at the input of the receiving apparatus S_2, so that the current to the receiving apparatus S_2 varies linearly with the output electromotive force from the sending apparatus S_1, although the current on the line varies as the square of the electromotive force at the sending end and the current at S_2 at the receiving end of the line. Thus, the apparatus of Fig. 2 operates according to the characteristic B of Fig. 1 and realizes the advantages discussed in connection therewith.

Fig. 4 illustrates how a higher power than the square may be involved in practice. It will readily be seen that in Fig. 4 two tandem sets of valves D_1, D_2 are employed at the sending end. Thus, the current on the line corresponds to a fourth power instead of the square as in Fig. 2. At the receiving end in Fig. 4 two sets of shunt valves C_1, C_2 are employed, thus giving two tandem square root operations, so that the input current for the receiving apparatus S_2 varies as the fourth root of the current on the line but varies linearly with the output electromotive force from the sending apparatus S_1.

In Figs. 5 and 6 we have shown how an exponential relation such as that of curve C or D may be realized. Such an exponential relation can be expressed by a convergent series, thus,

$$a^x = 1 + kx + \frac{(kx)^2}{2'} + \ldots$$

where k is a suitably chosen constant. In the apparatus of Fig. 5, there are elements corresponding in function to the respective terms of such a series. Light from the source 31 in Fig. 5 is concentrated by the lens 32 on a spot of the moving film 33. Part of this light is transmitted, depending on the degree of transparency of the film at the spot involved. The transmitted light enters the photoelectric cell 34 and determines the magnitude of the current due to the electromotive force of the battery 35. This current through the resistance 36 produces a corresponding component of input electromotive force to the two-stage amplifier A_1 arranged so that its output current is proportional to film density at 33. This output current determines the input voltage applied to the two-way valve D_1, and accordingly its output current varies as the square of picture density. This current goes through the adjustable resistance R_1 and determines the electromotive force to another two-stage amplifier A_2, and so on through two-way valve D_2 and resistance R_2, and then a third set of two-stage amplifier A_3, two-way valve D_3 and resistance R_3.

It will be seen that multiple taps go to modulator M through resistances R_7, R_8, R_9 and R_{10} from each stage of the apparatus heretofore described. Each tap by suitable adjustment contributes to modulator M a component of input corresponding to a respective term of the foregoing convergent series, and hence the input to modulator M is the desired exponential function of the picture density at 33.

At the receiving end, we rely on the expansion,

$$\log cy = (cy-1) - \frac{1}{2}(cy-1)^2 + \frac{1}{3}(cy-1)^3 - \ldots$$

where $2 > cy > 0$. The quantity $cy-1$ is obtained in the first amplifier A_4 by arranging the circuit to add to the voltage of the amplified received line current cy, a portion of the direct current voltage in the plate circuit representing unity. The input transformer of this amplifier must be properly poled to give the desired algebraic signs to the terms. The remaining amplifiers A_5 and A_6 should each be single-stage and arranged to alternate the signs as in the foregoing series. The various components are assembled through the respective resistances R_{11}, R_{12}, R_{13} and R_{14} and thus a current is applied to light valve 40 which is a logarithmic function (that is an inverse exponential function) of the line current; hence the light valve current at the receiving end is proportional to the photoelectric cell current at the sending end. The light valve 40 determines the quantity of light from source 41 to an elemental area of sensitive film 42 which is moved in synchronism with the sending film 33. The means for accomplishing this synchronism may be of well known construction and mode of operation, one preferred method is that disclosed in British Patent 242,694, granted to Western Electric Company, Incorporated, August 8, 1924.

In Fig. 7 we have shown a modified system which may readily be adapted to give any desired functional relation between the light value in the picture elements and the current on the line. At the sending end, light from the source 50 is directed by the lens 49 through a small spot of the moving film 51. The light transmitted through the film enters the photoelectric cell 52 and determines the current therethrough and accordingly determines the electromotive force to the amplifier 53. A corresponding output current from the amplifier 53 goes through the moving conductors carrying the oscillograph mirror 54. Accordingly, this mirror oscillates with an amplitude determined by the magnitude of the current, which in turn corresponds to the degree of shade in the spot of the film 51 that lies across the path of the light to the photoelectric cell 52.

The mirror 54 receives light from the source 50 through the lens 55 and reflects this light through an opening in the screen 56 (see also Fig. 8) and thence through a lens to the photoelectric cell 57. The light in the cell 57 determines the input electromotive force for the amplifier 58 and the corresponding output current therefrom goes to a modulator 59 and modulates a carrier current that is put on the line.

At the receiving end, the received currents go through an amplifier 60 and thence to a light valve 63. This light valve is a ribbon of metal carrying the received current in a strong magnetic field so that the ribbon deflects in accordance with the magnitude of the current. Before this ribbon is an opening in a screen as shown in Fig. 9, and this opening is uncovered by the deflection of the ribbon due to the received current. Light from the source 61 is directed by the lenses 62 and 64 through the light valve 63 and on a sensitive receiving film 65, which is moved in synchronism with the sending film 51. Synchronizing means may be of any suitable well known kind such as disclosed in British Patent 242,694 referred to hereinabove.

By giving the proper shape to the opening in the screen 56 at the sending end, as shown in Fig. 8, the modulating current can be made to have any desired single-valued functional relation to the picture density. The shape shown corresponds to curve C, Fig. 1. Thus, any one of the four functional relations shown in Fig. 1 can be obtained and evidently other such functional relations would be equally possible by giving the proper shape to the opening in the screen 56.

At the receiving end, the shape of the opening uncovered by the light valve 63 will be such as to give the inverse relation as compared with that at the sending end so that the light to the sensitive receiving film will be a linear function of the picture density in the sending film. Fig. 9 illustrates such an opening so designed as to restore linearity when the sending end is equipped with the slot of Fig. 8.

In the disclosures of examples of our invention that have gone heretofore in this specification it has been tacitly assumed that transmission on the line was distortionless so that whatever transformation was made at the sending end to make the current on the line a non-linear function of picture density, the inverse transformation at the receiving end would restore the linear relation. In many cases the line will introduce some distortion, and to some extent correction may be made for this by adjustment at the receiving end. For example, in Fig. 6 some correction for distortion on the line may be effected by adjustment of the resistances, such as R_4, R_5, etc. However, in certain cases other measures may be resorted to in order to correct or compensate for line distortion.

In Fig. 10 we have shown a symbolic diagram of a system comprising picture sending apparatus S_1, whence the current corresponding to picture density goes to a "non-linear device" which effects the desired transformation in the current before putting it on the line. This non-linear device may be such as shown in any one of Figs. 2, 4, 5 or 7.

The line in Fig. 10 may be assumed to be a loaded cable circuit with repeaters at proper intervals. At the receiving end the current goes first to an attenuation equalizer such as disclosed in British Patent 242,694 referred to hereinabove and then to a phase equalizer such as disclosed in Patent 1,675,460 issued to H. Nyquist July 3, 1928. The line will attenuate the component currents of different frequency in different degree and the attenuation equalizer will further attenuate these components in different degree to compensate so that the output from the attenuation equalizer will have all its components of different frequency attenuated in the same degree.

From the attenuation equalizer the picture transmitting current next goes to the phase equalizer. The loaded cable circuit will retard components of different frequencies by different amounts, thus altering the wave form from that at the transmitting end. The phase equalizer will further retard the different components of various frequencies by different amounts, but so that the over-all phase retardation is equalized; that is, the delay in time of transmission over the line and through the phase equalizer will be the same for all frequencies which are of interest. Stated otherwise, the over-all phase shift in angular measure will be proportional to the frequency.

Thus, the current at the receiving end, after passing through the attenuation equalizer and the phase equalizer, will have the same wave form as the output from the non-linear device at the sending end. This current will then go to an amplifier A, then through an "inverse non-linear device", and then to the picture receiving apparatus S_2.

It will be noted that each of the systems heretofore disclosed confers advantages with respect to sensitivity to variations in attenuation from time to time on the line, but at the expense of some other factor. In the case of the power curves, such as illustrated by B in Fig. 1, the sensitivity to noise and echoes is increased. On account of the wider range in value of line current required for transmission, the same is true of the system represented by the curve D; for both B and D the line current ranges from h to f, as shown on the scale of ordinates on Fig. 1. Curve C does not have this disadvantage but does have the disadvantage, like curve D, of introducing a distortion in the contrasts of the picture in the case of all transmission changes except those that are comparatively small. All of these systems require a more nearly distortionless transmission line. The frequency range is increased considerably and the necessity for nearly uniform delay in transmission of the various components at different frequencies is increased accordingly. However, as shown in Fig. 10, the uniform delay can be secured, if necessary, by the introduction of a phase equalizer.

We claim:

1. In the transmission of pictures by electric currents, the method which consists in sending currents varied in a non-linear relation to the light values of the successive elements of the picture to be transmitted, and at the receiving end exposing corresponding elements of a sensitive surface to light varied in inverse non-linear relation to the received current.

2. In the transmission of pictures by electric currents, the method which consists in sending currents dependent on the light values of successive elements of the picture to be transmitted, continuously varying said currents in a manner advantageous for transmission, at the receiving end exposing corresponding elements of a sensitive surface to light dependent in value on said currents as received, and continuously varying said light in a manner advantageous for recording the picture in proper degree of shade.

3. In the transmission of pictures by electric currents, the method which consists in sending currents whose rate of increase with picture density is greater at large values of picture density than small values, and at the receiving end exposing a sensitive surface to light varied in inverse relation to the said currents.

4. In combination in an electrical system for transmitting images of pictures or other objects, means at the sending end to vary the transmitted current as a non-linear function of the light values of the successive elements of the picture or other object, a line to carry the said current to the receiving end, and means at the receiving end to vary the exposure of a receiving element in inverse relation to the received current.

5. In combination in an electrical system for transmitting images of pictures or other objects, means at the transmitting end to vary the transmitted current as a function of light values of successive elements of the picture or other object whose image is to be transmitted, and means at the receiving end to compensate the current for phase distortion in transmission and to expose corresponding elements of a receiving medium to light varied as a function of the compensated current.

6. The method of electro-optical transmission which consists in producing electrical currents whose instantaneous values vary in accordance with the light tone values of successive elements of a picture or other object whose image is to be transmitted, employing said currents in producing electrical current whose instantaneous values are a non-linear function of the light tone values of successive elements of the picture or other object whose image is to be transmitted, and sending corresponding non-linear currents over a line and applying them at the receiving end to control the degree of exposure of corresponding successive elements of a receiving medium.

7. The method of transmitting electric currents and thereby producing images of pictures or other objects which comprises producing electrical currents varying in accordance with the light tone values of successive elements of a picture or other objects to be transmitted, employing these currents to produce currents having a non-linear function of said light tone values, transmitting them to the receiving end and applying them to control the exposure of corresponding elements of a picture or image receiving medium.

8. The method of transmitting electric current and thereby producing images of pictures or other objects which comprises generating an electric current corresponding to the light tone values of the successive elements of a picture or other object whose image is to be transmitted, sending this current over a line, compensating the received current for phase distortion, and applying the compensated current to control the production of an image of said picture or other object.

9. The method of picture transmission which consists in varying an electric current as a function of picture density, causing the current to vary over a wider range of ratio values than the variation of picture density, transmitting this current and at the receiving end applying it to control the exposure of a sensitive receiving surface.

10. The method of transmitting electrical current and thereby producing images of pictures or other objects which comprises varying an electric current as a function of the light tones of the picture or other object, causing the current to vary over a wider range of ratio values than the variation of the light tones of the picture or other object, transmitting this current, compensating the received current for phase distortion at the receiving end, and applying the compensated current to control the exposure of an image receiving medium.

11. In an electro-optical transmission system, an object whose image is to be transmitted, means for producing a photoelectric cur-

rent whose variations in intensity bear a linear relation to the light tone values of successive elements of the object, means for using said photoelectric current to produce another photoelectric current whose variations bear a non-linear relation to the light tone values of the elements of the object, a transmission line subject to attenuation changes, means for amplifying and applying said second mentioned photoelectric current to said line, means for receiving the transmitting current, means for utilizing said received current to produce a light beam whose variations in intensity vary inversely and non-linearly as regards the received current, and means for causing the variations in the intensity of the said light beam to produce an image of the object.

12. The combination of a source of light, means for producing fluctuations in a beam of light from said source, a light sensitive cell actuated by said beam thereby producing fluctuating electric current, a second light sensitive cell, a second beam of light, an apertured baffle plate in the path of said second beam, means for controlling the current from said second cell in accordance with the intensity of the said fluctuating electric current and in accordance with the portion of the area of the opening in said apertured baffle plate exposed to said second beam.

13. In an electro-optical transmission system, an object whose image is to be transmitted, means for producing a photoelectric current whose instantaneous values bear a linear relation to the light tones of corresponding elements of said object, means for translating said photoelectric current into a current whose instantaneous values vary exponentially as regards corresponding light tone values of the elements of the object, a receiving station, means to transmit said second mentioned current to said receiving station, and means at said receiving station for translating the received current into light variations which bear a linear relation to said light tone values of the elements of said object.

14. In a system of picture transmission, a picture to be transmitted, means for producing currents corresponding in amplitude to the variations in density at the picture elements, a transmission line subject to attenuation changes, means for varying the amplitudes of said currents to compensate for said changes prior to the application of said currents to said line, means for applying said currents to said lines, a receiving station, means at said receiving station to produce a beam of light varying in intensity according to the received currents, and means for insuring that the variations in intensity of said beam bear a linear relation to the variations in density of corresponding elements of the picture.

15. In an electro-optical transmission system, a receiving surface, means for exposing said surface to a beam of light, an electromagnetic light valve, and a light baffle for varying the intensity of the light upon said surface exponentially as regards the degree of opening of said valve.

16. In an electro-optical transmission system, a picture or object whose image is to be transmitted, means for producing a photoelectric current which varies non-linearly as regards the variations in the light tone value of the elements of the picture or object, a receiving station, means for amplifying and transmitting said photoelectric currents to said receiving station, an electromagnetic light valve operated by the amplified currents, a light receiving medium, and a light baffle between said valve and said surface having a light passage of such shape as to compensate for the non-linear relation between the amplified currents and the light tone values of corresponding elements of the picture or object.

17. The method of electro-optically producing images by electric energy transmitted from a distant point which comprises causing energy at the transmitter representing tone values of the object to change with change of light values of the successive elements of said object at a rate different in one part of the range of light values than at another, and means at the receiver for compensating for the non-rectilinearity of the relationship between said rates of change.

18. The method of electro-optically producing images by electric energy transmitted from a distant point which comprises causing energy at the transmitter representing tone values of the object to change with change of light values of the successive elements of said object at a rate greater at the small values of light than at the large, and means at the receiver for compensating for the non-rectilinearity of the relationship between said rates of change.

19. The method of transmitting electric current and thereby producing images of pictures or other objects which comprises sending current varied in a non-linear relation to the light values of the successive elements of the picture or other object whose image is to be transmitted, and at the receiving end illuminating corresponding elements of a receiving medium by light varied in inverse non-linear relation to the received current.

20. The method of transmitting electric current and thereby producing images of pictures or other objects which comprises sending current dependent on the light tone values of successive elements of the picture or other object whose image is to be transmitted, continuously varying said current in a manner advantageous for transmission, at

the receiving end exposing corresponding elements of a receiving medium to light dependent in value on said current as received, and continuously varying said light in a manner advantageous for producing an image of the picture or other object in proper degree of shade.

In testimony whereof, we have signed our names to this specification this 2nd day of June, 1925.

ALVA B. CLARK.
HARRY NYQUIST.
DANFORTH K. GANNETT.