

March 19, 1929.

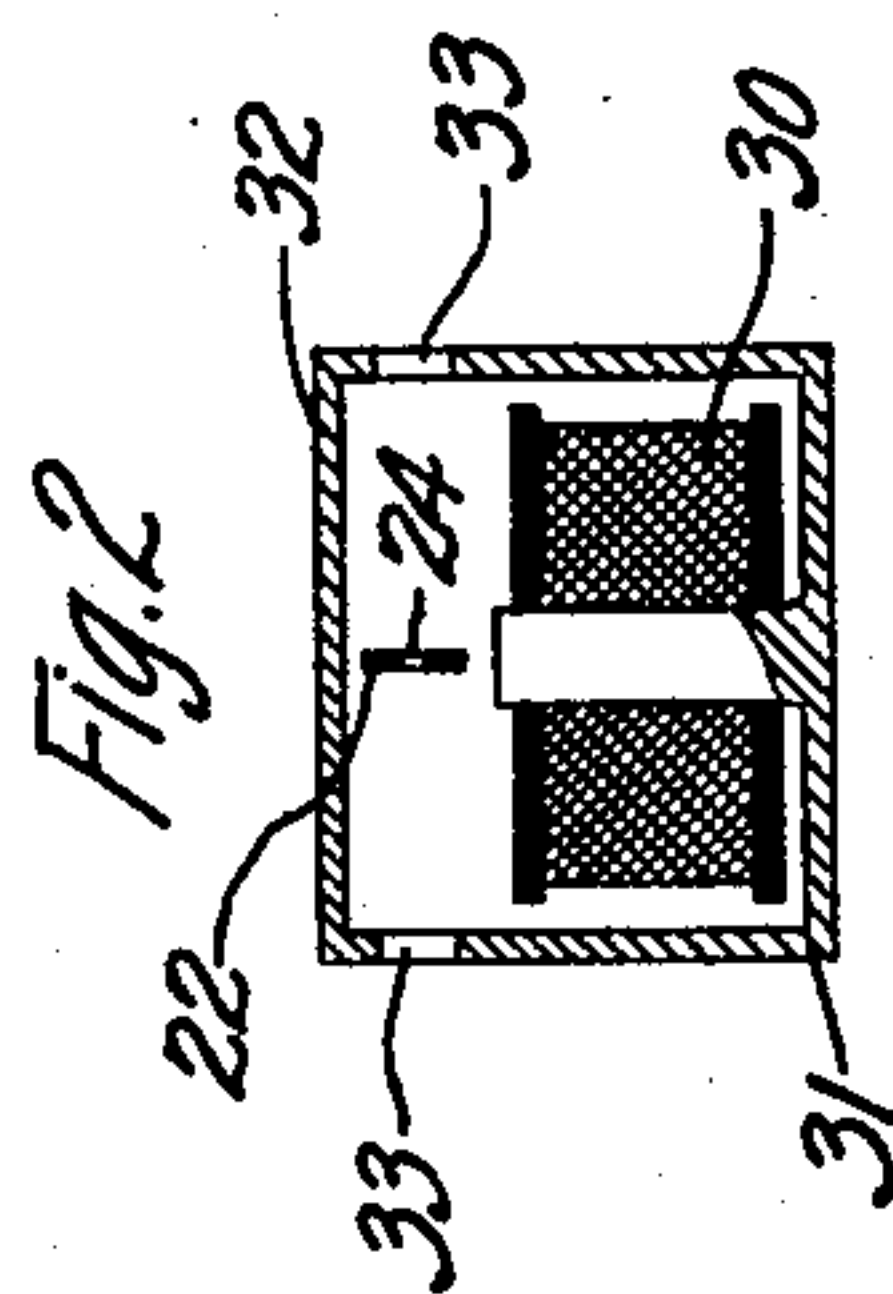
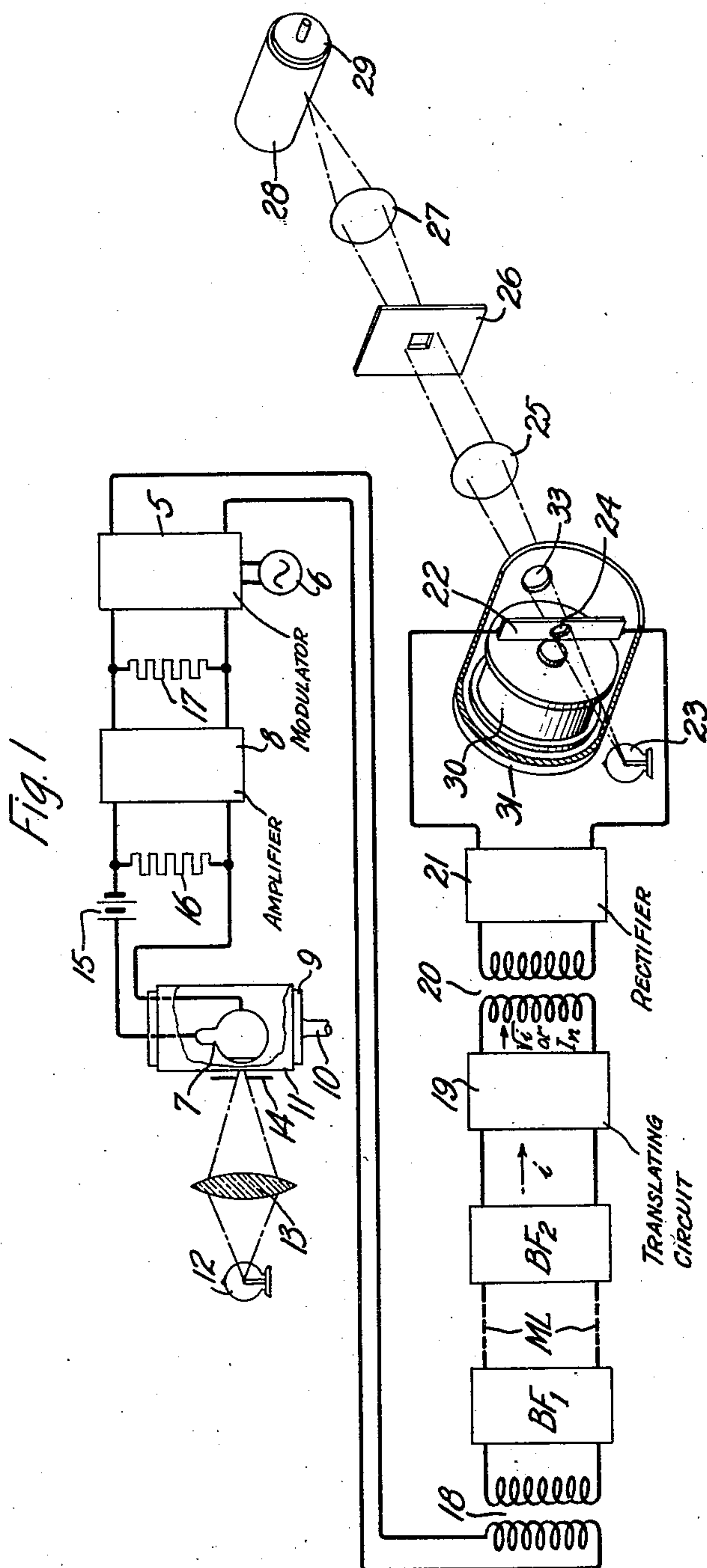
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1,705,551

ELECTROOPTICAL TRANSMISSION

Filed Feb. 5, 1927

2 Sheets-Sheet 1



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2 Sheets-Sheet 2

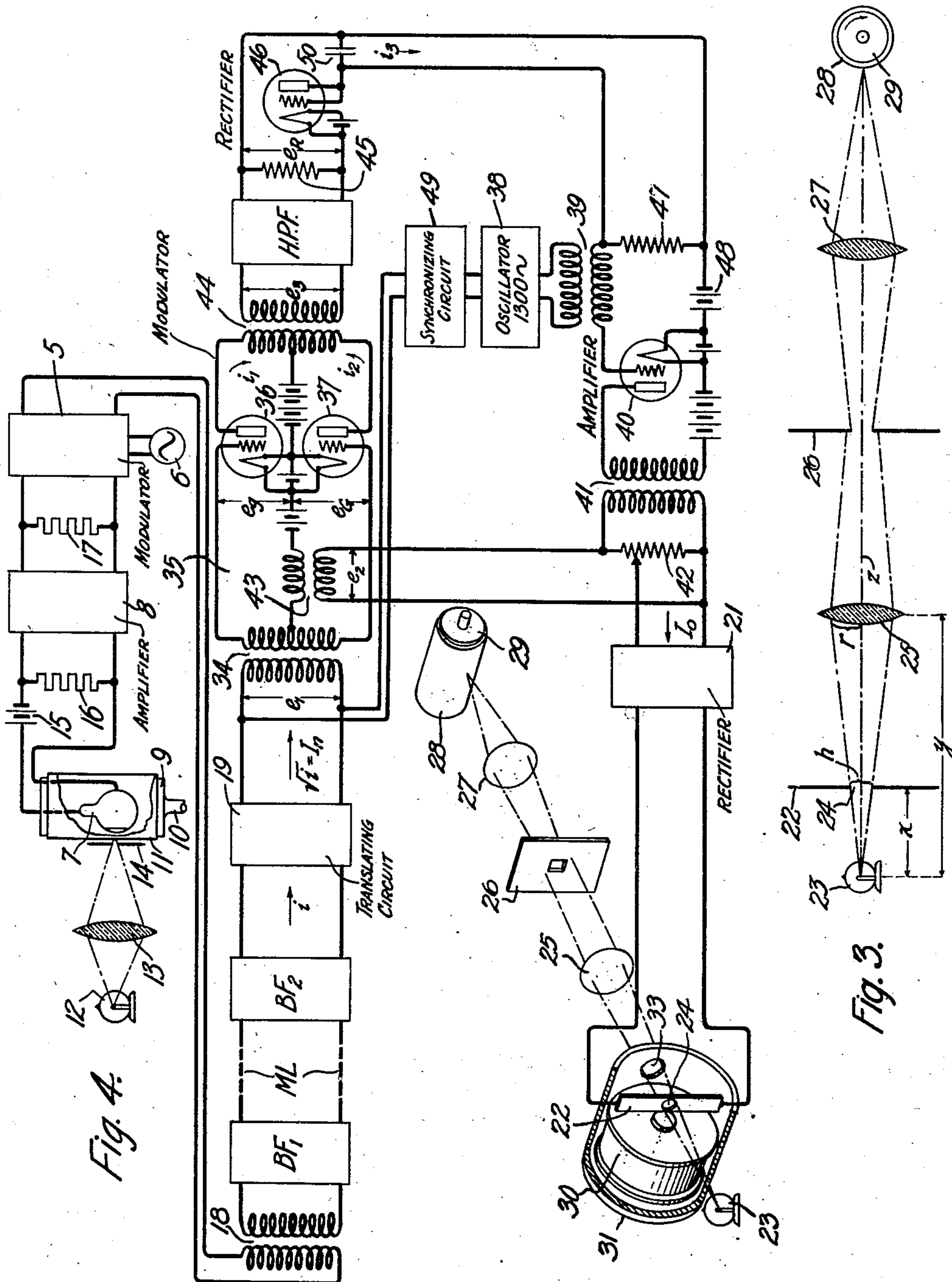


Fig. 4.

Fig. 3.

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UNITED STATES PATENT OFFICE.

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ELECTROOPTICAL TRANSMISSION.

Application filed February 5, 1927. Serial No. 166,242.

This invention relates to the electrical transmission of signals, and particularly to electro-optical signal receiving apparatus.

5 An object of the invention is to produce at a receiving point faithful facsimiles of pictures, objects, images, messages, etc., which are translated into electric current at the transmitting point for transmission to said receiving point.

10 Another object of the invention is to provide a system for obtaining a reciprocal relationship between input and output waves, which system may be used with the type of light valve hereinafter described.

15 The invention in its principal aspects is a light valve which may be used in the production of facsimiles of pictures, objects, etc., and a system in which such a light valve may be used.

20 This light valve accomplishes the purpose of the common iris diaphragm without the large inertia that is present in the latter. It consists, specifically stated, of a flat ribbon suspended in a constant magnetic field between a constant source of light and the recording film. The light passes through a small opening in the ribbon and is focused on the film. The received picture current is rectified and that portion of the rectified current is passed through the ribbon which will cause the latter to be initially deflected toward the light source and to oscillate in accordance with the current variations while maintaining a deflection toward the light source. The degree of exposure of the film is greater when the distance from the ribbon to the light source is decreased and is proportional to the square of the current passing through the light valve ribbon. The received current before being impressed upon the light valve is transformed into a similar current of amplitude equal to the square root of the original current. The degree of exposure of the film is therefore proportional to the picture current as received from the transmitter.

It is desirable to have the light source very close to the ribbon, in which case it may be advantageous to initially deflect the ribbon

away from the light source rather than toward it. This may be accomplished by utilizing the proper portion of the rectified received current. In this case the degree of exposure of the sensitive film is proportional to the reciprocal of the picture current as received from the transmitter. To correct for this undesired relationship the received picture currents are impressed upon a translating arrangement for obtaining a reciprocal relationship between input and output waves. This translating system is capable of use in a variety of situations in the electrical arts where it is desired to obtain a current which is the reciprocal of a given current.

The various features of the invention will be described in detail in connection with the accompanying drawings, in which similar reference characters designate corresponding parts in the several views, and in which:

Figure 1 is a diagrammatic illustration of a picture transmission system employing the electro-optical system of the invention;

Fig. 2 is a side view of the light valve employed in the electro-optical system;

Fig. 3 is a diagram for reference in connection with the description of the electro-optical system; and

Fig. 4 is a diagrammatic illustration of a picture transmission system similar to that shown in Fig. 1, employing the translating system of the invention.

The transmitting terminal shown in Fig. 1 is similar to that disclosed in Patent No. 1,667,805, May 1, 1928 of H. E. Ives. This terminal comprises a modulator 5 supplied with carrier waves, which may be of 1300 cycles frequency, from a source 6 and with picture current from a photoelectric cell 7 and picture current amplifier 8. Modulated carrier waves from the modulator 5 are impressed upon the transmission line ML through an output transformer 18 and a band filter BF₁. The photoelectric cell 7 is located within a transparent drum 9, which is driven in any suitable manner by a shaft 10. A transparency 11 of the picture to be transmitted is mounted on the drum 9. Light from a source 12 is focused by means of lens 13 upon

the transparency of the picture through an aperture in screen 14. The amount of light affecting the photoelectric cell 7 is determined by the tone value or density of the elemental area of the transparency 11 which is at that instant adjacent the aperture in the screen 14 at the focal point of the light beam. The amount of light within the photoelectric cell 7 in turn determines the amount of current which can flow from the battery 15 through the photoelectric cell 7 and resistance 16 and consequently the potential drop across the resistance 16, which potential is impressed upon the input circuit of the picture current amplifier 8. The amplified picture current is impressed upon the modulator 5 by resistance 17 simultaneously with carrier current from the source 6. Modulated carrier waves from the modulator 5 are impressed upon the transmission line ML for transmission to the distant receiving terminal.

At the receiving terminal the incoming modulated carrier waves pass through a band filter BF_2 into a translating circuit 19 of the type disclosed in a copending application of G. Crisson, Serial No. 737,415, filed September 12, 1924, having the property of producing a current the amplitude of which varies as the square root of the amplitude of the received current. The purpose of the circuit 19 will appear hereinafter. It is evident that if a current i is received from the line ML the current in the output of the translating circuit 19 may be designated

$$\sqrt{i}.$$

For convenience, in the following description, this latter current will be called I_n . The band filters at the transmitting and receiving terminals serve to pass only the picture modulated carrier current and to suppress currents of other frequencies. Among the other currents present on the transmission line ML which are suppressed by these filters, is a control current which is usually employed in systems of this general type to effect synchronization of the transmitting and recording apparatus. The apparatus for transmitting and receiving such synchronizing current forms no part of the present invention and hence is not shown in the drawing.

The output of the translating circuit 19 is coupled by means of a transformer 20 to the input circuit of a rectifier 21 whereby the current I_n is rectified and passed through a flat ribbon 22 of the light valve which forms a part of the electro-optical system. A suitable constant source of light 23 evenly illuminates a considerable area on the ribbon 22. In the center of the ribbon is a small circular opening 24 which allows the light to pass through to the lens 25 which directs it to the screen 26 having a central aperture, the beam of light at this point always being somewhat greater than the aperture in the screen. The

image of this aperture is focused by the lens 27 on the light sensitive film 28 which is wrapped around the drum 29.

The light valve includes a winding 30 mounted on the central core of a magnetic frame 31. A magnetic plate 32 connected to the frame 31, as shown in Fig. 2, provides an air gap in which the ribbon 22 is suspended. Circular apertures 33 in the magnetic frame 31 permit the passage of light from the source 23 through the optical system. In practice it is desirable to mount the light source 23 in as close proximity to the ribbon 22 as is possible. Accordingly, while for the purpose of simplifying the drawing the light source is shown outside the magnetic frame 31, it will be understood that it may be mounted conveniently inside the frame. The ribbon 22 is so mounted that its plane is parallel to the magnetic field produced by the valve winding. The rectified current in the output of the rectifier 21 may be so polarized that the ribbon will be deflected either toward or away from the light source 23 an amount which is proportional to the current, thus varying the total quantity of light falling on the film 28. In the following description of the operation of the electro-optical system of Fig. 1 it will be assumed that the rectified current in the output of the rectifier 21 is so polarized that an increase in this current will cause the ribbon 22 to be deflected toward the light source 23. Under such conditions the picture will be reproduced on the film 28 in the same form as it exists on the sending film 11. For example, if the sending film 11 is a positive the reproduced film 28 will also be a positive, and vice versa. In order to obtain this desired result it is understood that the apparatus at the transmitting terminal is so arranged that the dark condition of the photo-electric cell 7 results in the maximum amplitude of the modulated carrier wave which is to be transmitted, while the maximum light condition of the photoelectric cell results in the minimum amplitude of the modulated carrier wave.

In the diagram of Fig. 3, the diameter of the circular opening 24 in the ribbon 22 is designated h , and the axis z of the light-beam marks the radius r of the area of illumination on the lens 25. Let x represent the distance from the source of light 23 to the ribbon 22 at any instant, and let y represent the distance from the source of light to the lens 25. The light which passes through the opening 24 in the ribbon is inversely proportional to the square of the distance x . Since the lens 25 focuses the light at all times at such a point as to distribute the light uniformly over the aperture in the screen 26, the change in the intensity of the illumination of this aperture and its image upon the light sensitive film 28 will be a function of the distance x of the ribbon from the source of light 23. Assume

that $x=0$ when the current I_n is at a maximum, a decrease in I_n causing x to increase proportionately. Then x varies inversely as the current I_n , which may be expressed as

$$x = \frac{k}{I_n} \quad (1)$$

It is also apparent that

$$\frac{r}{y} = \frac{h}{2x} \quad (2)$$

$$r = \frac{yh}{2x}$$

Substituting in Equation (2) the value of x given in Equation (1),

$$r = \frac{yhI_n}{2k} \quad (3)$$

It is assumed that the beam of light from the source 23 has a constant intensity per unit area at a given cross-section of the beam, and hence the total quantity of light A_x collected by the lens 25 is a function of the cross-section, or,

$$A_x = Pr^2 \quad (4)$$

and substituting in Equation (4) for the value of r obtained in Equation (3),

$$A_x = \frac{Py^2h^2I_n^2}{4k^2} \quad (5)$$

which may also be written

$$A_x = \frac{Py^2h^2}{4k^2} \times I_n^2 \quad (6)$$

It was shown above that the current I_n in the output of the translating circuit is equal to

$$\sqrt{i}$$

i being the current received from the transmission line ML. Substituting

$$\sqrt{i}$$

for the current I_n in Equation (6),

$$A_x = \frac{Py^2h^2}{4k^2} \times i, \quad (7)$$

from which it will be seen that the total quantity of light collected by the lens 25 is proportional to the current i received from the transmission line ML. Since the density of light within the aperture in screen 26 varies in direct proportion to the amount of light transmitted from the lens 25, the total quantity of light falling on the light sensitive film 28 is likewise proportional to the current i received from the transmission line ML.

It was pointed out above that in the system of Fig. 1 the rectified current in the output of the rectifier 21 is so polarized that an increase in this current will cause the ribbon 22 to be deflected toward the light source 23, and that therefore the picture reproduced

on the film 28 will be in the same form as the picture on the sending film 11. If desired, however, the rectified current in the output of the rectifier 21 may be so polarized that an increase in this current will cause the ribbon 22 to be deflected away from the light source 23, in which case the picture reproduced on the film 28 will be the reverse of the picture on the sending film 11. This arrangement may be employed when it is desired to reproduce a positive from a negative, or vice versa. Whichever arrangement is used, however, the translating system shown in Fig. 4 may be employed to produce the reverse effect. In the system of Fig. 4 it will be assumed that the rectified current in the output of the rectifier 21 is so polarized that an increase in this current will cause the ribbon of the light valve to be deflected away from the light source. In the system shown in Fig. 1 this arrangement would result in reproducing a picture on the film 28 which would be the reverse of the picture from which transmission was effected at the transmitting terminal, that is, if the sending film 11 were a positive the receiving film 28 would be a negative. By means of the translating system shown in Fig. 4, however, an inverse effect is produced whereby the picture reproduced on the film 28 is in the same form as the picture on the sending film 11.

In the system shown in Fig. 4, the output of the translating circuit 19 is coupled by means of a transformer 34 to a balanced modulator 35 which may be of the type disclosed in Patent No. 1,449,382 to J. R. Carson, issued March 27, 1923. This modulator comprises a pair of similar space discharge tubes 36 and 37 having divided input and output circuits connected in push-pull relation. The receiving circuit also includes an oscillator 38 for producing carrier waves of the same frequency as the waves produced by oscillator 6 at the transmitting terminal, namely 1300 cycles frequency. The oscillator 38 has its output circuit coupled by means of transformer 39 to the input circuit of a space discharge tube amplifier 40. The output circuit of the amplifier 40 is connected by means of transformer 41 and potentiometer 42 to the rectifier 21 which supplies rectified current to the ribbon of the light valve. A branch circuit connected across the secondary winding of transformer 41 supplies carrier waves of 1300 cycles frequency through transformer 43 to the common branch of the input circuits of modulator 35.

The balanced output circuits of the modulator 35 are coupled by means of a transformer 44 to a gain control circuit including a high pass filter HPF which is connected by means of a resistance 45 to a space discharge tube rectifier 46. The output circuit of the rectifier 46 is connected across a resistance 47 in the input circuit of the amplifier 40.

A source of negative grid biasing potential 48 in the input circuit of the amplifier 40 is of such value that the amplifier tube 40 operates on the curved portion of the output current-grid voltage characteristic, whereby very small changes in the voltage across the resistances 47 produce large changes in the gain of the amplifier. A synchronizing circuit 49 is connected between the primary winding of transformer 34 and the oscillator 38 to maintain the output of the oscillator 38 at the same frequency and phase as the modulated waves flowing through the primary winding of the transformer 34. The translating circuit 49 may be of the type disclosed in Patent No. 1,450,966 to H. A. Affel, issued April 10, 1923.

The principle of operation of the balanced modulator 35 is well known, and need not be repeated except so far as it is considered necessary in pointing out the distinguishing features of the present invention. Following generally the analysis given in the above mentioned Carson patent, if a voltage e_1 is impressed upon the primary winding of transformer 34 and a voltage e_2 is impressed upon the primary winding of transformer 43, then the voltage e_g impressed upon the grid

of the modulator tube 36 may be expressed by the equation

$$e_g = e_1 \cos \omega t + e_2 \cos (\omega t + \theta) \quad (8)$$

and the voltage e_g impressed upon the grid of the modulator tube 37 may be expressed by the equation

$$e_g = e_1 \cos \omega t - e_2 \cos (\omega t + \theta) \quad (9)$$

The current i_1 in the upper primary winding of the output transformer 44 is represented by

$$i_1 = a + be_g + ce_g^2 \quad (10)$$

and the current i_2 in the lower primary winding of this transformer is represented by

$$i_2 = a + be_g + ce_g^2 \quad (11)$$

in which equations, a , b and c are constants depending upon the tube characteristics.

The voltage e_3 induced in the secondary winding of the transformer 44 is

$$e_3 = K_1(i_1 - i_2) = K_1b(e_g - e_g) + K_1c(e_g^2 - e_g^2) \quad (12)$$

Let $e_g = \alpha + \beta$. Then $e_g = \alpha - \beta$. Substituting these values in Equation (12).

$$\begin{aligned} e_3 &= K_1b(\alpha + \beta - \alpha + \beta) + K_1c(\alpha^2 + 2\alpha\beta + \beta^2 - \alpha^2 + 2\alpha\beta - \beta^2) \\ &= 2K_1b\beta + 4K_1c\alpha\beta \\ &= 2K_1be_2 \cos (\omega t + \theta) + 4K_1ce_1e_2 \cos \omega t \cos (\omega t + \theta) \\ &= 2K_1be_2 \cos (\omega t + \theta) + 2K_1ce_1e_2 [\cos(2\omega t + \theta) + \cos(-\theta)] \\ &= 2K_1ce_1e_2 \cos \theta + 2K_1be_2 \cos (\omega t + \theta) + 2K_1ce_1e_2 \cos (2\omega t + \theta) \end{aligned} \quad (13)$$

The voltage e_3 induced in the secondary winding of the transformer 44 thus includes a component of the signaling frequency, that is, a 1300 cycle component, and a component of twice the signaling frequency. By properly choosing the constants of the high pass filter HPF the first component may be suppressed and there is available across the input circuit of the rectifier 46 a voltage which is proportional to the instantaneous values of the voltages across transformers 34 and 43. That is, if the high pass filter HPF is given a characteristic such that the cut-off frequency is

$$\frac{\omega}{2\pi} < f_c < \frac{\omega}{\pi}$$

the voltage e_R impressed across the resistance 45 is given by

$$e_R = 2K_1ce_1e_2 \cos (2\omega t + \theta) \quad (14)$$

Since ω and θ are constant, the rectified current i_3 in the output circuit of the rectifier 46 may be expressed by the equation

$$i_3 = Se_1e_2 \quad (15)$$

A condenser 50 in the output circuit of the rectifier 46 is of such a value as to by-pass the high frequency components in the output of the rectifier. It is evident that the po-

tential impressed upon the grid of the amplifier tube 40 is a function of the rectified current i_3 . Letting $\partial F(i_3)$ represent the change in the voltage impressed upon the grid of the amplifier tube 40 for a change $\partial(i_3)$ in the rectified current, the relation between these instantaneous changes may be expressed as

$$R = \frac{\partial F(i_3)}{\partial(i_3)} \quad (16)$$

It is desirable that large changes be produced in the current I_0 in the output circuit of the amplifier 40 for relatively small changes in the rectified current i_3 . I_0 may be expressed as

$$I_0 = (\mu E_g + E_p + E)_2 \quad (17)$$

$$I_0^1 = \mu E_g + E_p + E,$$

and since E_p and E are constants,

$$I_0^1 = \mu E_g + K_2$$

$$= [f(i_3) + K_2] \quad (18)$$

$$= [C \pm g(i_3) + K_2]$$

Letting $K_2 + C = M$, it is evident that

$$I_0^1 = [M \pm g(i_3)] \quad (19)$$

$$I_0 = A \pm R(i_3) \quad (20)$$

The current i_3 flows through the resistance 47 in such a direction as to increase the nega-

tive voltage impressed upon the grid of the amplifier tube 40, and hence

$$I_o = A - RSe_1e_2 = A - K_2 I_o I_n \quad (21)$$

Since A is much greater than I_o it is evident that for practical purposes

$$I_o I_n = \frac{A}{K_2} \quad (22)$$

that is, the product of I_o and I_n is approximately equal to a constant, and hence the output current I_o is the reciprocal of the input current I_n . It follows that the output current I_o is always equal to some constant divided by the input current I_n , or in other words,

$$I_o = \frac{K_2'}{I_n} \quad (23)$$

and since the current I_n is the same as the current $\sqrt{i}$ in the output of the translating circuit 19,

$$I_o = \frac{K_3}{\sqrt{i}} \quad (24)$$

Referring again to the diagram of Fig. 3, since x is proportional to the rectified current through the ribbon 22 of the light valve, it is also proportional to the current I_o in the input circuit of the rectifier 21, that is, $x = k_2 I_o$, and hence,

$$r = \frac{yh}{2k_3 I_o} \quad (25)$$

By substituting in Equation (4) for the value of r obtained in Equation (25), the total quantity of light A_x collected by the lens 25 may be represented as

$$A_x = \frac{P_y h^2}{4k_3^2 I_o^2} \quad (26)$$

which may also be written

$$A_x = \frac{P_y h^2}{4k_3^2} \times \frac{1}{I_o^2} \quad (27)$$

It was shown in Equation (24) that

$$I_o = \frac{K_3}{\sqrt{i}}$$

Hence

$$I_o^2 = \frac{K_3^2}{i}$$

and substituting this value of I_o^2 in Equation (27),

$$A_x = \frac{P_y h^2}{4k_3^2} \times \frac{i}{K_3^2}$$

$$A_x = \left[\frac{P_y h^2}{4k_3^2 K_3^2} \right] i \quad (28)$$

from which it will be seen that the total quantity of light collected by the lens 25 is propor-

tional to the current i received from the transmission line ML.

Since, as pointed out above, the density of light within the aperture in the screen 26 varies in direct proportion to the amount of light transmitted from the lens 25, the total quantity of light falling on the light sensitive film 28 is likewise proportional to the current i received from the transmission line ML.

It will be obvious that the general principles herein disclosed may be embodied in many other organizations widely different from those illustrated without departing from the spirit of the invention as defined in the following claims.

What is claimed is:

1. In an electro-optical system, the method of obtaining signal modulated light from a steady light source which comprises passing light from said source through an aperture, and alternately increasing and decreasing the distance between said source and said aperture in accordance with signaling current.

2. In an electro-optical system, the combination with a source of light, a source of signaling energy, and a screen having an aperture therein through which light from said light source passes, of means for setting up a variable field of force in accordance with energy from said signaling energy source for varying the distance between said light source and said aperture to produce signal modulated light.

3. In an electro-optical system, means for producing an image in response to variable received current which comprises a light source, a screen having an aperture therein through which light from said source passes, and means for varying the distance between said source and said screen in response to said variable current.

4. An electro-optical system comprising a source of light, an electrically conducting element for controlling the amount of useful light from said source, means for variably energizing said element, and means cooperating with said element to cause the latter to move to and from said source in accordance with its energization.

5. An electro-optical system comprising a source of light, a vibratable electrically conducting element for controlling the amount of useful light from said source, means for passing a varying current through said element, and means for setting up a steady magnetic field to react with the field set up by said currents to cause said element to vibrate to and from said light source.

6. An electro-optical system comprising a source of light of substantially constant intensity, a light sensitive element, an electrically conducting element between said source and said light sensitive element through which varying signal current passes, and means for

setting up a magnetic field which reacts with the field of said vibratable element to cause the latter to vibrate to and from said source.

7. An electro-optical system comprising a source of light of substantially constant intensity, a light sensitive element upon which light from said source falls, a vibratable electrically conducting element having an aperture therein through which light from said source passes, means for impressing receiving varying energy upon said vibratable element, and means for setting up a field of force which reacts with a field of force set up by said vibratable element to cause the latter to move to and from said light source in accordance with the variations in said received energy.

8. In an electro-optical system, means for obtaining modulated light which comprises an element having an aperture through which light passes from a stationary source and adapted to vibrate in the direction of transmission of the light, and means for impressing variable unidirectional energy upon said element to cause said element to vibrate.

9. An electro-optical system comprising a source of signaling current, and an optical means actuated by signaling current from said source for producing light, the instantaneous effective value of which is proportional to the reciprocal of the square of the actuating current.

10. In a signaling system, means for producing signaling current, and means for producing current therefrom which is proportional to the reciprocal of a root of said first current.

11. A signaling system comprising means for producing signaling current, means for producing therefrom a second current, the instantaneous value of which is a root of said first current, and means for producing therefrom a third current which is proportional to the reciprocal of said second current.

12. In a signaling system, means for producing a modulated carrier current, means for

producing therefrom a second modulated carrier current of the same carrier frequency, said second current being proportional to the reciprocal of the square root of said first current, and a receiving device controlled by said second current.

13. In a signaling system, means for producing a signal modulated carrier wave, and means for producing therefrom a second modulated carrier wave which is always proportional to the reciprocal of said first carrier wave.

14. An electro-optical system comprising means at the transmitter for scanning an object or image, means for producing a carrier current the amplitude of which varies directly as the tone value of the elemental areas of the scanned object or image, means for producing from said current a second current the instantaneous value of which is equal to the square root of said first current, means for producing from said second current a third modulated carrier current of the same carrier frequency as said second current and which is proportional to the reciprocal thereof, and an optical reproducing system controlled by said third current.

15. In an electro-optical system, the method of obtaining signal modulated light from a steady light source which comprises passing light from said source through a clear aperture, and alternately increasing and decreasing the distance between said source and said aperture in accordance with signaling current.

16. In an electro-optical system, the combination with a source of light and a screen having a clear aperture therein through which light from said source passes, of means for setting up electrostatically a variable field of force for varying the distance between said light source and said aperture.

In testimony whereof I have signed my name to this specification this 3rd day of February 1927.

LEONARD G. ABRAHAM.