June 23, 1936. J. P. SMITH 2,045,315

TELEVISION SYSTEM

Filed May 23, 1932 2 Sheets-Sheet 1

Fig. 1

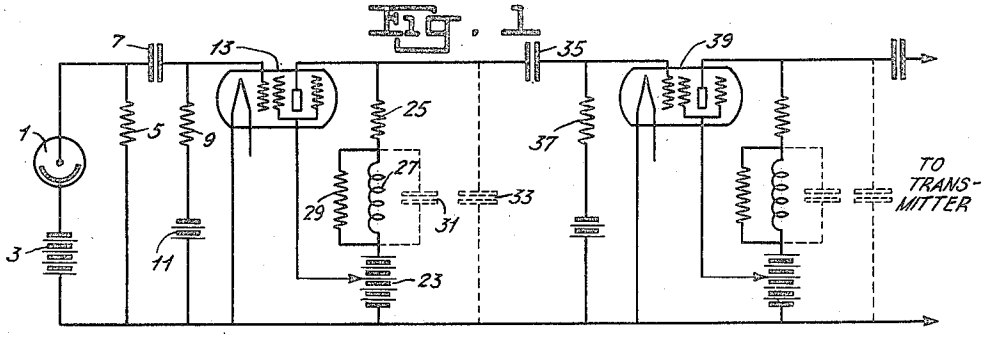


Fig. 2

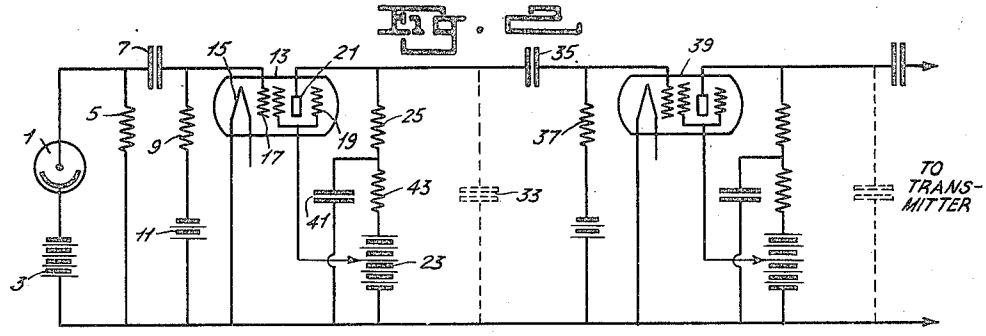


Fig. 3

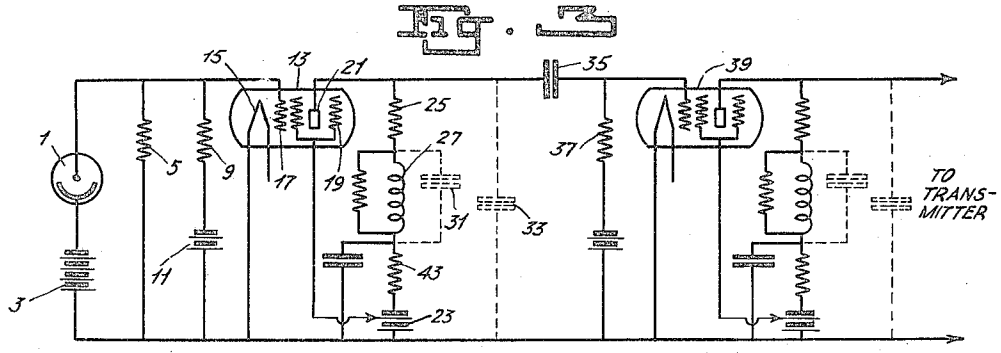


Fig. 4

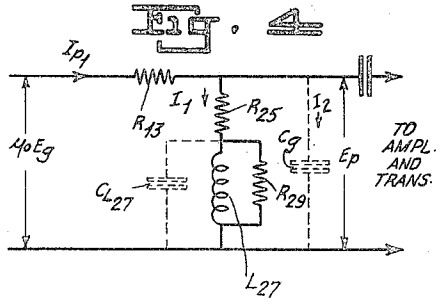
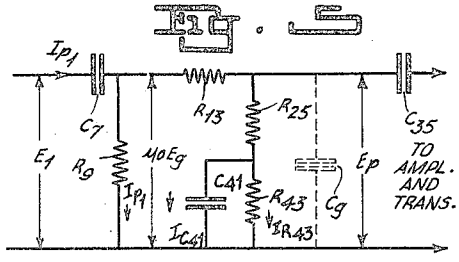


Fig. 5



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Fig. 6

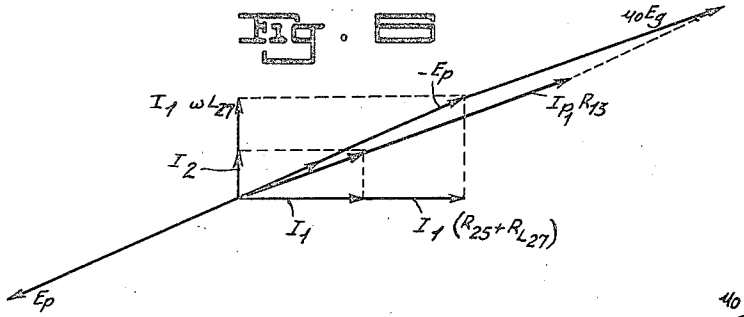


Fig. 7

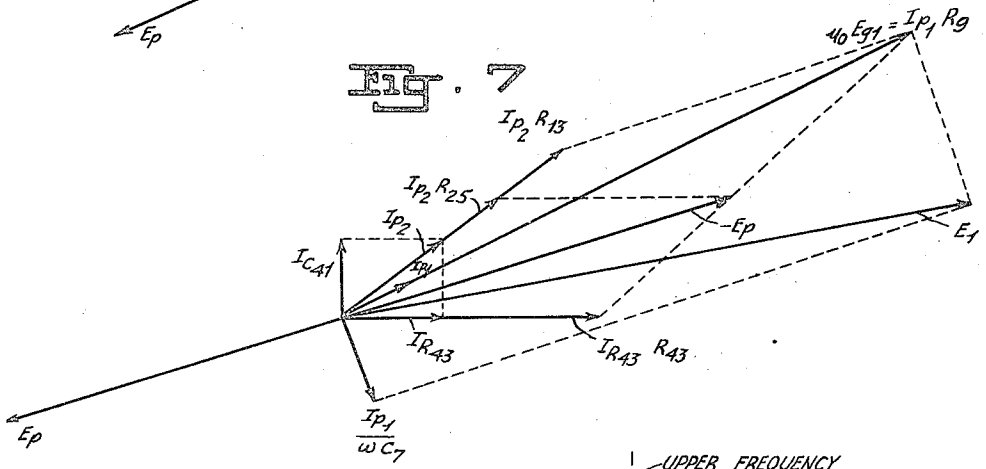


Fig. 8

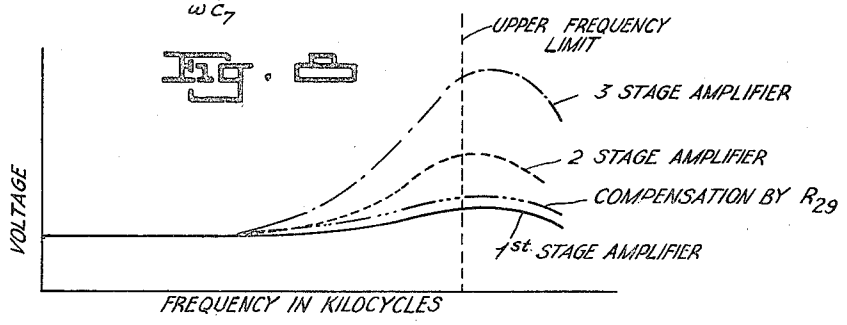
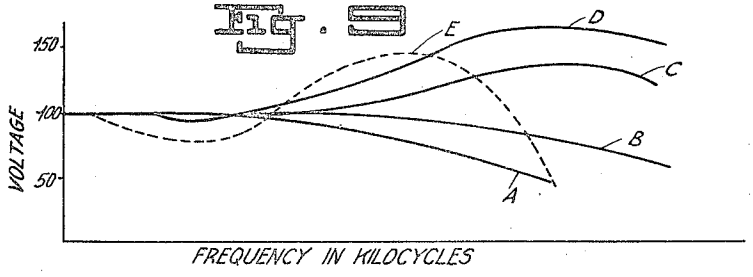


Fig. 9



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UNITED STATES PATENT OFFICE

2,045,315

TELEVISION SYSTEM

John Paul Smith, Erlton, N. J., assignor to Radio Corporation of America, a corporation of Delaware

Application May 23, 1932, Serial No. 612,913

5 Claims. (Cl. 179—171)

The present invention relates to television systems, and, particularly, to the circuits used to amplify the photoelectric currents produced from different values of light and shadow on a record subject of which an image is to be produced at various points of reception.

In television apparatus, when images of various subjects are to be transmitted so as to be viewed at various points of reception, light values on the subject influence or activate, either directly or indirectly, one or more light sensitive elements in such manner as to cause photoelectric currents to flow therefrom. The light sensitive elements are influenced in such manner that the instantaneous current output from the light sensitive photoelectric element is a current which is proportional to the intensity of light and shadow on different elemental areas of the subject. Thus, as the elemental areas of the subject are explored by a suitable scanning device the light coming to act upon the light sensitive elements may vary continuously to cause continuously varied output current providing there are continuous changes in the intensity of the subject over each elemental area, as would be the case if the subject were represented by a checker-board where each square of the checker-board were of small enough size to represent a single elemental area. For other types of scanned subjects, however, the rate at which the current output from the photoelectric element varies is similarly proportional to the rate of changing intensity on the subject. It is seen that the greater the rate of change of current output from the photo cell the higher the frequency developed, and the slower the change in current output from the photo cell the lower the frequency developed.

It has been found in the prior art that amplifying systems for amplifying these photoelectric currents resulting from an exploration of the subject of which an image is to be desired do not follow faithfully a linear response for all frequencies but at both the higher and lower frequencies there is produced within the amplifier attenuations and phase shifts which are sufficient to distort or spoil the quality of the picture resulting at the points of reception. That this is so can be seen from the fact that if for a certain time period the amplitude at some frequency is low, there will be light values of one intensity produced, and if the frequency then changes suddenly to a value giving normal amplitude there will be produced at the receiving points light values which are not truly representative of the proper intensity which is to be portrayed. Likewise, if certain frequencies generated in the photo cell circuit are amplified, so that some frequencies arrive in certain phase relations to other frequencies different from the relations before amplification, there will be produced at the receiving points light values which are not truly representative of the proper intensity which is to be portrayed.

It is, therefore, an object of the present invention to provide an amplifying system for amplifying photoelectric currents for transmitting picture or television signals in which the response may be what is known as "flat" or substantially flat throughout any selected frequency range.

A further object of my invention is to provide a system for compensating for high and low frequency attenuation and phase shift in amplifiers for photoelectric currents particularly adapted to television where the frequencies which must be passed by the amplifier may vary from twenty-four cycles per second (this being assumed to be the repetition frequency of the subject of which an image is transmitted) up to as many as five hundred thousand cycles per second, or even greater.

Other objects of the invention are to provide an amplifying system for amplifying photoelectric currents in which the resulting signals will represent more accurately the light and shadow values on successive elemental areas of a subject which is being scanned or analyzed.

Further objects of the invention are to provide for the above outlined improved quality of transmission while avoiding extensive changes in existing transmitter amplifier circuits.

Other objects of the invention are to provide ways and means by which improved response characteristics may be obtained from a photo cell amplifier at both high and extremely low frequencies.

Still other objects of the invention are to provide an improved picture signal amplifying system which is simple in its construction and arrangement, efficient in its operation, easy to install, and which can be applied for the most part to present existing types of apparatus used for television and picture work.

Still other and further objects and advantages of the invention will be appreciated and become apparent from a reading of the following specification and claims in connection with the accompanying drawings, wherein:

Fig. 1 represents a portion of a photo cell amplifier circuit provided with compensation for improving the response at high frequencies;

Fig. 2 illustrates a portion of a photo cell amplifier circuit with provisions by which the response at extremely low frequencies may be improved;

Fig. 3 illustrates a preferred form of my invention applied to a photo cell amplifier circuit wherein the arrangement of Figs. 1 and 2 have been combined;

Fig. 4 illustrates conventionally a circuit which is substantially the equivalent of one stage of the amplifier arrangement shown by Fig. 1;

Fig. 5 illustrates conventionally a circuit which is substantially the equivalent of one stage of the amplifier arrangement shown by Fig. 2;

Fig. 6 illustrates graphically the phase relationship between the impressed and output voltages from any single stage of the amplifier circuit arrangement shown by Fig. 1;

Fig. 7 illustrates graphically the phase relationship between input and output voltages from a single stage of the amplifier system shown, for example, by Fig. 2;

Fig. 8 illustrates graphically the manner in which the means provided in the arrangement of Fig. 1 functions to prevent the amplifier stages from becoming unstable and particularly responsive to high frequency noises; and,

Fig. 9 shows graphically the effect on amplitude response with frequency of an amplifier compensated by means of inductances.

To refer now to the drawings, and first to Fig. 1 thereof, a system which is particularly adapted to increase the amplifier gain at high frequencies and minimize phase shift has been illustrated. Fluctuating light values, as determined by any suitable type of scanning, are adapted to influence any suitable form of light translating element, such as the photo cell 1 supplied with operating voltages from a voltage source 3, to produce resulting output currents therefrom which appear as voltages across the resistor 5. The photo cell 1 may be of any desired type, such as the present known caesium or potassium-hydride cell, and the scanning by which light values representative of different successive elemental areas of the subject may be caused to influence the photo cell may be any known type of scanning, such as that illustrated, for example, by the Bell System Technical Journal for October, 1927, pages 561 and 562, showing both direct and indirect scanning, or the scanning may be from a film and take place according to the arrangement shown by patent to Theodore A. Smith, #1,797,378, granted March 24, 1931, or, where purely electrical methods are to be utilized for scanning, the scanning operation may take place, for example, in accordance with the teachings of any of the following copending applications of V. K. Zworykin, Serial #683,337, filed December 29, 1923; Serial #448,834, filed May 1, 1930; Serial #468,610, filed July 17, 1930.

Such forms of scanning as have been above suggested are merely intended to serve as illustrative examples of systems which are suitable for association with any desired type of photo cell amplifier for television signals, and it is, therefore, to be understood that the amplifier arrangement to be hereinafter disclosed is not in any way intended to be limited to use with the particular types of scanning systems suggested, although from the above enumerated examples it will be apparent that the amplifier system shown is adapted equally well for use with either mechanical or electrical types of scanning apparatus.

As signals appear across resistor 5, and which vary in accordance with the varying intensities of light and shadow influencing the photo cell 1, they are transferred through the capacity coupling 7 to the grid electrodes 17 of the amplifier tube 13 which is provided with a suitable grid resistor 9 and a source of biasing potential 11. The filament or cathode 15 may be heated directly or indirectly in any suitable and desired manner. As signals are impressed across the grid cathode members 17 and 15 of the vacuum tube amplifier 13 they appear in amplified form in the output circuit of this tube which includes the plate electrode 21 supplied with voltage from a suitable source 23. The screen grid element 19 is also supplied with a suitable voltage from the same potential source 23. In this disclosure, each tube is shown as being supplied with a separate source of plate and screen voltage as well as separate biasing batteries for the grids, but this has been shown merely for convenience and it is intended that a single power supply shall be provided for all tubes.

It is a well known fact that the gain in any amplifier is substantially a function of the plate circuit impedance up to a predetermined limiting value. Therefore, in the plate circuit of the amplifier 13 there has been included a resistor 25 and series inductance element 27 connected between the plate electrode 21 and the source of plate potential 23. The inductance element 27 is preferably placed on the battery side of the resistor 25 so that the capacity effect between the inductance and ground, which is represented conventionally by the imaginary capacity element 31, will be minimized. The circuit arrangement shown by Fig. 1 is represented in schematic form by the arrangement of Fig. 4 and it will be seen, by referring to this figure, that the voltage appearing across the cathode and grid electrodes 15 and 17 of the tube 13 is represented by $\mu_0 E_g$, the current being supplied by the photo cell 1, or, if the arrangement of Fig. 4 be intended to represent an amplification stage beyond the tube 13, the current output from the preceding stage is represented as I_{p1}. The internal resistance of the tube 13, or any other tube of the cascade, is represented by the resistor R_{13} and the plate resistor 25 is represented by R_{25} with the inductance element 27 represented by L_{27}. The current through R_{25} and L_{27} is represented as I_1. As is shown by Fig. 1, the inductance 27 is shunted by a resistor 29 which is of high ohmic value so as to maintain the desired effect of the inductance 27 in the tube plate circuit except at very high frequencies, as will be apparent from the discussion to follow. The distributed capacity of the inductance 27 to ground is represented conventionally by the dotted capacity C_{L27}. The capacity to ground of the entire system is represented by the capacity 33 on Fig. 1 and the capacity C_g on Fig. 4, and the current through this capacity by I_2. The plate voltage in the output circuit of the amplifier 13 is conventionally shown as E_p on Fig. 4.

If now the arrangement of Fig. 4 is to be considered and a graphical analysis is to be made of the entire system, it will be appreciated that the difficulty with previously existing types of photo amplifier circuits has been that it was impossible to cause a phase shift of one hundred and eighty degrees of the output voltage with respect to the input voltage at all frequencies, which must be done to obtain substantially perfect reproduction of the image signals. In mak-

ing this statement it is, however, appreciated that if a phase shift can be made proportional to the frequency, then it is immaterial, so far as the effect of distortion is concerned, whether the phase shift be one hundred and eighty degrees or some other angle, it then being merely the proportionality factor which is to be considered. However, the subject matter of the present case is related primarily to a device in which the phase shift is substantially one hundred and eighty degrees in each stage of the amplifier.

Now referring again to the inductance shown by Fig. 4, and also to the circuit arrangement of Fig. 1, it will be appreciated that at the higher frequencies the reactance of the inductance **27** becomes appreciable and this causes the external plate circuit impedance to increase and the gain per stage to increase. If now the value of the inductance **27** is chosen of such value that with its own distributed capacity resonance is not reached within the working band of frequencies, it can be seen that the response of the amplifier tends to become more even throughout a wide band of frequencies. The effect of the inductances in increasing the gain at any given frequency is determined by the amount of resistance in series therewith. If now there is a given shunt capacity, or capacity from the high side of the circuit to ground, represented by the capacity **33** or C_g, there is a certain maximum value of resistance that when used in series with an inductance with a resonant frequency out of the working range will allow a flat amplitude characteristic. Lower values of resistance with the same inductance will cause the amplifier to be "peaked" at the higher frequencies. The effect of the inductance with regard to the phase shift is to produce a phase shift that is opposite in direction to that caused by the capacity to ground. The resistance **29** shown as shunting the inductance **27** only becomes effective at extremely high frequencies and then tends to minimize the effect of the inductance **27**. This can be seen from Fig. 8 where, if there are a plurality of stages of the amplifier arrangement shown by Figs. 1 and 2, the system will tend to become unstable and oscillate at the extremely high frequencies and, therefore, especially sensitive to high frequency noise, so that, it can be seen from the curve designated as "Compensation by R_{29}" in Fig. 8, the extremely high voltage output on the very high frequencies will be substantially avoided by the effect of the resistor **29** in parallel with the compensating inductance.

To refer now to Fig. 6, a graphical analysis of the arrangement has been shown wherein I_2 represents the current through the capacity to ground and I_1 the current through the resistance R_{25} and the inductance **27**, which together produce a resulting plate current from the amplifier **13** represented as I_{p1}. R_{L27} represents the ohmic resistance of the inductance L_{27}. The voltage drop $-E_{p1}$ produced through the entire output circuit including the resistor **25** is represented by the vectorial sum of $I_1(R_{25}+R_{L27})$ and the voltage drop across the inductance component of L_{27}, which is $I_1\omega L_{27}$. This voltage $-E_p$, if reversed or moved through an angle of one hundred and eighty degrees, may be represented by the vector E_p. The internal voltage drop in the tube **13** is represented by the vector $I_{p1}R_{13}$ which is in phase with the vector I_{p1}, and this value vectorially added to the vector E_p will produce, it is seen, the vector $\mu_0 E_g$, which represents the input voltage and is seen to be substantially one hundred and eighty degrees out of phase with the resulting output voltage, which is the condition sought to be obtained.

In plotting the vectors shown by Fig. 6, since the inductance **27** is provided by a small coil and is, therefore, very small, the distributed capacity is also small and is, therefore, neglected in the diagrams, and since the resistor **29** represented as R_{29} on Fig. 4 takes effect outside of the frequency band utilized, as can be seen from Fig. 8, this resistor is not considered in the vector diagrams. Also, at the low frequencies, the impedance of the inductance **27** is very small as compared to the resistance **25**, and, therefore, the gain at the low frequency, with the arrangement shown by Fig. 1, is substantially the same as any other amplifier where the amplification

$$(\mu)=\mu o\,\frac{\text{External resistance}}{\text{Internal}+\text{external resistance}}$$

and, according to formulae which can be derived easily, the gain in the system herein disclosed at the high frequencies may be represented as

$$\mu=\mu o\,\frac{1}{1+R_p\left[\dfrac{1-\omega^2 L_{27}C_g+j\omega C_g(R_{25}+R_{L27})}{(R_{25}+R_{L27})+j\omega L_{27}}\right]}$$

When using the compensating arrangement disclosed by Fig. 1, it should be remembered that although the resonant frequencies of the inductance **27**, due to distributed capacity, are made to fall outside the working range of frequencies, the resonant peaks may be multiplied with several stages of amplification until the amplifier breaks into oscillation at this high frequency, and it is to offset this condition that the inductances, such as the inductance **27**, of the various amplifier stages are paralleled or shunted by the resistors **29** which are of sufficient resistive value to prevent the inductive reactance of the coil from being effective beyond the desired working range of frequencies. The resistor thus prevents the impedance of the coils from rising to abnormally high values at frequencies higher than the working range.

In providing for several stages of amplification, the output voltage from the tube **13**, such as is shown by Fig. 1, is directed through a capacity coupling **35** to the input circuit of the tube **39** which has included in its output circuit a compensating inductance and shunt resistor, both in series with the usual plate resistor and connected in substantially the same manner as above described in connection with the first amplifier stage. This amplifier may then have its output energy coupled to any suitable form of modulator wherein the amplified signals are adapted to modulate the carrier frequency for transmission by radio or, with suitably designed transmitting networks, by wire line transmission.

The curves shown by Fig. 9 illustrate the effect on amplitude response with the frequency of the amplifier compensated by means of the inductances such as have been above described in connection with Figs. 1, 4 and 6. From the curves of Fig. 9, it can be seen that the curve A shows the response of an amplifier with no compensation for the high frequencies and indicates a falling off in response at the higher frequencies; curve B shows the compensation of an amount sufficient to make the amplifier characteristic approximately flat within the desired frequency working range; curve C shows a degree of over-compensation; curve D shows a higher degree of over-compensation or, what is known in

the art as, "peaking"; and curve E, which is dotted, shows the effect of using too high a value of resistance in series with inductance of a higher value than for the other curves of the series.

Now, to refer to a system for compensating for the attenuation and phase shift at the lower frequencies, which are due primarily to the coupling circuits, such as the capacity coupling provided by the capacity elements 7, 35, etc. The circuit arrangement shown by Fig. 2, and exemplified in a schematic representation for the particular type of circuit for a single stage of the amplifier in Fig. 5, is somewhat like the conventional amplifier circuit with the added feature of capacity resistance networks in series with the external plate resistors for the purpose of increasing the gain from the amplifier system at the lowest frequencies at which it may be desirable to make the system responsive.

By referring to Figs. 2 and 5, it will be seen that the circuit arrangement for low frequency compensation is in many respects quite similar to that for high frequency compensation except for the fact that the inductance 27 has been replaced by a capacity 41 which connects from the end of the plate resistor 25 nearest the source of plate potential to the lowest voltage point in the circuit, and shunting this capacity and in series with the plate voltage supply there is a resistor such as has been shown by 43. The values of the capacities 41, provided for each stage of the amplifier, are so chosen with respect to the values of the resistors 43 that at the frequency where the reactances of the capacities 7 and 35, for example, become high enough to cause attenuation these reactances, represented on Fig. 5 as C_{41}, begin to increase, and increase the gain of the amplifier at this particular frequency. The phase relations of the various currents and voltages for the type of circuit arrangement shown by Figs. 2 and 5 is graphically illustrated by the vector diagram of Fig. 7, wherein it is seen that as the reactance of the capacity C_7 becomes appreciable, the input voltage on the grid of the tube 13 begins to lead the voltage supplied from the photo cell and designated on Fig. 5 as E_1, or the voltage from the preceding stage impressed upon the coupling circuit. At the same time, the plate voltage represented as E_p begins to lag behind the voltage impressed upon the grid of the amplifier tube by means of the compensating arrangement provided by the condenser combination 41 so that the input voltage across the coupling circuit continues to remain substantially one hundred and eighty degrees out of phase with the plate voltage from the amplifier tube.

By means of the compensation system just described for the low frequency end of the spectrum, which applies, for example, to frequencies below one hundred cycles per second, the amplifier system may be made to respond to frequencies which are much lower than it would otherwise be able to handle without appreciable phase shift, and in compensating for the low frequency phase shift it should be understood that this is, in general, even slightly more important than the compensation for the high frequency phase shift because the low frequency shift is, for the most part, more detrimental to the received television picture.

In the circuit diagram, shown for two stages of amplification by Fig. 3, I have provided an arrangement wherein the two stages of amplification shown are arranged so as to provide for compensation at both the extremely low and the extremely high frequencies. This circuit provides all of the advantages of both the circuits of Figs. 1 and 2, since at the very low frequencies the inductance 27 acts purely as a resistance in series with the resistor 25 forming the plate resistor of each amplification stage, and the capacity arrangement 41 is then adapted to compensate for the capacity coupling, whereas, at the higher frequencies, the inductance 27 provides increased impedance in the plate circuit of the tubes 13, 39, etc. to provide for compensation and, at this time, the capacity elements 43 have no substantial effect upon the operation of the circuit, since there is no need for compensating for the reactance of the coupling condensers. It is in this form that the invention is particularly useful for television image transmissions.

From the above description it will be quite apparent that many modifications and changes may be made without departing from the spirit and scope of the invention, and I, therefore, believe myself to be entitled to make and use any and all changes in this invention which make use of inductance, capacity or resistance elements, or the equivalent, in the output circuit of an amplifier system for the purpose of compensating in the output circuit for changes in the input circuit causing attenuation or phase shift at either low, intermediate, or high frequencies of the impressed picture signals so as to provide for more faithful and accurate reproduction of the television image signals.

Having now described my invention, what I claim and desire to secure by Letters Patent is the following:

1. A circuit arrangement for compensating for phase shift and attenuation in signal transmission which comprises an amplifier, a resistor connected in the output circuit of the amplifier, and an impedance comprising a parallel combination of inductance and resistance elements and a parallel combination of capacity and resistance elements also in series with the output resistor and the parallel combination of inductance and resistance elements for compensating both for high and low frequency attenuation and phase shift of the amplifier output voltage relative to the input voltage.

2. An amplifying system comprising a source of input frequency varying arbitrarily from extremely low to extremely high frequency, an amplifier, a resistor in the output circuit of said amplifier, a parallel combination of an inductive impedance and a shunting resistor in series with the output resistor for compensating for phase shift and attenuation due to high frequency impressed signals, and a parallel combination of a capacitive reactance and a shunting resistor in series with the high frequency compensating means for compensating for low frequency phase shift and attenuation whereby the response characteristic of the amplifier is substantially uniform over a wide range of frequencies.

3. A circuit arrangement for compensating for phase shift and attenuation in signal transmission which comprises an amplifier, a resistive impedance forming a part of the output circuit of the amplifier, and capacitive and inductive impedance elements in series with each other and with the output resistive impedance for compensating both for high and low frequency attenuation and phase shift.

4. An amplifier system comprising a source of input frequency varying arbitrarily from a fre-

quency of at least as low as 60 cycles per second to a frequency at least as high as 500,000 cycles per second, an amplifier, a resistor in the output circuit of said amplifier and a parallel combination of two impedance elements only, said impedance elements being an inductive impedance and a shunt resistor, said parallel combination being in series with said output resistor, said shunt resistor and said inductive impedance having their impedance values so related as to compensate for phase shift and attenuation of the output voltage due to high frequency impressed voltage.

5. An amplifying system comprising a source of input frequency varying arbitrarily from a frequency at least as low as 60 cycles to a frequency at least as high as 500,000 cycles, an amplifier and resistor in the output circuit of said amplifier and a compensating circuit comprising a parallel combination of two impedance elements only, said impedance elements being a capacity reactance and a shunt resistor, said parallel combination being in series with said output resistor, said shunt resistor and said shunt capacity reactance having their values so related as to compensate for phase shift and attenuation of the output voltage due to low frequency impressed energy.

JOHN PAUL SMITH.