July 6, 1948. K. SCHLESINGER 2,444,854

TELEVISION AMPLIFIER

Filed June 12, 1946 2 Sheets-Sheet 1

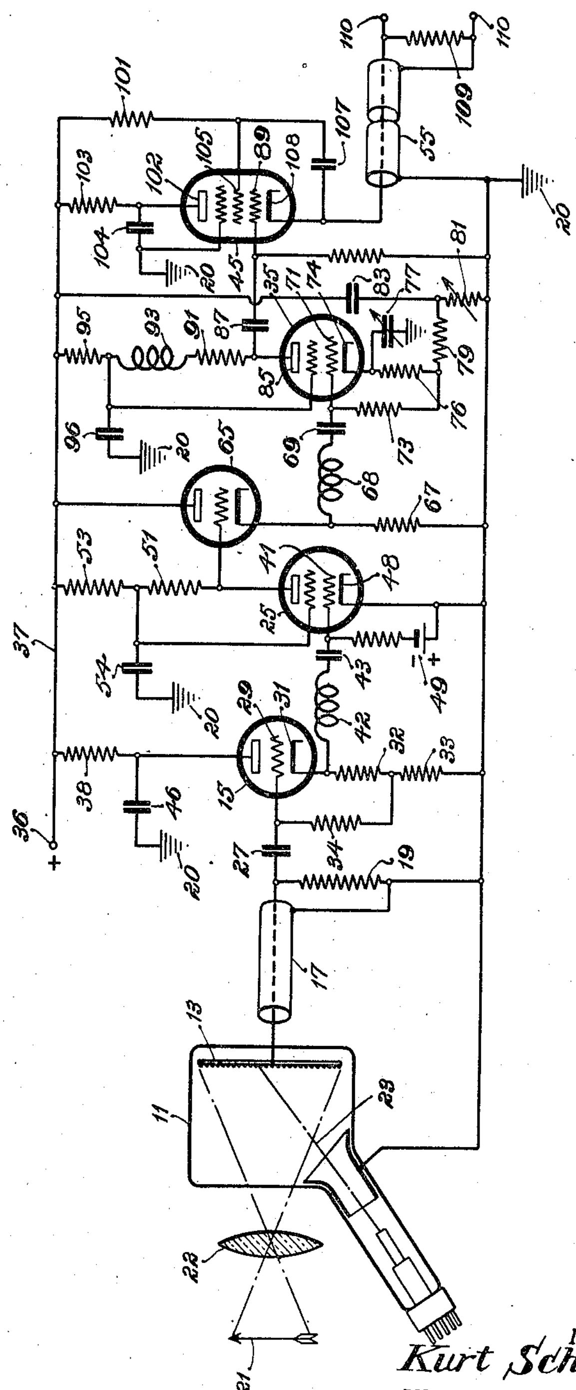

Fig. 1.

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Fig. 2

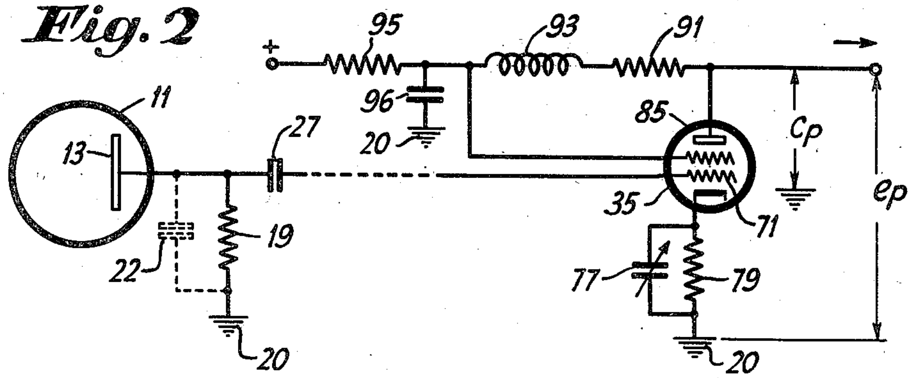


Fig. 3

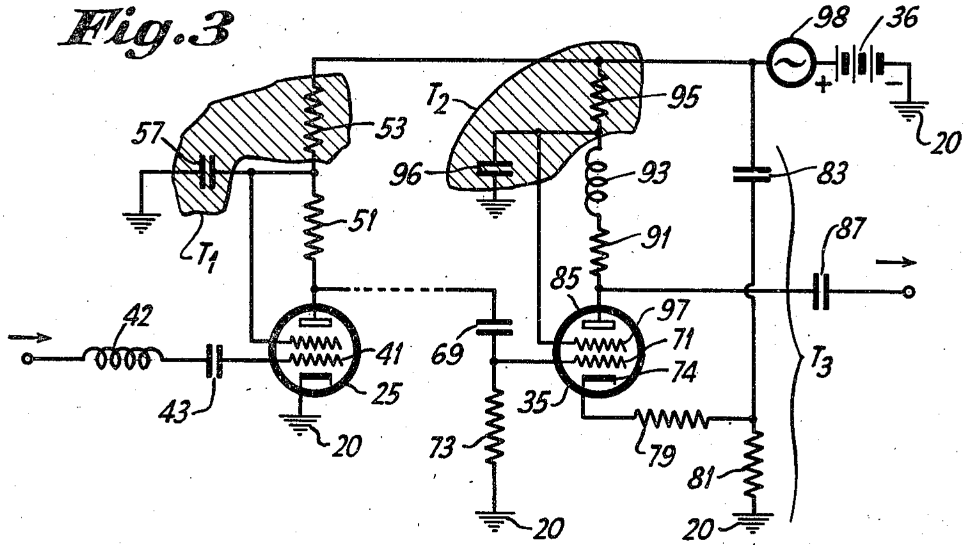
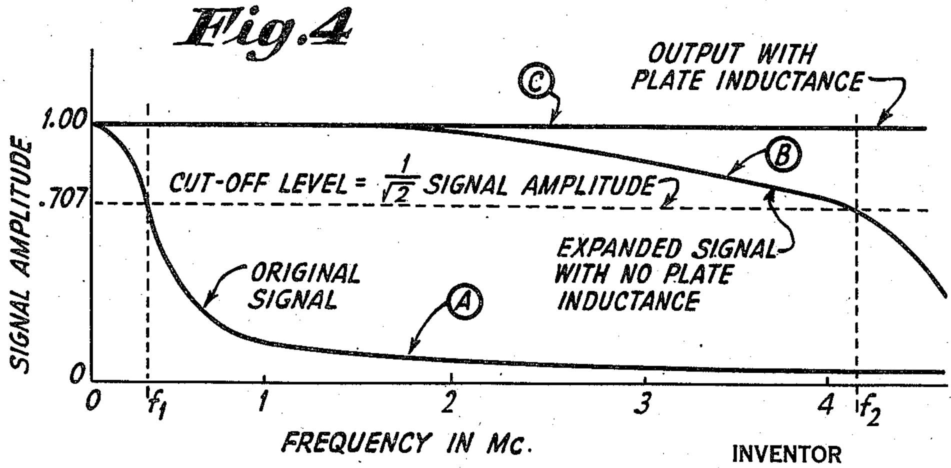


Fig. 4



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UNITED STATES PATENT OFFICE

2,444,854

TELEVISION AMPLIFIER

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Application June 12, 1946, Serial No. 676,190

5 Claims. (Cl. 179—171)

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This invention is a continuation-in-part of my copending application for Letters Patent of the United States, Serial No. 488,609, filed May 26, 1943, now abandoned, and it relates to television amplifiers. In general, it is particularly concerned with that portion of the television amplifier system which is to derive its input energy from a suitable television scanning or camera tube whereby the signal energy resulting from scanning in the camera or scanning tube is converted into an amplified train of video signalling energy wherein the amplification level is held at least uniform throughout the wide frequency band of the impressed signal energy.

In television apparatus the video signals which are to be transmitted may be developed from any sort of a signal source, which might be very broadly characterized as being of the so-called "constant-current" variety. Signal sources of these general types are disclosed in the book entitled "Principles of Television Engineering" by D. G. Fink, published by McGraw-Hill Book Co., Inc., New York, in 1940, where, particularly in the portion of that book between pages 81 and 117, various forms of scanning systems and television video signal sources are set forth. These forms include, among others, photocells (phototubes) operating in combination with scanning discs or the equivalent, image dissector tubes or without electron multipliers, and storage types of scanning tubes, such as those conventionally known in the art as "Iconoscopes," "Image Iconoscopes," "Orthicons," and "Image Orthicons," these last two types of storage tubes being used with or without electron multiplication. Still further, the signal source may be of the types commonly known in the art as the "monoscopes," the phase-majectors, the monotron, or the like.

In any case, in an arrangement of the type herein to be described, the output from the instrumentality which produces the video signal is loaded by a resistor which is normally of a relatively high value such that there results, in combination with the natural and stray capacitances, an input resistance-condenser combination supplying signals to the signal amplifier where the resistance-capacity combination has a time constant which is greater than that of the duration of the shortest signal which occurs. This means that the higher frequency video signals (that is, those signals which produce the sharpest picture delineation or detail) are attenuated. The apparatus and circuit herein to be described is concerned with overcoming the high frequency drop or attenuation of the input signal which

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would otherwise occur with increasing frequency.

While, as above explained, many and various forms of signal sources may be used to supply the input video or picture signals, this application and disclosure will refer to one general form of such types of signal sources and, accordingly, from purely an illustrative viewpoint, it will be assumed that the television camera or scanning tube or signal source is of the electronic variety and also the "storage" type for the purpose of providing some intensification at least of the output signal resulting from scanning.

In a television system of such an electronic type, an optical image of any character is cast and focused upon a light sensitive electrode member or surface within the scanning or camera tube. The electrode member used to receive such an optical image is commonly referred to as the "mosaic" element of the tube, although, in some instances, it may be termed the image receiving target or plane. This mosaic element usually comprises a conductive area, known generally as the signal plate, which supports an insulating element or dielectric upon which minute, isolated droplets or particles of light sensitive or photoelectrically active material are coated. Thus, the photosensitive particles each form one element of a condenser with a common dielectric for all condensers and a common second element, which is the conducting plate. In this way, an optical image cast upon the light sensitive elements produces charges across the mosaic, with the charges at different areas being proportional to the brilliance of the impinging optical image. The charges are sequentially neutralized and released as video signalling energy to an external circuit by means of a scanning beam or cathode ray beam which is suitably deflected and caused appropriately to traverse the mosaic element by element and line by line a predetermined number of times per second.

Purely for more specific illustrative purposes, reference herein will be made to one of the forms of storage type canning tubes which may be used for such purposes, which tube has become known in the art as the "Orthicon," and which has been described in some detail on pages 111 et seq. of the above mentioned book entitled "Principles of Television Engineering." For the purpose of this invention and its description, reference may be made also to the group of papers published by Messrs. Iams and Rose concerning a scanning tube of this variety, which papers are referred to as a footnote on page 111 of the above named Fink publication.

In the translation of the signals in such a scanning or camera tube, they are first amplified in an amplifying unit known as the "pre-amplifier," in that it derives its input signal energy directly from the scanning tube and delivers its output energy, under most circumstances, to energize the control and line amplifiers by way of a relatively low impedance coaxial cable. The text above named also discusses generally the pre-amplifier of a television system in that portion which begins on page 392 thereof and which continues on page 396 to describe the transfer of the pre-amplifier output to a coaxial cable which is terminated in an extremely low resistance or impedance to energize the remaining amplifiers of this system.

It, accordingly, becomes one of the objects of the present invention to provide an amplifier circuit for use with television apparatus wherein the signal output from an appropriate scanning system or camera tube is amplified to be delivered to an output circuit with substantially uniform response over a very wide band of frequencies generated, which, in the present apparatus, may be frequencies covering a frequency band of the order of four to six megacycles and higher, for example.

A further object of the invention is that of providing an amplifier which is particularly usable in connection with a signal source where there is a high impedance signal input with falling or drooping frequency response.

Still a further object of the invention is that of providing a television amplifier wherein losses inherent in the signal source shall be compensated by providing an amplifier response wherein the amplifier gain shall rise with increase in frequency of input in a characteristic manner.

Other objects of the invention are those of providing a television amplifier whose output can readily be made to match the low impedance of concentric cable customarily used to connect the output of the pre-amplifier to the control, mixing or line amplifier and, at the same time, the invention has as an object that of providing an amplifier which will develop a reasonably high signal voltage across the very low characteristic impedance of such a connecting cable.

Further than this, the present invention has as another of its main objects, that of providing a pre-amplifier system wherein the "hum" level shall be so low as to be of but a negligible portion of the total output signal.

Other objects and advantages of the invention are those of overcoming one or more known defects of prior art systems and to improve upon the prior art systems by providing an amplifier of improved efficiency and ease of adjustment during operation while, at the same time, reducing the number of component parts and the complexities of the circuit to a minimum.

Other objects and advantages of the invention will become apparent and at once suggest themselves to those skilled in the art to which the invention is directed when the following specification is considered together with the accompanying drawings, wherein,

Fig. 1 is a schematic illustration of one form of the complete circuit;

Each of Figs. 2 and 3 is a schematic illustration of certain portions of the circuit of Fig. 1 to explain more readily its operation; and,

Fig. 4 is a series of curves to indicate the response of the system to be described herein for different conditions of operation.

If reference is now made to the drawings for a further understanding of this invention, it will be seen, by a consideration of Fig. 1, that the scanning or camera tube 11 is arranged to supply its output signal into a group of tubes which can readily be divided into four separate classifications of which the first tube 15 of the sequence may be considered as the camera matching input tube. This tube is arranged to receive its input signal from the camera or scanning tube 11 and to feed its output energy to a voltage amplifier tube 25 which, in turn, energizes an equalizer and hum compensator tube 35 which supplies its output energy to the final cable matching tube 45. The tube 45 supplies its energy to a suitable load circuit which is represented by the coaxial cable section schematically shown at 55.

For the purpose of coupling the voltage amplifier tube 25 to the equalizer and hum compensator tube 35, there is included a suitable coupling tube 65 which derives its input energy directly from the output of the voltage amplifier 25 and delivers its output as a cathode coupled element to the input circuit of the equalizer and hum compensator tube 35.

Referring now more particularly to the circuit herein disclosed, it will be assumed, for reference purposes, that the scanning or camera tube 11 is in the nature of the "Orthicon" tube, hereinabove mentioned and described in the Fink publication, as well as in the mentioned articles by Iams and Rose. To this end, it is usually customary to have the signal plate or mosaic electrode 13 of the scanning or camera tube 11 connected to ground 20 (or at least held at substantially cathode potential of the camera tube), which may be provided through the coaxial load cable 17 and the load resistor 19.

For the formation and development of signals from the "Orthicon" or other form of camera tube (represented in purely schematic form in Fig. 1 by the tube 11) an optical image of a subject 21 is directed upon the mosaic element 13 by way of a conventionally represented optical system 22. The mosaic or signal plate 13 of the camera tube 11 is then scanned by a scanning beam, conventionally shown at 23, which is subjected to the influence of suitable deflecting fields (not represented), so that trains of video signals are supplied to the coaxial cable 17 and, when so connected, produce a voltage drop across resistor 19. In the design of the apparatus and circuit herein described, the resistor element 19 is usually chosen between ten and thirty times as large as would be compatible with faithfully high frequency transmission. This selection is made because of a resulting improvement in the signal-to-noise ratio, as compared to the low impedance unit. However, when this is done, the higher frequency components which are developed across the output resistor 19 under such circumstances, form but a small fraction of the low frequency components. Accordingly, equalization of the dropping response characteristic at the high frequencies forms an essential part of the function of the pre-amplifier circuit herein to be described. The outer shell of the cable 17 is grounded at 20.

The energy output resulting from scanning in the camera tube is then supplied by a coupling condenser 27 to the grid or control electrode 29 of the camera matching input tube 15. This tube 15 has its cathode element 31 connected to ground 20 through the cathode resistors 32 and

33 and its grid or control electrode 29 is connected at an intermediate point on the cathode resistors (such as that point intermediate the cathode resistors 32 and 33) through the grid leak resistor 34. In this connection, resistor 32 is relatively small as compared to resistor 33. Suitable plate voltage for the tube 15, as well as for the other tubes of this series, is provided from a source of energy (not shown) connected at the input terminal 36 and supplying its voltage by way of conductor 37 to the plate or anode tube 15 through the plate resistor 38.

In some cases, substantially perfect insulation may exist between the backing plate 13 of the mosaic and the remainder of the camera tube 11 and the rest of the discharge space in it, or, under some circumstances, the signal electrode 13 may have a certain positive bias applied to it without impairing the operation (while the structure of the signal source would be different to some extent, under such circumstances, a case of this nature would be where the photoelectric tube served as the original signal source). Under these conditions, the capacitive coupling provided by the condenser 27 and the resistor 34 might be replaced by a direct conductive coupling from the upper end of the load resistor 19 to the grid or control electrode 29 of the tube 15 and, in this case, the resistor 34, instead of connecting at its upper end to the grid or control electrode 29, would connect to the lower end of the load resistor 19 and to the junction point of the cathode resistors 32 and 33. Then, between the lower end of the load resistor 19 and ground 20, a condenser element, substantially like the condenser 27, might be included. However, it should be pointed out that even under these circumstances the condenser suggested between the lower end of the resistor 19 and the ground 20 might be omitted, as well as the resistor suggested to be connected between the lower end of the resistor 19 and the junction of the cathode resistors 32 and 33, since such condenser and resistor combination serve to smooth. If the load resistor 19 is relatively large (or the order of one hundred thousand ohms or more), the resistor and condenser may be omitted.

The type of camera tube hereinabove suggested is generally so designed as to make desirable a grounded signal plate 13. Acordingly, a conductive coupling between the camera tube and the control grid 29 of the camera matching input tube 15 is not desirable so that the capacity coupling 27 supplies the output energy from the camera tube 11 to its matching input tube 15. The particular form of triode tube chosen as the tube 15 should preferably be of the type such that low losses occur. The capacity across the signal input resistor, while of itself rather small, is, nevertheless, large enough to cause a loss in the transmission of the high frequency components relative to the low frequency components in the range of approximately 1 to 30. The invention provides for keeping this capacity as small as possible and for compensating for the effects of the high frequency losses as much as possible. The cable length 17 should be made short and with an extremely small size wire (such, for example, as No. 32) for its inner conductor, which means that the total capacity across the signal plate to ground is primarily due to the signal plate itself. It is desirable to make the coupling condenser 27 reasonably large, so that the time constant is such as to make the design particularly suitable for low frequencies.

In order that suitable plate current may flow through the tube 15, the connection of the grid leak resistor 34 to the point between the cathode resistors 32 and 33 furnishes a means whereby automatic grid bias is obtained from the cathode of the tube rather than from the plate. Obtaining grid bias in this manner has an additional advantage in that efficient "hum" filtering (about twenty times that obtained in the plate circuit of the tube by means of the circuit elements including the plate resistor 38 and condenser 46, later to be described) is brought about by the shielding effect of the grid 29 with respect to the cathode element. It was above noted that the capacities across the load 19 for the camera tube 11 should be as small as possible and, to this end, the camera matching input tube 15 has its output signal connected to the voltage amplifier tube 25 in such a way that the voltage amplifier tube appears as a cathode load on the camera matching tube 15, rather than on the camera output resistor 19. The connection of the input grid or control electrode 41 of the tube 25 is by way of the series peaking inductance element 42 and the coupling capacity 43. A connection of this general type, including the series peaking element 42, has been set forth and described more particularly in my copending application, Serial No. 485,981, filed May 7, 1943, and now issued as United States Letters Patent No. 2,384,263, granted September 4, 1945, for an invention entitled "Video amplifier." The application above named describes in detail the functioning of a self-biased cathode follower and reference may be made thereto for further details of this particular type of tube connection.

A connection of the self-biased type of cathode follower hereinabove described is particularly useful in supplying the output energy of the camera matching tube 15 to the input circuit of the voltage amplifier 25 because it serves to reduce both the influence of any ripple in the plate supply voltage and at the same time any noise due to the so-called "shot effect."

In the arrangement shown, the plate resistor 38 of the tube 15 functions together with the capacity 46 to form a plate filter circuit whereby the effect of the power supply voltage appearing in conductor 37 and a possible 120 cycle ripple (assuming the rectified voltages are derived from a 60 cycle power supply) may be reduced to a substantial extent, but not enough to be negligible as compared to the signal input level. However, with the connection of the tube 15 as a cathode follower stage, the circuit is such that any hum voltage appearing at the plate of the tube 15, assuming the tube to be a pentode, for instance one of the 6J7 type, would have to carry through all of the suppressor, screen, and control grids of the tube 15 in order to affect the cathode 31. In this way, the effects of the hum are reduced a still further number of times which correspond to the amplification factor of the tube in triode-connection, with a final result that the hum voltage, which is impressed upon the signal as it is fed from the cathode circuit of tube 15 to the control electrode 41 of the voltage amplifier tube 25, may be made to be but a small percentage of the average video signal voltage which is supplied from the camera tube 11 to the input of the camera matching tube 15.

It will be apparent that further filtering may be obtained by feeding the screen electrode of this tube through a resistance-capacity filter connected to the plate electrode. In such a case, any residual plate "hum" would be able to affect the cathode only after the shielding effect of both the screen grid and control grid is overcome. In usual practice, however, the triode connection, as shown, is usually sufficient "hum" filtering.

The voltage amplifier tube 25, which by way of illustration may be a 6AC7 or 1852 type, is the only tube stage which provides voltage amplification, and this tube functions, together with the coupling tube 65, to supply energy to the equalizing and compensating tube 35, which also may be a 6AC7 type, for instance. The general connections of the coupling tube 65 (preferably of the 6J5 type, for example) have also been described in the above mentioned copending application entitled "Video amplifier" and, accordingly, detailed description thereof need not be made herein, although reference may be had to the companion case. With the signal supplied to the control electrode or grid 41 of the voltage amplifier tube 25 by way of the peaking inductance 42 and the coupling capacity 43, it will be appreciated that any degeneration should be avoided in the voltage amplifier tube 25. Accordingly, the cathode element 48 thereof connects preferably directly to ground. Suitable bias for the voltage amplifier tube 25 is preferably provided by the bias source 49, which is conventionally represented by a battery 49 in order that hum may be minimized. At this point it may be mentioned that rectification of the A. C. heater voltage for the tube 25 may provide the bias voltage. Such rectification may be provided by a copper-oxide rectifier, a vacuum tube (such as the 6H6, for instance), or by any other suitable means. However, at this point it is usually not desirable to use a cathode resistor bias as the degenerative effect thereof results in a loss of amplification. The load resistor 51 for the tube is connected in series with a filter resistor 53 which, in turn, connects to the power supply conductor 37. The capacity element 54 forms, with the resistor 53, a time constant circuit later to be described.

The input capacity and coupling is such that the lowest frequency energy (such as that representing the usual 30 cycle frame frequency) is transmitted undistorted, and the output coupling for the tube noticeably reduces the effect of any 60 cycle power supply line interference. The time constant of the filter network comprising the resistor 53 and condenser 54 is such as to give adequate low frequency emphasis in the signals passed through the tube and the voltage drop across the feeder resistor 53 provides, at the same time, necessary plate voltage for the coupling tube 65. The condenser 54, in this instance, is preferably of the paper variety, in that it is a reasonably large condenser and this type is usually to be preferred in the particular use over the electrolytic variety. However, the filtering effect of the condenser-resistor combination 54, 53 is generally designed so as to have only moderate effect and if, for example, the power supply line 37 happened to have a ripple of even 3% at 120 cycles and 200 volts, it will be evident that the ripple is of the order of six volts and the filter 53, 54 would normally transmit approximately one-eighth of this voltage so that more efficient hum-elimination is provided by the compensation of such ripple effects in the next succeeding stage.

The output energy of the coupling tube 65 is fed across its cathode resistor 67 by way of the peaking inductance 68 and the coupling condenser 69 into the input circuit of the equalizer tube 35. This equalizer tube circuit is preferably of the variety which provides a gain which increases with frequency and, as shown, this is generally accomplished by the degenerative amplifier connections as shown more particularly by Fig. 2, which cause the system to act generally as a "frequency expander," which increases the band width to any desired amount, although this occurs at the expense of over-all gain.

Reference will be made to Fig. 2 for a further complete understanding of the invention, but first it will be seen, from the showing of Fig. 1, that the signals sent through the peaking inductance 68 and the coupling condenser 69 are supplied to the control electrode 71 of the equalizer and hum compensating tube 35. This tube has its grid or control electrode 71 suitably biased by the grid resistor 73. The cathode element 74 is appropriately biased to provide both adequate and critical degeneration by the series connected cathode resistors 76 and 79 which are shunted to ground 29 by the variable capacity element 77. In the arrangement shown, the grid resistor 73 corresponds approximately to the resistor 34 associated with the tube 15 and the cathode 74 connects to ground 29 through the cathode resistor 76 and the series connected resistor 79, and thence through a very low variable resistor 81, which last named resistor, when functioning in combination with the capacity element 83, serves in a manner later to be explained (particularly in connection with Fig. 3) to provide for hum compensation. The output energy from tube 35 is fed from the anode 85 through the coupling condenser 87 to the grid or control electrode 89 of the final cable matching tube 45. The plate load for the tube 35 is provided by the plate resistor 91 connected in series with the shunt peaking inductance 93, as well as the resistor element 95 of a filter combination comprising resistor 95 and condenser 96.

Considering now the circuit schematically represented by Fig. 2, the camera tube herein assumed as the "Orthicon" device 11 is schematically represented so that its plate or mosaic element 13, when scanned by a suitable scanning beam, provides a signal across the load resistor 19 across which some distributed capacity value exists, represented in Fig. 2 by the capacity 22, which is the inherent stray capacity of the scanning or camera tube which cannot be avoided. The connections by way of the tubes 15, 25 and 65 intermediate the camera tube output and the equalizing tube 35 are indicated by the dotted outline in Fig. 2 separating the coupling condenser 27 and the control electrode 71 of the tube 35. Also, it will be appreciated that, for reasons of simplicity of illustration, some of the connected cathode elements are omitted in the arrangement of Fig. 2, so that the particular showing of the capacitive cathode degeneration provided by the cathode degenerative resistor and the shunt condenser 77 is made more clearly apparent.

The circuit arrangement shown by Fig. 2 is both schematic and extremely generalized in form, but parts of the system are shown apart from the showing of Fig. 1 to make still clearer certain of the essential features of the invention. It can be appreciated, in this sense, that the source of video signals which is to be fed to the final output may be assumed to be generated by a signal generator tube of the so-called "constant-current" type, such as the tube schematically illustrated as the "Orthicon" 11 which is terminated by a relatively large load resistor 19 connected to its signal plate.

As was above explained, the inevitable capacity to ground, indicated in the dotted outline of capacity element 11, causes a characteristic decay of the higher frequency signals with respect to the lower frequency video signals across this load resistor 19. One of the purposes of this invention, as was above suggested, is to provide cathode degeneration in the compensator tube 35 by means of the cathode resistor 79 which is shunted by the variable capacitor 77. This resistor combination may be so adjusted and the time constants so established and the relationship between the cathode, resistance, input resistance and plate inductance so established that the voltage drop produced is just equalized and the plate voltage drop across the plate resistor 91 assumes a substantially constant value for all frequencies.

It thus becomes apparent that the conditions of the cathode circuit are critical, and that the time constant formed by the product of the cathode resistor 79 and its shunt capacity 77 should be equal to the time constant of the camera tube output circuit including the product of the stray capacity 22 and the load resistor 19. Mathematically expressed, this condition is represented as follows:

$$r_k c_k = r_{in} c_{in} = \frac{1}{2\pi f_{co}}$$

where r_k represents the cathode resistor 79; c_k represents the cathode capacity 77; r_{in} represents the resistor 19; c_{in} represents the input capacity 22; and f_{co} represents the cutoff frequency of the signal which will be at frequency f_1 for curve A in Fig. 4. Next, the value chosen for the cathode resistor 79 should be such that the degeneration factor equals the voltage drop at the input system. This condition may be mathematically expressed as follows:

$$r_k = \frac{1}{g_m}\left(\frac{b}{f_{co}} - 1\right)$$

where r_k again represents the cathode resistor 79 of the tube 35; g_m represents the transconductance of the tube 35; b represents the band width which is to be considered, for example, 0 to f_2 for curve B in Fig. 2; and, again, f_{co} represents the cutoff frequency, which will be at frequency f_2 in curve B in Fig. 2. Summarized in slightly different terminology, it might be stated that the time constant of the equalizer cathode circuit equals the time constant of the input and the degeneration factor equals the signal attenuation. When these conditions are fulfilled, the plate voltage from the equalizer tube 35 appears to be equalized to the first order and the system disclosed acts and functions as a band-stretcher, so that any desired band width of signals may be uniformly transmitted, even though slightly and somewhat at the expense of over-all gain, but with the product of gain and band width being constant.

Under such circumstances, some relatively minor high frequency losses occur, but adequate compensattion is accomplished by the inductance element 93 connected in series with the plate load resistor 91 to serve as a peaking coil. Also, Fig. 2 makes still clearer the showing of the inductive plate impedance 93, which serves not only to expand considerably any falling frequency response of the input signal but to yield a substantially constant gain and negligible phase shift over the entire expanded frequency band up to the peaking frequency. This third condition may be mathematically expressed as follows:

$$\frac{L_p}{r_p} = \frac{r_k c_k}{1 + g_m r_k}$$

where L_p represents the plate inductance 93; r_p represents the plate load resistor 91; r_k again represents the cathode resistor 79; c_k again represents the cathode capacity 77; and g_m again represents the transconductance of the tube 35.

It might be remarked that the inductance element 93 is limited only by the condition that resonance with the plate capacity of the tube 35, which is represented schematically by the condenser C_p on Fig. 2, should preferably occur outside the frequency band to be transmitted. In this way, the maximum size of the plate resistor 91 is also limited to some extent. It also may be remarked in connection with the peaking inductance 93, that if conditions occur such that resonance with it and the plate capacity C_p of tube 35 is omitted in the upper portion of the frequency spectrum to be transmitted, the plate coil or inductance 93 may be used to some extent for aperture correction, in which case a larger plate impedance of the tube 35 becomes possible. It thus becomes apparent, from what is shown by Fig. 2, that there has been provided a source of video signals which normally occupy a wide frequency band of the order of 4 to 6 megacycles, for instance, according to presently accepted standards, although for higher definition scanning and increased field repetition ratio the frequency band naturally becomes wider. The frequency band mentioned, for illustrative purposes only, is for a 525 line picture scanning at 30 frames per second interlaced.

From the foregoing it will be appreciated that the problem which is solved by this invention is broadly that of providing equalization of a signal over a predetermined and selected frequency band to include all frequencies from the lowest up to and including some selected high frequency, such as represented by f_2 in Fig. 4. Thus, for instance, at this selected frequency an input voltage represented by e_1 which may be assumed to be equal to 1.00 in signal amplitude, as per Fig. 4, will be transmitted uniformly throughout the complete frequency band between zero frequency (D. C.) and the selected upper frequency limit f_2. Under these circumstances, if it be assumed that the signal for transmission is obtained from a suitable constant current source, such as a television camera tube of the type disclosed, across an input circuit represented by the resistance 19 and the distributed capacity 22, it will be appreciated that the input voltage may be represented—

$$e_1 = \frac{i_1 r_1}{1 + p r_1 c_s} \qquad (1)$$

where r_1 represents the load resistance 19 of the source; c_s represents the source capacity (capacity 22); e_1 is the input voltage; i_1 is the input current and $p = j\omega$.

It will be seen, for instance, that without compensation, as shown by curve A of Fig. 4, the response drops to the half power point where

$$e_1' = 0.707 = \frac{1}{\sqrt{2}}$$

at frequency f_1 (for instance). This represents a response drop of 3 db. so that the signal response reaches a point which is frequently known as the "cut-off" frequency which has been represented by a frequency value f_1 on the curve of Fig. 4. This frequency

$$f_1 = \frac{1}{2\pi r_1 c_s} \qquad (2)$$

The present invention solves the problem of providing ways and means by which the band of frequencies between zero frequency and the frequency f_1, above noted, whereat the response was assumed to be at the cut-off value represented by a decrease of 3 db. in output, may be expanded by a factor s and still provide uniformity of response throughout the band of increased width. For reference purposes the "stretching factor" s may be assumed equal to the ratio of f_2 (the new frequency) to f_1 so that

$$s=\frac{f_2}{f_1} \qquad (3)$$

It is a well known fact that with cathode degeneration the plate current flowing in some tube, such as tube **35**, becomes as follows:

$$i_p=g_m(e_1-e_k)=\frac{e_1g_m}{1+\frac{g_mr_k}{1+pr_kc_k}}=e_1g_m\frac{1+pr_kc_k}{1+p\frac{r_kc_k}{1+g_mr_k}} \qquad (4)$$

where i_p represents the plate current, e_1 represents the input voltage, e_k represents the cathode output voltage, g_m represents the transconductance of the tube **35**, p is as above, r_k is the cathode resistance **79** and c_k is the cathode capacity **77**, for instance. If now Equation 4 above and Equation 1 above be combined and the plate inductance of the tube **35** be considered, then the overall amplification of the system shown by Fig. 2 may be considered as follows:

$$\frac{e_p}{i_1r_1}=\frac{g_mr_p}{1+g_mr_k}\cdot\frac{1+pr_kc_k}{1+pr_1c_s}\cdot\frac{1+\frac{PL_p}{r_p}}{1+\frac{pr_kc_k}{(1+g_mr_k)}} \qquad (5)$$

where e_p is the output voltage, as in Fig. 2, r_p is the plate resistor **91** of tube **35**, L_p represents the plate inductance **93** of tube **35** and the other quantities are as above noted.

From the foregoing it will be apparent that the first part of Equation 5, above, namely.

$$\frac{g_mr_p}{1+g_mr_k}$$

shows no frequency values and amounts to a mere representation of the fact that D. C. amplification takes place.

The second part of Equation 5, above, namely,

$$\frac{1+pr_kc_k}{1+pr_1c_s}$$

becomes unity where the time constant of the signal input equals the time constant of the cathode circuit of the tube **35**, as stated hereinabove should be the case.

The last portion of Equation 5, namely,

$$\frac{1+\frac{PL_p}{r_p}}{1+\frac{pr_kc_k}{(1+g_mr_k)}}$$

is one where the numerator of the equation would be equal to unity if there were no inductance in the plate circuit of tube **35**. This third part of the equation represents the capacity attenuation where a capacity element, such as capacitor **77**, is placed in shunt with the cathode resistance, such as resistor **79**. In this third portion of the equation that part of the denominator of the equation which is represented by

$$\frac{1}{1+g_mr_k}$$

is known as the degeneration factor. Accordingly, where a falling off in the response characteristic such as shown by curve B of Fig. 4 is apparent if there is no inductance in the plate circuit of the tube **35**, which falling off reaches the cut-off level or a point where the signal is equal to

$$\frac{1}{\sqrt{2}}$$

of the input or down 3 db. at a point, purely by way of example in Fig. 4, of about 4.25 megacycles, it becomes evident that this falling off of the response from the amplifier can be avoided through the inclusion of some factor which is of equal value out of opposite sign to the capacity factor of the denominator of the third portion of Equation 5. This inductance value is reached where the following condition holds true, namely,

$$\frac{L_p}{r_p}=\frac{1}{2\pi f_2}$$

Thus, the inductive time constant

$$\frac{L_p}{r_p}$$

may be regarded as some constant which might be assumed as equal to a constant factor K. Accordingly, as hereinabove indicated, the following relationships are established from the circuit hereinabove explained.

$$r_kc_k=r_1c_s \qquad (6)$$

$$1+g_mr_k=s=\frac{f_2}{f_1} \qquad (7)$$

and

$$\frac{L_p}{r_p}=\frac{1}{2\pi f_2} \qquad (8)$$

In Equations 6 and 7 above, it will be seen that each defines a cathode circuit in which both the resistance and the bypass capacities values are unique and, accordingly, the value of the cathode resistance may readily be established from the equation

$$r_k=\frac{1}{g_m}(s-1)$$

and by the same analysis the cathode capacity is equal to

$$\frac{g_m}{2\pi f_1(s-1)}$$

As is evident from the curve of Fig. 4, the response will now be down 3 db. at the frequency f_2 where there is no plate inductance element, such as the inductance **93**. However, the inclusion of inductance **93** tends to peak the response and prevents the falling off as the frequency f_2 is reached. To prevent any overshoot it is important that the plate resistance values, that is, the value of the resistor **91**, should be limited to a value where $r_p=\frac{1}{4}\pi f_2C_p$, where C_p represents the plate capacity as indicated by Fig. 2 of the drawings. It will be seen that this value is one-half that of the resistance value for conventional amplifiers with shunt peaking. Under these circumstances, the over-all gain in the system is then represented as

$$a=\frac{e_p}{i_1r_1}=\frac{g_mr_p}{s}$$

and it will be observed that the product of gain and bandwidth is again constant.

In connection with this invention, as hereinabove explained, and possibly at the expense of further repetition and additional reference to the mathematical analysis, it must be again emphasized in summary that the scanning system may be looked upon as a constant-current source where output is terminated by a load resistor (such as resistor 19) of such a magnitude that an attenuation of the higher signal frequencies, as compared to the lower signal frequencies, occurs across this output resistor. This signal energy output which appears across the load resistor 19 is then supplied to a signal amplifier tube 15, which is provided with a critically controlled cathode degenerative resistor 79 which is caused to become effective at the lower frequencies only, due to the fact that a by-pass condenser 77 to pass the high frequencies is placed in shunt with it. Then, in addition, an inductive element 93, to provide high frequency peaking, is included in series with the plate resistor 91 of the signal amplifier tube 35, so that the desired frequency band of signals is efficiently transmitted.

The equalization effects resulting from such a condenser shunted cathode degenerative resistor 79 is such that the time constant of the cathode circuit is made equal to that of the signal input and the degenerative factor is made equal to the signal attenuation factor. With regard to the plate circuit of such an amplifier, it will be appreciated that the time constant of the circuit formed by the plate resistor 91 and the peaking inductance 93 is at least equal to, or greater than, the shortest signal period to be transmitted.

To state the foregoing slightly differently, it will be seen that the circuits herein described furnish equalizing effects which compensate for the decaying or falling frequency response which results from an input circuit whose time constant is longer than that of the higher frequency signal components of the video signal output of the video signal source. To this end, cathode degeneration is provided, and the time constant of the cathode circuit of the tube 35 is made equal to that of the signal input circuit and the controlled amount of degeneration is made equal to that of the signal decay, that is, the ratio of the signal input at the highest signal or cutoff frequencies and at the critical frequency of the input circuit.

Now, considering the circuit of Fig. 3, there is also represented thereby certain of the elements shown more completely by Fig. 1, although Fig. 3, being schematic in nature, serves to explain more readily the operation and functioning of parts of the circuit of Fig. 1. In the circuit of Fig. 3, like numerals represent like parts of Figs. 1 and 2. It might be remarked further that the connection terminal 36 of Fig. 1 is represented in schematic form in Fig. 3 as the battery 36, although it must be appreciated that this is purely schematic and any desired source of energy may be utilized. Naturally, because of the ripple effects above explained, it is to be assumed that the operating voltages for the various tubes of the system will be derived from rectified alternating current. To this end, the ripple above mentioned, which occurs to some extent with fluctuations in the power supply, is represented in schematic manner by the element 98 in Fig. 3.

It was above pointed out in the discussion of Fig. 1 that the plate filters for the tubes 25 and 35, which filters are represented respectively by the filter networks 53, 54 and 95, 96 having time constants which are conventionally designated, respectively, by T_1 and T_2, cannot conventionally be designed in apparatus of the nature herein disclosed to be extremely efficient filtering elements, with the result that some fluctuations tend to become effective at the grid or control electrode 71 of the equalizing tube and the same energy fluctuation is found to be present also at the screen electrode of the compensating tube 35.

To provide an output signal which becomes substantially completely free from any hum effects, a compensating voltage, which is derived from the plate supply line for the various tubes, is fed through an appropriate network comprising the capacity element 83 and the resistor 81, so that a voltage equal, but of opposite sign to the hum voltage at the grid or control electrode 71, is injected into the cathode circuit of the equalizing tube 35 by way of the connection of the cathode resistor 79 to the junction point of connection of the capacity 83 and the resistor 81. The resistor 81 is usually of extremely low value with a maximum resistance of the order usually of about 20 ohms, which is variable, as indicated, and usually adjusted at approximately its centermost value. The result is that the combination of the condenser 83 and the resistor 81 may be made such that the hum frequency of 120 cycles, which would normally tend to be introduced from the usual A. C. power supply which is rectified and filtered, is substantially completely compensated. In addition, the hum compensation provided by the network formed in the capacity 83 and the resistor 81 and designated as having a time constant T_3 is also effective against any 120 cycle modulation which is caused by magnetic fields of heater elements of the tubes of the system where the heater elements are heated by the usual 60 cycle power supply from the A. C. power supply mains.

Continuing now with a consideration of the remaining portions of the circuit of Fig. 1, it was above explained that the output of the equalizing tube 35 is fed by way of condenser 87 to energize the cable matching tube 45 (for instance, a tube of the 6AG7 type to act as a class "A" amplifier) by application to its grid or control electrode 89. The input coupling, provided by condenser 87 has a relatively small time constant because the input signal to the cable matching tube 45 has, as above explained, already received a low frequency emphasis. A cable matching stage, provided by tube 45, has its screen current adjusted by way of the resistor 101 and is preferably operated in a linear manner over a relatively wide range of plate current. In order to avoid any feedback, the anode or plate electrode 102 is grounded through the trap circuit comprising the plate resistor 103 and the capacity 104 connecting to ground 20. The screen electrode 105 of the tube also is grounded by way of the connection of the by-pass condenser 107 to the tube cathode 108, so that the grid-to-screen capacitance is reduced by the degeneration factor of the tube. The result is that the total grid capacity of the tube 45 is extremely small and, therefore, can properly be placed in shunt with the plate resistor 91 of the equalizer tube 45 without impairing uniform transmission of the desired wide frequency band which, as above stated, may be at least in the range of four to six megacycles. The output energy from the cable matching tube 45 is fed by way of its cathode into the concentric output cable represented at 55 which, in accordance with known practice, has its outer shell connected to ground and which is also terminated in the so-called "characteristic impedance" 109 which is generally within the range of 75 to 120 ohms. The resultant output signal, as it appears at the output terminals 110, is then fed to a suitable line or control or mixing amplifier, not shown.

While purely for purposes of illustration various type of tube components used in the above described circuit have been illustrated, it will be understood that these are shown purely by way of example.

Having now described the invention, what is claimed is:

1. In a television circuit, a constant current source of video signalling energy covering a relatively wide predetermined frequency band and across which source an inherent capacity exists, a load resistor connected to the said source and producing an attenuation of the higher range of the signalling frequency energy as compared to the lower frequency range of the said energy, a video signal amplifier tube having at least a cathode, an anode and a control electrode, means to impress the signal output from the said load resistor upon the control electrode of said tube, a degenerative resistor element connected to the cathode of said tube to provide controlled degeneration at the lower frequencies of the said video signal energy range, and a by-pass condenser connected in parallel with the said cathode degenerative resistor to pass readily the higher frequencies of the said video signal frequency range, the time constant of the cathode resistor and cathode capacity being made equal to that of the input resistor and the input capacity of the signal source, and the value of the cathode resistor being such that the degeneration factor introduced thereby is equal to the voltage drop at the input due to the load resistor of the signal source at the cutoff frequency.

2. In a television circuit, a constant current source of video signalling energy covering a relatively wide predetermined frequency band and across which source an inherent capacity exists, a load resistor connected to the said source and producing an attenuation of the higher range of the signalling frequency energy as compared to the lower frequency range of the said energy, a video signal amplifier tube having at least a cathode, an anode and a control electrode, means to impress the signal output from the said load resistor upon the control electrode of said tube, a degenerative resistor element connected to the cathode of said tube to provide controlled degeneration at the lower frequencies of the said video signal energy range, a by-pass condenser connected in parallel with the said cathode degenerative resistor to pass readily the higher frequencies of the said video signal frequency range, the time constant of the cathode resistor and cathode capacity being made equal to that of the input resistor and the input capacity of the signal source, and the value of the cathode resistor being such that the degeneration factor introduced thereby is equal to the voltage drop at the input due to the load resistor of the signal source at the cutoff frequency, a peaking element and a load resistor element serially connected in the anode circuit of said tube to provide peaking in the higher frequency range, and the ratio of the plate inductance to the plate resistance being equal to the ratio of the time constant of the cathode resistor and cathode capacity combination to the quantity one plus the product of the tube transconductance times the tube cathode resistor.

3. A television amplifier comprising a substantially constant current source of video signalling energy for developing video signal energy output having a frequency range covering a frequency band between extremely low and extremely high frequencies and across which source an inherent capacity exists, a load resistor connected to receive the output energy from said video signalling energy source, said resistive output being of such magnitude that it, together with the inherent capacity of the signal source, produces attenuation of the higher signal frequencies as compared to the lower signal frequencies, a thermionic signal amplifier tube for amplifying said signals, resistive means connected in the cathode circuit of said tube to provide controlled cathode degeneration at the lower frequency range of the said signals only, a condenser element connected in parallel with said cathode resistor for by-passing the higher frequency range of signals to be amplified, the time constant of the said resistor and capacitor of the cathode circuit being made substantially equal to that of the signal input circuit and the degeneration of the low frequency signalling energy being made substantially equal to the signal decay at the higher frequency range, a resistor and inductance element serially connected in the output circuit of said tube and together having a time constant substantially of the same order as that of the shortest signal period to be transmitted and being resonant outside any frequency band to be passed, and a load circuit connected to receive the output energy from said tube.

4. A television amplifier comprising a substantially constant current source of video signalling energy for developing video signal energy output having a frequency range covering a frequency band between extremely low and extremely high frequencies, a load resistor connected to receive the output energy from said video signalling energy source, said resistive output being of such magnitude that it, together with the inherent capacity of the signal source, produces attenuation of the higher signal frequencies as compared to the lower signal frequencies, a thermionic signal amplifier tube for amplifying said signals, resistive means connected in the cathode circuit of said tube to provide critical controlled cathode degeneration at the lower frequency range of the said signals only, a condenser element connected in parallel with said cathode resistor for by-passing the higher frequency range of signals to be amplified, the time constant of the said resistor and capacitor of the cathode circuit being made substantially equal to that of the signal input circuit and the degeneration of the low frequency signalling energy being made substantially equal to the signal decay at the higher frequency range, a resistor and inductance element serially connected in the output circuit of said tube and together having a time constant substantially of the same order as that of the shortest signal period to be transmitted, a coupling tube to receive the output energy from said output load impedance, and a load circuit connected as a cathode follower to said coupling tube.

5. In a television circuit, a constant current source of video signalling energy covering a predetermined frequency band, a load resistor connected to receive the output from said source and tending to cause an attenuation of a higher range of signalling frequencies as compared to the lower frequency range of the said signalling frequencies, said constant current source providing an inherent and unavoidable distributed capacity, a video signal amplifier tube having a predetermined transconductance characteristic and having, at least, a cathode, a control electrode, and an anode, means to impress the signal

output developed across the said load resistor upon the control electrode of the said tube for amplification, a degenerative resistor element connected to the cathode of the tube, a by-pass condenser connected in parallel with the said cathode resistor to pass readily the higher frequency components of the said video signal frequency range impressed upon the control electrode of the said tube, a series combination comprising an inductive peaking element and a load resistor serially connected in the anode circuit of the said tube, the said capacitors, resistors, tube, and inductive element bearing a relationship one to another such that

$$r_k c_k = r_1 c_s; \text{ and } r_k = \frac{1}{g_m}\left(\frac{b}{f_{co}} - 1\right); \text{ and } \frac{L_p}{r_p} = \frac{r_k c_k}{1 + g_m r_k}$$

where r_k represents the cathode resistor; c_k represents the cathode resistor bypass condenser; r_1 represents the load resistor; c_s represents the inherent capacity of the source; g_m represents the transconductance of the amplifier tube; b represents the band width or frequency range of the signalling frequencies developed by the source; f_{co} represents the cutoff frequency at which the high frequency signal components are attenuated; L_p represents the plate or anode inductance; and r_p represents the plate or anode resistance of the amplifier tube.

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