Feb. 27, 1945. E. D. GOODALE 2,370,399

ELECTRICAL CIRCUIT

Filed July 14, 1942

Fig. 1.

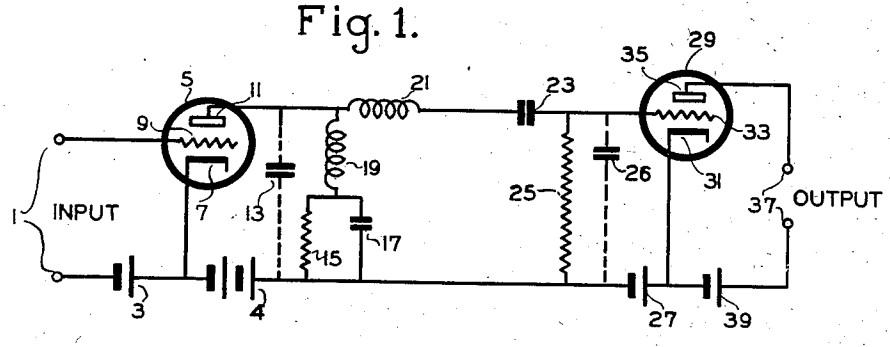


Fig. 2.

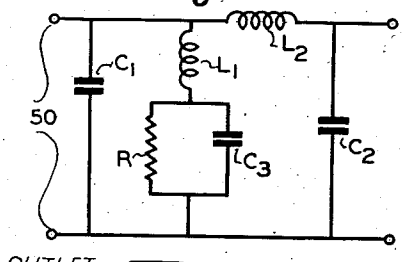


Fig. 3.

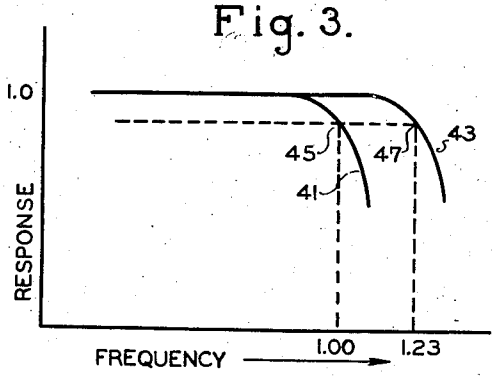


Fig. 5

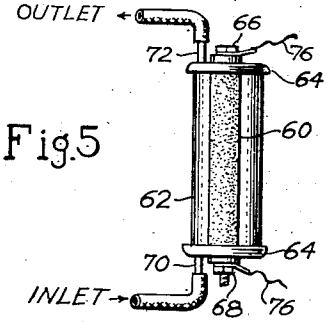
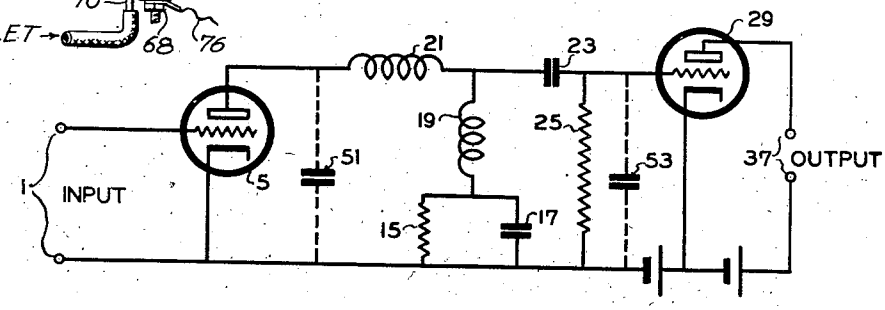


Fig. 4.



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Patented Feb. 27, 1945 2,370,399

UNITED STATES PATENT OFFICE

2,370,399

ELECTRICAL CIRCUITS

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Application July 14, 1942, Serial No. 450,888

4 Claims. (Cl. 178—171)

This invention relates to thermionic amplifiers, and more particularly, to thermionic amplifiers requiring substantially uniform amplification and substantially linear phase characteristic of a very wide band of frequencies, such as are used in television and video systems.

In many applications, it is necessary to have thermionic amplifiers capable of amplifying frequencies of a very wide band, and at the same time to insure that the relative phase positions of the currents to be amplified are maintained after amplification. Uniform amplitude of a wide band of frequencies cannot be achieved without some form of compensation due to the inherent anode-to-cathode capacity and control grid-to-cathode capacity. These inherent capacities of the thermionic amplifier, while relatively small, being only on the order of tens of micro-micro-farads, nevertheless become important at frequencies above 0.1 megacycle.

The usual practice to obtain uniform amplification is to insert compensating inductances of low values which tend to resonate with the inherent tube capacities, and consequently, to maintain the input and output impedances of the thermionic tubes in the amplifier. However, use of such inductances may result in an impedance characteristic which oscillates about a mean value in the region of the resonant frequency of the compensating inductance and tube capacity, and such an oscillatory impedance characteristic is accompanied by a phase characteristic which is no longer linear.

By my invention, I overcome the shortcomings of previously known compensated amplifiers by first of all providing a monotonic impedance characteristic up to a predetermined limiting frequency, together with a phase characteristic which is substantially linear throughout the useful band of frequencies to be amplified.

In accordance with my invention, I use a form of "series-shunt-peaking" circuit in which the shunt arm comprises an inductance in series with a parallelly connected resistor and condenser, while the series arm comprises an inductance. The value of the series arm inductance is on the order of twice of that of the value of the inductance in the shunt arm, while the parallelly connected condenser of the shunt arm is of the order of one-tenth of the total distributed capacities which includes the inherent plate-to-cathode capacity, control electrode-to-cathode capacity and stray circuit capacity to ground. Under these conditions, it is possible to obtain substantially constant amplification and substantially linear phase characteristic over a band of frequencies 20% greater than is possible by using other forms of compensating or "peaking" networks.

Moreover, it is possible to utilize the distributed capacity of one or more of the circuit elements to provide the necessary relationship among the elements to give uniform amplification and substantially linear phase characteristic. For example, in a television transmitter where a water cooled resistor is used in series with the inductance in the shunt arm, the distributed capacity across the water cooled resistor, by suitable design, may be made to have the proper value to meet the conditions necessary for uniform amplification.

The benefits of my invention arise from the careful proportioning of the values of the circuit parameters used with respect to each other, taking into account the values of the tube distributed capacities, as well as the stray capacities of the circuit elements to ground.

Accordingly, the main object of my invention is to provide a new and improved thermionic amplifier having substantially uniform amplification and substantially linear phase characteristic over a wide band of frequencies.

Another object of my invention is to provide a thermionic amplifier which is compensated to give substantially uniform amplification and linear phase characteristic over a given wide band of frequencies with increased over-all gain.

Another object is to provide a thermionic amplifier having a load circuit comprising a shunt arm of an inductance connected in series with a parallelly connected resistor and capacity and a series arm comprising an inductance to provide substantially constant impedance over a wide band of frequencies.

Still another object of my invention is to provide a thermionic amplifier in a television transmitter in which the distributed capacity of a water cooled resistor is so chosen and utilized to provide uniform amplification and substantially linear phase characteristic.

Other objects of my invention will become apparent to those skilled in the art upon reading the following detailed description in conjunction with the drawing.

In the drawing,

Figure 1 shows schematically a circuit of a thermionic amplifier embodying my invention;

Figure 2 shows schematically an equivalent electrical network of the circuit arrangement shown in Figure 1;

Figure 3 shows in graphical form the response curve of an amplifier embodying my invention, compared to the response curve of an amplifier having a different form of compensating network;

Figure 4 shows schematically a modification of my invention embodied in Figure 1; while

Figure 5 shows details of a water cooled resistor.

Turning now to Figure 1, I have shown, for purposes of describing my invention, a two-stage thermionic amplifier comprising a first thermionic tube 5 having a cathode 7, a control electrode 9 and an anode 11. Input signals are supplied to the terminals 1 to impress the signals between the cathode 7 and the control electrode 9. A bias battery 3 serves to provide the proper operating characteristic of the tube 5. A battery 4 supplies the anode 11 with operating potentials through the resistor 15 connected in series with the inductance 19. The resistor 15 is shunted by condenser 17, and I have shown, in dotted lines, the distributed anode-to-cathode capacity as the condenser 13.

The second thermionic amplifier 29 is capacity-resistance coupled through the condenser 23 and resistor 25 to the anode circuit of the tube 5, through the inductance 21. There is thus impressed between the cathode 31 and the control electrode 33 of the tube 29, the amplified potentials from the tube 5. Suitable biasing and supply voltage sources 27 and 39 are provided to render the tube 35 properly operative, and the amplified output may be obtained from the output terminals 37. The control electrode-cathode distributed capacity is shown as the condenser 26. By properly proportioning the size of the elements 15, 17, 19 and 21 with respect to the stray or distributed capacities 13 and 26, the amplifier may be given a flat response characteristic together with a substantially linear phase characteristic over a predetermined frequency band. The frequency band will be on the order of 20% greater than obtainable in other forms of amplifiers.

In order to correctly proportion the various circuit elements, it is necessary that the elements be so chosen as to provide a substantially monotonic impedance characteristic. Such a characteristic may be obtained by writing down the generalized impedance function, which will generally be a quotient of two polynomials, squaring the impedance function and then equating like orders of terms in the numerator and denominator to each other, and solving for the coefficient of the polynomials from the simultaneous equations obtained by equating the like terms of the polynomials. The derived coefficients will then determine the proportions between the circuit parameters necessary to obtain the proper impedance characteristic.

In Figure 2, I have shown the equivalent network of a load circuit of the amplifier shown in Figure 1. In Figure 2, the condenser C_1 has the value of the distributed capacity 13 between the anode 11 and the cathode 7 of tube 5, plus the stray capacity to ground of the circuit elements up to L_2. The condenser C_2 of Figure 2 has the value of the capacity 26 representing the electrode capacity between the control electrode 33 and the cathode 31, plus the stray capacity to ground of the elements associated with the control electrode. The resistor R of Figure 2 represents the resistance 15, while the capacity C_3 of Figure 2 represents the condenser 17 of Figure 1. The inductances L_1 and L_2 of Figure 2 represent the inductances 19 and 21, respectively, of Figure 1. Since the condenser 23 and resistor 25 are used for coupling purposes, these can be neglected as far as the high frequency response is concerned, since the condenser 23 has a very large value and, consequently, its impedance is so low as to comprise effectively a short circuit in the connection between the inductance 21 and the control electrode 33. Likewise, the resistor 25 has such high resistance that it is effectively an open circuit between the control electrode 33 and the cathode 31, so that these two elements may be neglected.

It can be shown that the generalized impedance squared function is as follows:

$$\left|\frac{Z}{R}\right|^2=\frac{1+(a^2-2ab)x^2+a^2b^2x^4}{\begin{array}{l}1+(1+2b+b^2-2a-2d)x^2\\+(a^2+2ad+d^2+2adm-2dm-2ab-2bd-2ab^2-2bdm-2b^2d)x^4\\+(4abdm-2a^2dm-2ad^2m+2ab^2dm+a^2b^2+2ab^2d+d^2m^2+2bd^2m+b^2d^2)x^6\\+(a^2d^2m^2-2a^2b^2dm-2abd^2m^2-2ab^2d^2m)x^8\\+a^2b^2d^2m^2x^{10}\end{array}}$$

where Z is the impedance of the network looking in at the terminals 50, R is the element independent of frequency, a, b, d and m are constants, and x is equal to ωCR, where ω represents the angular velocity of the currents to be amplified and C is equal to C_1+C_2.

Equating now the like powers of the polynomials in the denominator and numerator, the following simultaneous equations will be obtained.

$$\begin{array}{l}a^2-2ab=1+2b+b^2-2a-2d\\a^2b^2=a^2+2ad+d^2+2adm-2dm-2ab-2bd-2ab^2-2bdm-2b^2d\\4abdm-2a^2dm-2ad^2m+2ab^2dm+a^2b^2+2ab^2d+d^2m^2+2bd^2m+b^2d^2=0\\adm(adm-2ab^2-2bdm-2b^2d)=0\end{array}$$

from which the following values of the coefficients may be obtained:

$$\begin{array}{c}a=0.29\\b=0.10\\d=0.30\\m=0.45\end{array}$$

Attention is called to the fact that the x^{10} term in the denominator must be equal to zero, which requires at least one of the coefficients equal to zero if the impedance characteristic is to be constant over all ranges of frequency out to infinity. From this, it is clear that the circuit arrangement cannot provide uniform amplification over an infinitely wide band of frequencies, but the solution can be restricted to giving uniform impedance characteristic up to a predetermined frequency by making the value of x^{10} term negligible. The solution will then be monotonic and the impedance will be substantially constant. The values above tabulated for the coefficients a, b, d and m give a solution in which the x^{10} term can be safely neglected without disturbing the condition of uniform amplification

and substantially linear phase characteristic for all values of x up to 2.2.

From these values the magnitude and relationship of the circuit arrangements may be readily obtained since

$C=C_1+C_2$
$L_1=aCR^2$
$L_2=\frac{d}{1-m}CR^2$ $\omega CR=2.15$ for .1 *db.* deviation
$C_1=mC$
$C_2=(1-m)C$
$C_3=bC$

By substituting the above determined values for the coefficients, it will be noted that L_1 equals .53 L_2 and C_2 equals 1.22 C_1.

In view of the fact that L_1 and L_2 are elements which are added to the circuit, the achievement of the necessary relationship between the magnitude of these two inductances can be readily obtained. The relationship between the anode distributed capacity and the control electrode distributed capacity can likewise be obtained by careful designing of the circuit element. For example, in a television transmitter the high power stages may have a water cooled resistor corresponding to the resistor 15 of Figure 1. In such a case, by proper design of the resistor, the distributed capacity of the resistor may be made equal to that shown by the condenser 17, and consequently no additional capacitor is necessary.

A conventional water cooled resistor is shown in Figure 5 and may be used as resistance element 15 in Figure 1 where power demands and dissipation requirements are such as will make the use of a water cooled resistor necessary or desirable. The resistor includes a ceramic tubular member 60, the outside surface of which is coated with a resistance material. Surrounding this ceramic tube is a glass tube or cylinder 62 and the ends of the ceramic cylinder 60 and glass cylinder 62 are closed by means of metallic caps 64. The caps are maintained in position by a bolt 66 which passes through the center of the ceramic tube 60 while a nut 68 is threaded on the bolt 66 to maintain the desired pressure. Naturally, gaskets may be used to prevent leakage of the cooling fluid. The caps 64 are provided with inlet and outlet tubes 70 and 72 respectively and since the caps 64 are in contact with the ends of the ceramic tube 60, an electrical current may be conducted to the resistor 60 by way of lead conductors 76. Water or an appropriate cooling liquid or medium is circulated through the space between the ceramic tube 60 and the outer tube 62. The heat produced by current flow over the resistance element is readily carried away. Naturally, in the construction of such a resistance, a predetermined distributed capacity exists between the two end plates 64. This distributed capacity, if of proper value, may replace the condenser 17 shown in Figures 1 and 4. The water cooled resistor shown in Figure 5 is only by way of example since various other types of water cooled resistors may be used.

In certain amplifiers, it may be found that the stray capacity of the plate-cathode circuit may be greater than the stray capacity of the control electrode-cathode circuit. Under these conditions, the coupling circuit may be reversed so as to enable the relationships among the circuit elements to be maintained. In Figure 4, such an amplifier is shown in which the same numerals are used to designate the same component parts. It will be noted in this case that the serially connected inductance 19 and the parallelly connected resistor 15 and condenser 17 are now in shunt to the control electrode circuit of the tube 29, and that the series arm comprising the inductance 21 is connected directly to the plate so that the distributed plate capacity 51 acts as the terminating element of the network, while the distributed control electrode cathode capacity 53 is substantially in shunt to the shunt arm of the correcting network. Since it has been assumed that the distributed capacity 51 is larger than the distributed capacity 53, the relationship that $C_2=1.22\ C_1$ can still be met to provide the uniform amplification above described.

In Figure 3, I have shown the response characteristic of an amplifier embodying my invention in the curve 43, which curve is only 1½% down from unity response at predetermined frequency. For comparison purposes, I have shown the response characteristic 41 of a compensated amplifier using ordinary "series-shunt" peaking known to the art, which is down 1½% on a generalized frequency scale of 1.00. It will be noted that my new amplifier deviates from unity response on a generalized frequency scale at 1.23. In other words, the band width for the same amplification has been increased 23% by my new circuit arrangement.

It will be appreciated that, while I have shown various power supplies as batteries, these may be derived from rectified current, and that the thermionic tubes, which are shown merely conventionally for illustration only as triodes, may be any other type of thermionic amplifiers such as pentodes.

From the above description, it, of course, will be apparent that many and varied modifications of the invention may be made without departing from the general principles described and outlined hereinabove, and I, therefore, believe myself to be entitled to make any and all of these modifications such as would suggest themselves to those skilled in the art to which the invention relates, provided, of course, that such modifications and changes fall fairly within the spirit and scope of the invention as set forth in the hereinafter appended claims.

Having now described my invention, what I claim is:

1. An amplifier comprising a first thermionic tube having at least a cathode, control electrode and an anode, an inductance connected in series with a parallelly connected resistor and condenser connected between said anode and said cathode, a second thermionic tube having at least a cathode, control electrode and anode, and a second inductance connected between the anode of said first thermionic tube and the control electrode of said second thermionic tube.

2. An amplifier comprising a first thermionic tube having at least a cathode, control electrode and an anode, an inductance connected in series with a parallelly connected resistor and condenser connected between said anode and said cathode, a second thermionic tube having at least a cathode, control electrode and anode, a second inductance connected between the anode of said first thermionic tube and the control electrode of said second thermionic tube, said first named inductance having a value substantially equal to .53 of said second named inductance.

3. An amplifier comprising a first thermionic tube having at least a cathode, control electrode and an anode, an inductance connected in series with a water cooled resistor, said series inductance and resistance being connected between the

anode and cathode of said tube, a second thermionic tube having at least a cathode, control electrode and anode, a second inductance connected between the anode of said first thermionic tube and the control electrode of said second thermionic tube, said first named inductance having a value substantially equal to .53 of said second inductance, and the distributed capacity across said water cooled resistor being chosen to have a value equal to substantially one-tenth the sum of the inter-electrode capacity between the anode and cathode of the first thermionic tube and the inter-electrode capacity between the control electrode and cathode of the second thermionic tube.

4. A television transmitter amplifier comprising a first thermionic tube having at least a cathode, control electrode and an anode, a serially connected inductance and water cooled resistor connected between said anode and said cathode, said resistor having distributed capacity, a second thermionic tube having at least a cathode, control electrode and an anode, a second inductance connected between the anode of said first thermionic tube and the control electrode of said second thermionic tube, said first named inductance having a value substantially equal to .53 of said second inductance, and said distributed capacity having a value equal to substantially one-tenth of the sum of the stray capacity between the anode and cathode of the first thermionic tube and the stray capacity between the control electrode and cathode of the second thermionic tube.

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