Aug. 22, 1939. L. C. PETERSON 2,170,645

HIGH FREQUENCY AMPLIFIER

Filed Jan. 3, 1938 2 Sheets-Sheet 1

FIG. 1

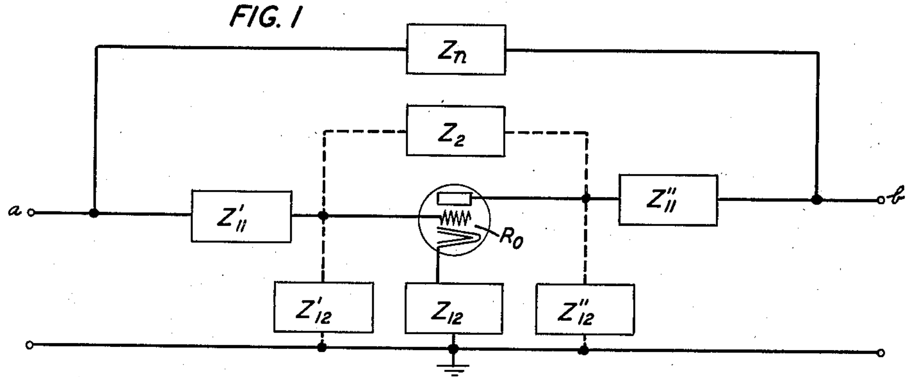


FIG. 2

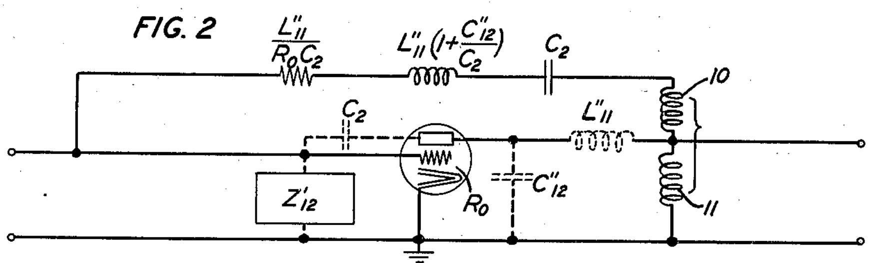
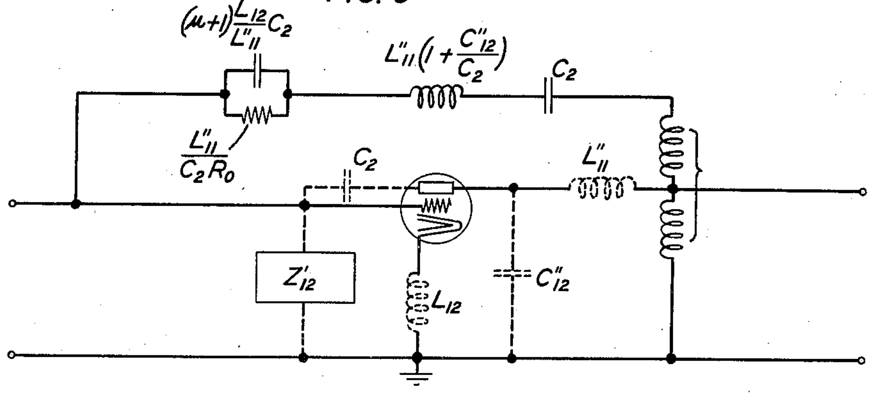


FIG. 3



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Filed Jan. 3, 1938 2 Sheets-Sheet 2

FIG. 4

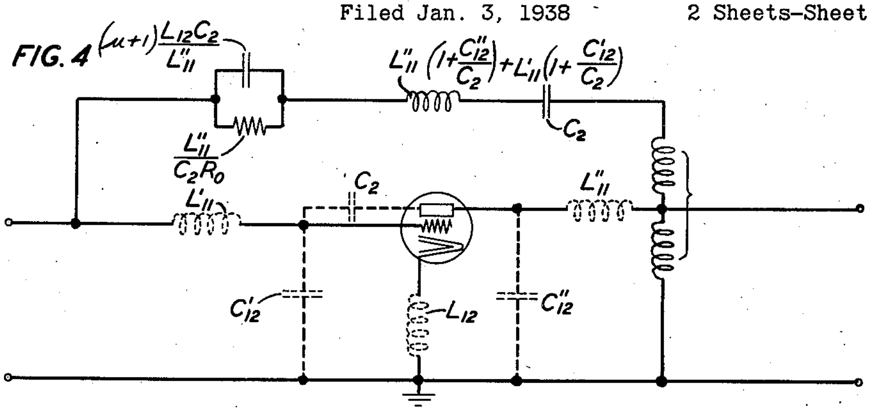
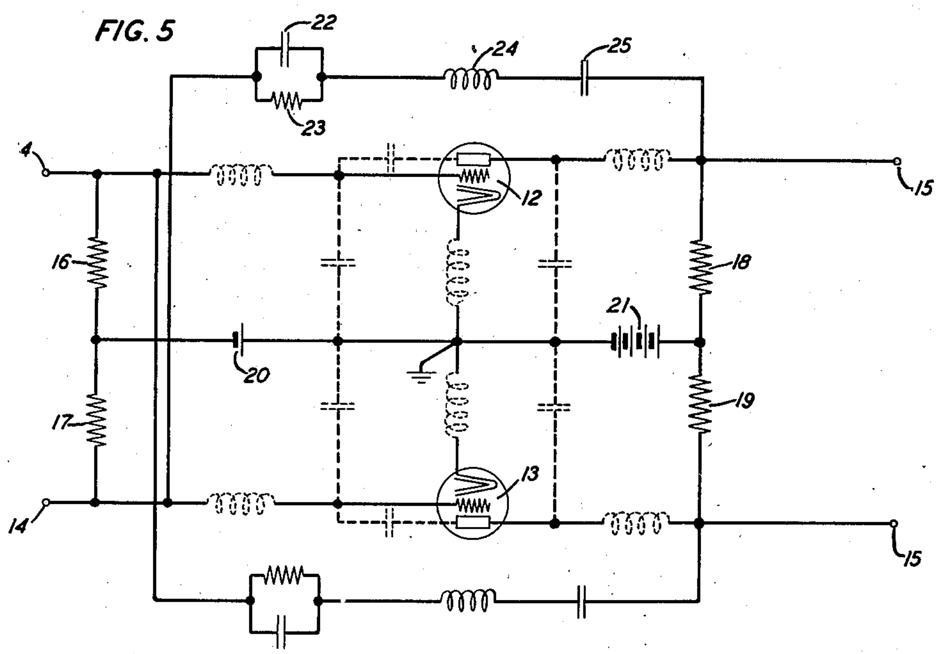


FIG. 5



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UNITED STATES PATENT OFFICE

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HIGH FREQUENCY AMPLIFIER

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Application January 3, 1938, Serial No. 182,955

6 Claims. (Cl. 179—171)

The present invention relates to electrical wave amplifying circuits, especially for use at high frequencies where the effect of parasitic impedances may prove troublesome.

The general object of the invention is to provide effective neutralization of the inherent tube and circuit capacities and inductances which, when not neutralized, reduce the effective transmission through the amplifier circuit or produce singing tendency.

The usual capacity neutralization of triodes or their equivalents proves inadequate as the frequencies become higher and higher principally because of the inductance of the tube leads which makes it impossible to locate the neutralizing capacity at the ideal position in the circuit.

The present invention provides a type of neutralizing network which takes account of the tube and circuit capacities and the lead inductances and gives a high degree of neutralization for the tube and circuit. In the treatment to follow the electron transit time is assumed to be negligibly small. While triodes are mentioned as examples, the invention is equally as applicable to pentodes and other types of tube with more than one grid, it being assumed that any grids other than the control grid are suitably bypassed to ground for alternating current.

The nature and objects of this invention will be more fully understood from the following detailed description of certain embodiments that have been chosen for illustration in the accompanying drawings:

Fig. 1 shows an impedance diagram corresponding to a triode with a neutralizing impedance, on which the calculations are based for a neutralized amplifier according to the invention; and

Figs. 2 to 5, inclusive, show in diagrammatic form physical embodiments according to the invention.

The diagram of Fig. 1 shows a triode with the principal parasitic or unavoidable impedances indicated that are significant at high frequencies. Starting at input terminal a there is a series input lead impedance Z_{11}' in the grid lead, for example the impedance inside the tube between the pin on the tube socket or tube envelope and the effective portion of the grid. There is at this point a shunt impedance to ground Z_{12}'. The internal grid-to-plate impedance is Z_2. The cathode lead impedance is Z_{12} and is the series impedance of the connecting lead to the active cathode surface. The plate lead series impedance between the anode and the output terminal b is Z_{11}'' and the shunt impedance to ground from the plate is Z_{12}''.

The invention is based upon the discovery that a single network can be found which will neutralize all of these parasitic impedances.

Assuming the four terminal network as in Fig. 1 with generalized impedances, applicant has found the following formula for the impedance of a series network which when connected between the terminals a and b through a 180 degree phase shifting arrangement, will neutralize the structure of Fig. 1 on the assumption of a negative grid.

$$Z_n=\left(1+\frac{Z_{11}'}{Z_{12}'}\right)\left[\frac{R_0'+Z_2}{R_0'}Z_{11}''+Z_2\left(1+\frac{Z_{11}''}{Z_{12}''}\right)\right]+ Z_{11}'\left[\frac{Z_{11}''}{R_0'}(\mu+1)+1+\frac{Z_{11}''}{Z_{12}''}\right] \quad (1)$$

In this expression $R_0'=R_0+(\mu+1)Z_{12}$ when R_0 is the internal plate resistance and μ the amplification constant.

The derivation of this formula is not given herein since the derivation, while straightforward, is long and very involved. The general method of solution is indicated, however, as follows: First, the general expression is written down for the input current as a linear function of the output voltage and input voltage for the tube circuit without the neutralizing network. A similar general expression is then written for the neutralizing network. By combining these two expressions, the general linear expression is obtained for the total input current in terms of input and output voltages for the complete structure of vacuum tube circuit and neutralizing network. Since the complete circuit is assumed to be neutralized, the input current is to be independent of the output voltage. Therefore, we equate to zero the coefficient of the output voltage in the general expression for the total input current. This leads directly to the expression for the impedance of the neutralizing network.

The problem now arises of finding a physically realizable network corresponding to the impedance function (1) after the functional forms of the parasitic elements have been assigned. We proceed here in steps and start with the following simple case.

Case 1—Zero grid and cathode lead impedances.—Since now $Z_{12}=0$ and $Z_{11}'=0$, Equation 1 reduces to

$$Z_n=\frac{R_0+Z_2}{R_0}Z_{11}''+Z_2\left(1+\frac{Z_{11}''}{Z_{12}''}\right) \quad (2)$$

Let us now further assume Z_2 and Z_{12}'' to be the impedances of pure capacities and Z_{11}'' the impedance of a pure inductance. Thus

$$Z_2=\frac{1}{pC_2},\ Z_{12}''=\frac{1}{pC_{12}''},\ Z_{11}''=pL_{11}''(p=i\omega,$$
$$i=\sqrt{-1},\ \omega=2\pi f,\ f=\text{cycles per second}) \quad (3)$$

and (2) becomes

$$Z_n=\frac{L_{11}''}{R_0C_2}+pL_{11}''\left(1+\frac{C_{12}''}{C_2}\right)+\frac{1}{pC_2} \quad (4)$$

which impedance function corresponds to a series resonance circuit containing all the three kinds of elements. With the assumptions made this network neutralizes exactly at all frequencies and it is to be noted that the impedance Z_{12}' does not enter. This particular case is illustrated in Fig. 2. The mutually coupled inductances **10** and **11** are for the purpose of giving the 180 degree phase shift assumed.

Case 2.—We now assume an impedance Z_{12} in the cathode lead but retain the assumption of zero impedance in the grid lead. Equation 1 then gives

$$Z_n=\frac{Z_0'+Z_2}{R_0'}Z_{11}''+Z_2\left(1+\frac{Z_{11}''}{Z_{12}''}\right) \qquad (5)$$

Assuming the cathode impedance Z_{12} to be a pure inductance L_{12} and the remaining parasitic elements defined by (3), Equation 5 reduces to

$$Z_n=pL_{11}''\left(1+\frac{C_{12}''}{C_2}\right)+\frac{1}{pC_2}+\frac{L_{11}''}{C_2}\cdot\frac{1}{R_0+p(\mu+1)L_{12}} \qquad (6)$$

The network corresponding to this impedance function consists of an inductance, a capacity and a capacity shunted by a resistance, all connected in series as is illustrated in Fig. 3. Again we observe the independence of the neutralizing network upon Z_{12}' and that the neutralization is exact under the stated assumptions.

Case 3.—We finally assume the grid to have a lead inductance L_{12}' and a capacity C_{12}' to ground, so that

$$Z_{11}'=pL_{11}',\ Z_{12}'=\frac{1}{pC_{12}'} \qquad (7)$$

Equation 1 reduces to

$$Z_n=p\left[L_{11}''\left(1+\frac{C_{12}''}{C_2}\right)+L_{11}'\left(1+\frac{C_{12}'}{C_2}\right)\right]+\frac{1}{pC_2}+$$
$$\frac{L_{11}''}{C_2}\,\frac{1}{R_0+p(\mu+1)L_{12}}+$$
$$L_{11}'L_{11}''\left(1+\frac{C_{12}'}{C_2}\right)\frac{p^2}{R_0+p(\mu+1)L_{12}}+$$
$$p^3L_{11}''L_{11}'\left(C_{12}''+C_{12}'+\frac{C_{12}'C_{12}''}{C_2}\right) \qquad (8)$$

Since this impedance function does not correspond to a physical network an exact neutralization is now not possible. However, one could design a network simulating the impedance (8) over a certain desired frequency band to a considerable degree of accuracy. Such a procedure would probably result in a too complicated structure unsuitable in the high frequency range.

We arrive at a first approximation by the observation that the first three terms of (8) correspond to a physical network and by the further observation that the small parasitic elements occur to a higher order than the first in the remaining terms. To a first approximation, therefore, we may take the first three terms of (8) and the physical configuration of this network is identical with that found for negligible grid lead inductance. The only modification required is in the value of the inductance of the neutralizing network. It is seen from the first term of (8) that to a first approximation the effect of the grid inductance and grid capacity is to introduce an inductance

$$L_{11}'\left(1+\frac{C_{12}'}{C_2}\right)$$

into the neutralizing network. This approximate neutralization arrangement is shown on Fig. 4.

For the sake of simplicity the foregoing discussion has dealt with the neutralization of a one tube circuit and it has been assumed that a means for reversing the phase was available, as for example, the transformer **10**, **11**. In practice it is difficult or impossible to build a transformer that will do this at very high frequencies, but resort may be had to a push-pull type of circuit for obtaining the necessary phase reversal. Such a circuit is illustrated in Fig. 5.

In this figure the tubes **12** and **13** have their grids connected to input terminals **14**, **14** across which is any suitable input impedance such as resistances **16** and **17** in series. The anodes are connected to output terminals **15**, **15** across which are impedances shown as resistances **18** and **19** in series. Grid bias battery **20** is connected between the cathodes and the junction of resistances **16** and **17**. Plate battery **21** is connected between the cathodes and the junction point of resistances **18** and **19**. Any other known or suitable means for providing grid bias and anode voltage may be used in place of the batteries shown. The parasitic impedances are shown in dotted lines and correspond to those indicated in the previous figures. The cross-neutralizing circuits are alike and each comprises a capacity **22** in shunt to a resistance **23** and both in series with an inductance **24** and a capacity **25** proportioned in accordance with the formulae above given and as indicated on Fig. 4. By comparison with Fig. 4 the corresponding elements will readily be identified.

It has been pointed out by F. B. Llewellyn in application Serial No. 104,193, filed October 6, 1936, now Patent No. 2,118,931, that at sufficiently high frequencies the inherent grid-to-plate impedance of a triode has an appreciable negative resistance component in series with the usually assumed capacity C_2 in the above discussion. To indicate how this may be taken into account in practicing my present invention, the following example is given. As a special and simplified case, assume negligiby small inductances in the grid and cathode leads (Z_{11}' and Z_{12}). The impedance between grid and plate is taken, in accordance with Llewellyn's findings,

$$Z_2=-r_2+\frac{1}{pC_2}\text{ where }r_2\geq 0$$

The neutralizing impedance then has the value

$$Z_n=\frac{L_{11}''}{R_0C_2}-r_2+pL_{11}''\left[\frac{C_{12}''}{C_2}-\frac{r_2}{R_0}\right]+\frac{1}{pC_2}-p^2rL_{11}''C_{12}''$$

To a first approximation we have

$$Z_n=\frac{L_{11}''}{R_0C_2}-r_2+pL_{11}''\left[\frac{C_{12}''}{C_2}-\frac{r_2}{R_0}\right]+\frac{1}{pC_2}$$

and the corresponding network consists of a series connection of resistance, inductance and capacity. It is, however, only physically realizable if

$$\frac{L_{11}''}{R_0C_2}\geq r_2\text{ and }\frac{C_{12}''}{C_2}\geq\frac{r_2}{R_0}$$

that is, when the negative resistance r_2 so combines with other elements as to make the resulting elements positive and therefore physically realizable.

What is claimed is:

1. In combination with a space discharge device having a cathode, an anode and a control grid, input and output circuits connected to the cathode and respectively to the grid and anode,

said device having inherent capacity between its grid and anode and the anode lead to said output circuit having effective series inductance, and a two-terminal network connected from a point of proper phase in the output circuit to the grid and consisting of capacity, inductance and resistance in series relation with one another, said network having its elements proportioned with respect to the other elements of the circuit to neutralize the said inherent capacity and effective inductance.

2. In combination with a space discharge device having a cathode, an anode and a control grid, input and output circuits connected to the cathode and respectively to the grid and anode, said device having inherent capacity between its grid and anode, the anode lead to said output circuit having effective series inductance and the lead from said cathode to said input and said output circuits having effective series inductance, and a two-terminal network connected through a phase reversing device from the output circuit to the grid consisting of a parallel resistance and capacity in series relation with a capacity and an inductance, said network having its elements proportioned with respect to the elements of the circuit to neutralize the said inherent capacity and effective inductances.

3. In a push-pull amplifier having an input circuit connected to the grids and an output circuit connected to the plates, cross-neutralizing circuits connected from the plate of each tube to the grid of the other tube, each neutralizing circuit comprising in series an inductance, a capacity and a resistance shunted by a capacity, the values of said inductance, resistance and capacity elements being proportioned to make the amplifier unilaterally conductive.

4. In an amplifier, a discharge device having a cathode, an anode and a control grid, with an interelectrode capacity C_2 between control grid and anode, an output terminal, a lead inductance L_{11}'' between the anode and said output terminals, an anode cathode shunt capacity C_2 and an internal anode-cathode resistance R_0, means for neutralizing the effect of C_2 and L_{11}'' on the transmission characteristic comprising a circuit connected between the grid and said output terminal consisting of a phase-reversing means in series with a capacity of value C_2, an inductance of value

$$L_{11}''\left(1+\frac{C_{12}''}{C_2}\right)$$

and a resistance of value

$$\frac{L_{11}''}{R_0C_2}$$

5. An amplifier according to claim 4 having also a cathode lead inductance L_{12} and a capacity of value

$$(\mu+1)\frac{L_{12}}{L_{11}''}C_2$$

in shunt to said resistance, the resulting neutralizing circuit serving to neutralize the effect on the transmission characteristic of C_2L_{11}'' and L_{12}.

6. A push-pull space discharge circuit having the grids connected to respectively opposite input terminals and the anodes connected to respective output terminals, inherent grid-to-plate capacities and effective inductance in the anode and cathode leads, cross-neutralizing circuits connected from each output terminal to the opposite input terminal, each neutralizing circuit comprising in series a capacity equivalent in value to the grid-to-plate capacity of the corresponding space discharge device, an inductance and a parallel-connected capacity and resistance, for neutralizing said grid-to-plate capacity and said effective inductance in the anode and cathode leads.

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