July 18, 1933. W. H. T. HOLDEN 1,918,393

AMPLIFIER OF ALTERNATING CURRENTS

Filed Aug. 22, 1931

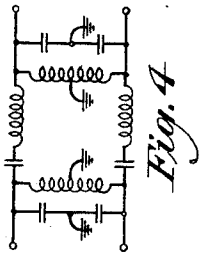


Fig. 4

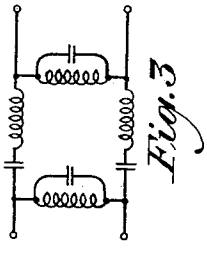


Fig. 3

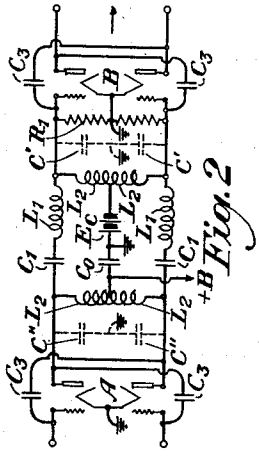


Fig. 2

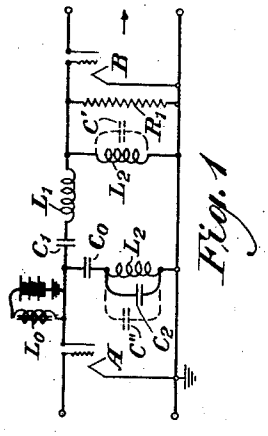


Fig. 1

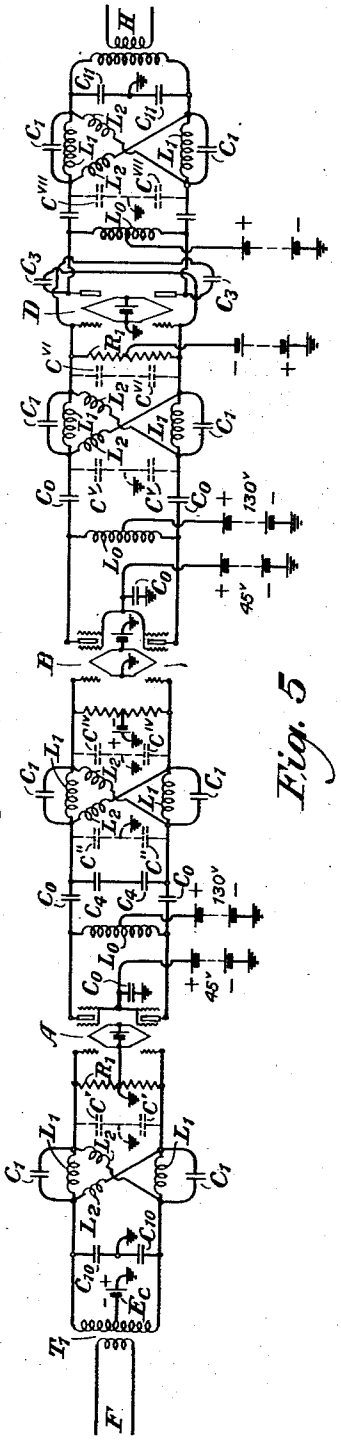


Fig. 5

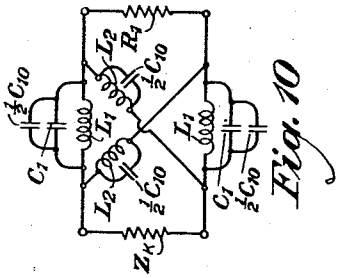


Fig. 10

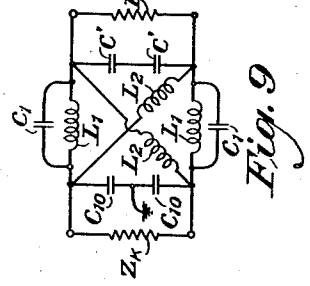


Fig. 9

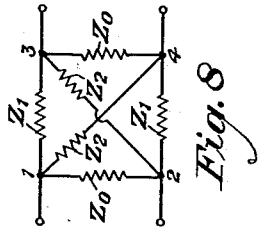


Fig. 8

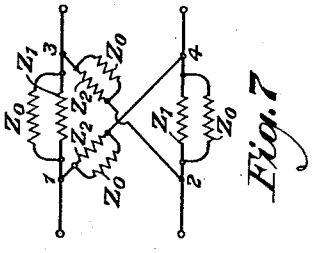


Fig. 7

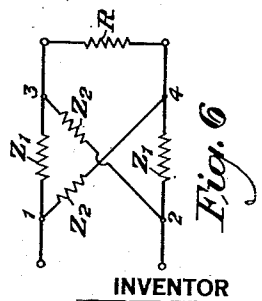


Fig. 6

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Patented July 18, 1933 1,918,393

UNITED STATES PATENT OFFICE

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AMPLIFIER OF ALTERNATING CURRENTS

Application filed August 22, 1931. Serial No. 558,766.

This invention relates to amplifiers of alternating currents, and more particularly to amplifiers which will operate effectively over a wide frequency band. Its object is to produce an amplifier, particularly for high frequency, which will treat all frequencies within certain working limits in the same way. Another specific object is that of neutralizing the effect of the capacities between the elements in a vacuum tube. Still another object is to do this in a manner which makes the amplifier independent of capacities to ground.

High frequency amplifiers have been built of two types, tuned to amplify a single frequency or a narrow band and untuned to amplify wide bands. The latter type has not generally been as satisfactory for frequencies in the broadcasting range, and their use is relatively infrequent in present practice. This is largely because of the shunting effect of the inter-electrode capacity of the vacuum tubes, which decreases the effectiveness of the amplifier at the higher frequencies.

I overcome these effects and thus accomplish the objects of my invention in part by using amplifier circuit arrangements associated with networks of certain types in which the capacities within the amplifying tube become a portion of a more extensive network, preferably of the band pass type of filter, the pass band filter covering that portion of the frequency spectrum which it is desired to use.

The invention will be better understood by reference to the following specification and the accompanying drawing, in which Figure 1 shows the application of my invention in a simple form; Fig. 2 shows a modification thereof in which, for the sake of symmetry, a balanced push-pull vacuum tube amplifier circuit is used; Figs. 3 and 4 are circuit diagrams which are to be used in the explanation of Figs. 1 and 2, respectively; Fig. 5 shows a further elaboration of my invention to a three-stage amplifier; and Figs. 6 to 10 are schematic diagrams useful in connection with the explanation of the circuit of Fig. 5.

Referring to Fig. 1, there are shown the essential portions of a two-stage amplifier comprising the vacuum tubes A and B. The output of the tube A is shown as supplied with voltage through the choke coil L_0, the alternating current output circuit of the tube being connected to the input circuit of the tube B through a network which, as will appear later, is one section of a ladder type filter. Appearing directly across the plate to filament is the inductance L_2 with the condenser C_0 of large capacity serving as a blocking condenser for direct current. Also connected to the plate of A and extending directly to the grid of B, is a circuit consisting of the condenser C_1 and inductance L_1 and across the grid circuit is a second inductance L_2 in parallel with a resistance R_1. It will be noted that the capacity from filament to plate of the tube A is connected in parallel to the first inductance L_2 and is represented in the circuit by the dotted condenser C''. Also it will be observed that the capacity from grid to filament of tube B is in parallel to the second inductance L_2 and is represented in the circuit by the dotted condenser C'. An expansion of this figure now reveals that between the amplifiers A and B there is a section of network of the ladder type commonly used in wave filters and shown more clearly in Fig. 3. By suitable choice of the values of the inductances L_1 and L_2 and condensers, this filter section may be adapted to have a pass band in any region of the frequency spectrum desired and over this band there will be no attenuation. If the capacities C' and C'' are not equal to each other, then it will be desirable that the two inductances L_2 should be of suitable different values or the difference may be compensated for by having in parallel with one of the inductances L_2, say the first one, a condenser C_2, which condenser in parallel with the capacity C'', yields a capacity equal to C'. In the event that the capacity C' is less than C'', then, of course, the capacity C_2 should be placed in parallel with C'. Under these circumstances there will be no attenuation of the high frequency voltage impressed on the grid of the second tube as a result of the input capacity of that second tube so long as the frequency

transmitted lies within the transmission band of the filter section thus shown.

The circuit of Fig. 1 is for illustrative purposes only, and for simplicity has been shown as connected between two stages of amplifier tubes. Obviously, a similar filter, preferably corresponding to a half section, should be inserted in the input of the first tube and the output of the second tube.

A filter of the type described should for its proper functioning be terminated by a load the impedance of which is equal to the impedance of the section itself. Thus the plate circuit of the tube A has a certain ohmic resistance and the values of the inductances and capacities of the filter section would in general be chosen of such value as to have a characteristic impedance equal to that of the plate circuit of the tube A at the same time as they cover the band of frequencies to be transmitted. Similarly across the output of the filter section there should be a load of this same characteristic impedance, and this is provided by a resistance R_1 of the appropriate value. Under these circumstances there will be no echo or reflection effects within the circuit.

As a further illustration of my invention, reference may be made to Fig. 2, in which the same principles are applied to a push-pull circuit. Here again, the amplifiers A and B are connected in tandem, each stage being push-pull, and there is shown 95 a coupling between the two stages a network analogous to that of Fig. 1. B battery in this case is applied to the plates of the first amplifier through the inductances L_2, one for each side of a push-pull circuit. The capacities from filament to plate of each of these tubes is shown in dotted lines by C'' and the capacities from filament to grid of the amplifier B are similarly shown in dotted lines by the condensers C'. In a manner similar to that of Fig. 1 series condenser C_1 and inductance L_1 are connected from plates of amplifier A to grids of amplifier B and inductances L_2 are connected across the input circuit of the amplifier B, these inductances being in parallel with resistance R_1. A blocking condenser C_0 of reasonably large capacity is connected from the midpoint of the first inductances L_2, thus giving a low impedance path for the alternating currents to ground or filaments of amplifier A. Also, grid biasing battery E_c may be introduced in the usual way. It will now be observed that this Fig. 2 comprises two stages of amplification coupled together by means of one section of a ladder type filter, such filter section being shown for simplification in Fig. 4. It will be observed that this section is a symmetrical one, making it possible to ground the midpoints of the shunt elements in a manner necessary for the proper operation of the tubes and yet in a manner which does not interfere with the operation of the network as a filter section.

As described in connection with Fig. 1, it is desirable that the filter section shall be terminated in a load whose impedance is matched with that of the filter section. This is accomplished through the resistance R_1 which is given the appropriate value for such matching.

In this Fig. 2 there is shown in each amplifier a condenser C_3 from the grid of each tube to the plate of the other tube, this being an old and useful expedient to neutralize the tendency of these amplifiers to "sing".

A further modification and a preferred form of my invention is illustrated in Fig. 5, which shows three stages of amplification, each stage being push-pull, the first two stages being of the type of tube known as screen grid tubes and the filter sections being of the form known as the lattice type. An incoming line F is connected by means of transformer T_1 to the input terminals of the push-pull amplifiers A, there being a filter section of the lattice type connected between the transformer and the amplifier, and the details of which will be described later. The plates of this amplifier A are connected through choke coils L_0 to positive of B battery, and the screen grids are connected directly to a positive point on the B battery with a by-pass condenser C_0 to ground. The output of the amplifier A is connected through blocking condensers C_0 and a filter section to the input of a similar amplifier B, and the output of this amplifier is connected through blocking condensers C_0 and a filter section to the input of the amplifier D, this amplifier being shown as of the usual three-element type, and is of a form adapted to deliver a substantial amount of power, the connections therefor being similar to that shown for the amplifiers of Fig. 2. The output of the amplifier D is supplied through a filter section and transformer to outgoing line H.

A better understanding of this invention will be had by reference to Figs. 6 to 10 which may be used for deriving the relationships and characteristics peculiar to the lattice type network. Thus a lattice type network of the form shown in Fig. 6 has an iterative impedance given by

$$Z_k = \sqrt{Z_1 Z_2} \quad (1)$$

and a propagation constant given by

$$P = 2 \tanh^{-1} \sqrt{\frac{Z_1}{Z_2}} \quad (2)$$

In case Z_1 and Z_2 are of opposite signs, as will in general be true for certain frequencies or ranges of frequencies, then the filter is a band pass filter over that region. On the

other hand, if Z_1 and Z_2 are of the same sign, then the filter for such frequencies is a stop band filter. In order that there shall be no reflection or echo effects produced with such a filter, it is important that the output terminals 3 and 4 shall be connected to an impedance R equal to the iterative impedance of the network.

Let us now consider the network of Fig. 7 which differs from Fig. 6 in that each branch of the lattice network has been shunted by an impedance Z_0. By the usual circuital theorems it can readily be shown that the impedance at 1 and 2 when 3 and 4 are short-circuited, is

$$Z_s = 2\frac{Z_1 Z_2 Z_0}{2Z_1 Z_2 + Z_0 Z_1 + Z_0 Z_2} \quad (3)$$

and the impedance at 1 and 2 with 3 and 4 open is

$$Z_\infty = \frac{Z_0}{2}\left[\frac{2Z_1 Z_2 + Z_0 Z_1 + Z_0 Z_2}{(Z_2 + Z_0)(Z_1 + Z_0)}\right] \quad (4)$$

Let us now consider the circuit of Fig. 8 which is similar to Fig. 6, except that impedances Z_0 have been bridged across the terminals 1 and 2 and across the terminals 3 and 4. It will be found that the impedance at 1 and 2 with 3 and 4 short-circuited is identically the same as for the corresponding case of Fig. 7. Also it will be found that the impedance at 1 and 2 with 3 and 4 open is identically the same as that for the corresponding case for Fig. 7. Therefore the networks 7 and 8 are electrically equivalent to each other. These results may be applied more specifically now to Fig. 5 by referring to Figs. 9 and 10. In Fig. 9 there is shown a network which is similar to that encountered in Fig. 5 at the input of the amplifier A and terminating in the resistance R_1 of proper magnitude. It will be noted that the circuit of Fig. 9 is similar to that of Fig. 8, the impedance Z_0 being replaced by the two condensers C_{10} in series or the two condensers C' in series. Furthermore, just as the circuit of Fig. 7 may be derived from the circuit of Fig. 8, so the circuit of Fig. 10 may be derived from the circuit of Fig. 9. Such derivation consists in shunting the inductances L_1 and L_2 of Fig. 9 by capacities equal to $\frac{1}{2}$ C_{10}, it being understood that the capacities C_{10} and C' are equal to each other, this having been provided for in Fig. 5. The usual design formulæ applicable to the lattice type network may now be applied to Fig. 10 with the assurance that they apply equally well to the circuit of Fig. 9. Such formulæ may be found in various treatises on the subject of wave filters, as in an article by G. A. Campbell in Bell System Technical Journal, Vol. I, No. 2, pages 1 to 64, or in application to Mason, Serial No. 489,269, filed October 17, 1930.

Reference to the above will show that the filter of Fig. 10 is a pass band filter from the frequency f_1 to f_2 where

$$f_1 = \frac{1}{2\pi\sqrt{L_1\left(C_1 + \frac{1}{2}C_{10}\right)}} \quad (5)$$

and

$$f_2 = \frac{1}{2\pi\sqrt{\frac{1}{2}L_2 C_{10}}} \quad (6)$$

and the iterative impedance is given by

$$Z_k = \frac{2f_1 f_2 \sqrt{L_1 L_2}}{(f_1 - f_2)} \quad (7)$$

It will be noted that the filter section of the type of Fig. 9 occurs before and after each amplifier stage in Fig. 5, thus giving a filter of four sections with certain amplification between the various stages. Throughout Fig. 5 C_0 is used to indicate a blocking condenser which in general would be sufficiently large so that its impedance for the frequency to be amplified is negligible. It will be noted, also, that in the output of each amplifier there is a choke L_0, this being an inductance of sufficient magnitude to offer substantially infinite impedance to the alternating currents to be amplified and very low impedance to direct current.

In the first filter section the condensers C_{10} are to be adjusted to the capacity C', and similarly, in the last section, the condenser C_{11} is adjusted to the capacity C^{VIII}. In the second filter, however, placed between the amplifiers A and B, it will not occur in general that the capacity from plate and screen grid to the filament will be equal to the input capacity of the amplifier B. Any lack of equality can, however, readily be adjusted for by supplemental condensers such as C_4. If the circumstances are such that the input capacity of amplifier B is smaller than the output capacity of A, then, of course, the supplemental condensers should be associated with the input of the amplifier B. It is to be understood that similar adjustments may be made in any of the other filters if need arises.

I have described in detail the use of a lattice type of filter section and prefer this form because of the relative simplicity of the design formulæ involved and the transformation from the standard type to the type shown in Fig. 5. It is to be understood, however, that my invention is not limited to such filters but that these may take on any form, of which one illustration is given in Figs. 1 and 2.

What is claimed is:

1. A vacuum tube amplifying circuit for amplifying frequencies over a given band, comprising two tubes associated in push-pull combination, and a filter associated with one

pair of terminals thereof and adapted to pass the desired frequency band, the capacities of the tubes as seen from said terminals being elements in the filter.

2. A vacuum tube amplifier circuit for amplifying frequencies over a given band, comprising two tubes associated in push-pull combination, and a lattice type filter in the input circuit with the input capacities of the tubes as elements thereof and with additional elements to compensate therefor.

3. A vacuum tube amplifier circuit for amplifying frequencies over a given band, comprising two tubes associated in push-pull combination, and a lattice type filter in the output circuit with the output capacities of the tubes as elements thereof and with additional elements to compensate therefor.

4. A vacuum tube amplifier circuit for amplifying frequencies over a given band, comprising a plurality of stages of amplification, each stage comprising two tubes associated in push-pull combination, and a lattice type filter between any two stages thereof, the internal capacities of the output terminals of one stage and the internal capacities of the input terminals of the next stage being elements in the filter, these with other elements making the filter a pass band filter over the given band.

5. A vacuum tube amplifier circuit for amplifying frequencies over a given band, comprising a vacuum tube and a filter associated with the input circuit and adjusted to pass the desired frequency band, the input capacity of the tube being an element in the filter a resistance across the input circuit of such value as to substantially match the characteristic impedance of the filter.

6. A vacuum tube amplifier circuit for amplifying frequencies over a given band, comprising a vacuum tube and a filter associated with the output and adjusted to pass the desired frequency band, the output capacity of the tube being an element in the filter, the values of the elements in the filter being such that the characteristic impedance of the filter is equal to the internal impedance of the tube across its output terminals.

7. A vacuum tube amplifier circuit for amplifying frequencies over a given band, comprising a vacuum tube, a filter associated with the input, and a filter associated with the output circuit, each adjusted to pass the desired frequency band, the input capacity and the output capacity of the tube being elements in the filters, and the characteristic impedance of the filters being adjusted so that there are no echo or reflection effects at the connections to the tube.

8. A vacuum tube amplifier circuit for amplifying frequencies over a given band, comprising two stages of vacuum tube amplifiers and a filter connected between the two stages, the internal capacity of the output terminals of the first stage and the internal capacity of the input terminals of the second stage being elements in the filter, these elements with others making the filter a band pass filter over the given range, the characteristic impedance of the filter being made equal to the output impedance of the first tube.

9. The combination of claim 8 characterized by a resistance across the grid of the second tube of such value that the filter is terminated in its characteristic impedance.

10. The combination of claim 8 characterized by a supplemental condenser in the filter to equalize the internal capacities of the output of the first tube and the input of the second tube, and further characterized by a resistance across the grid of the second tube of such value that the filter is terminated in its characteristic impedance.

11. A vacuum tube amplifier circuit for amplifying frequencies over a given band, comprising a screen grid vacuum tube amplifier, a filter associated with the output circuit thereof and adjusted to pass the desired frequency band, the capacity of the plate and the screen grid being an element in the filter.

12. The combination of claim 1 characterized by the fact that the filter is of the symmetrical type with midpoints of the shunt elements grounded.

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