April 16, 1946. W. E. BRADLEY 2,398,691

WIDE BAND AMPLIFIER

Filed April 28, 1944

Fig. 1.

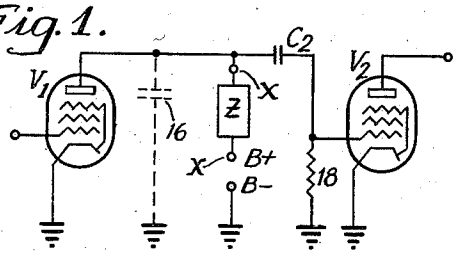


Fig. 2.

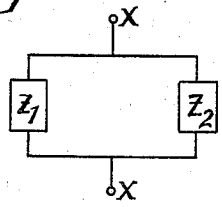


Fig. 3.

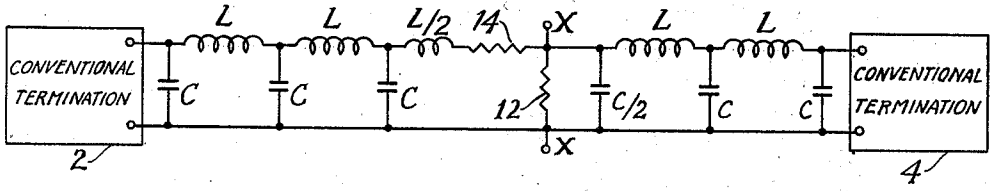


Fig. 5.

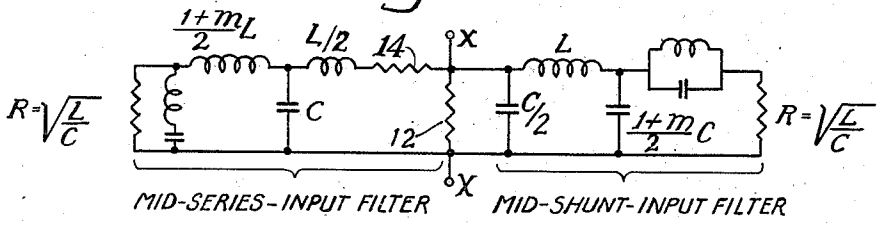


Fig. 6.

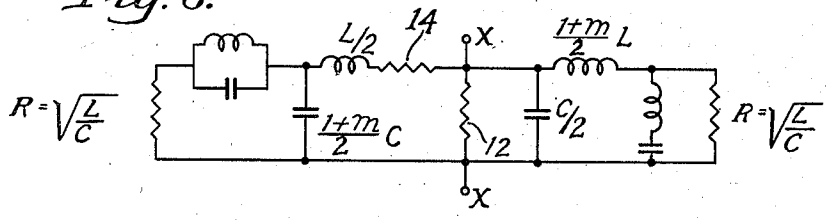


Fig. 4

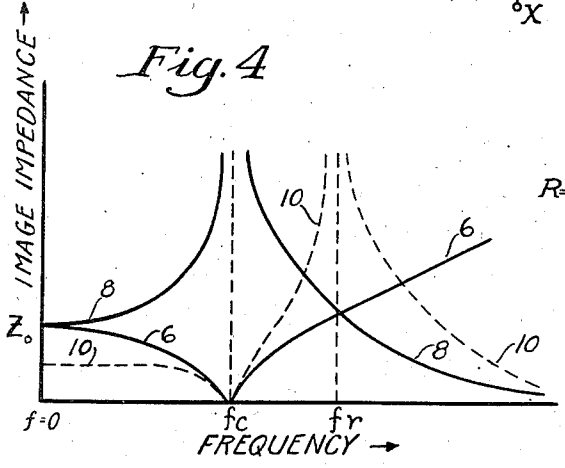
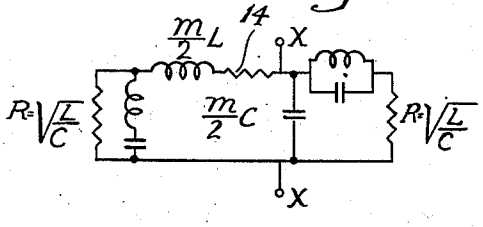


Fig. 7.



INVENTOR
William E. Bradley
BY
Howson & Howson
ATTORNEYS

Patented Apr. 16, 1946

2,398,691

UNITED STATES PATENT OFFICE

2,398,691

WIDE BAND AMPLIFIER

William E. Bradley, Swarthmore, Pa., assignor to Philco Radio and Television Corporation, Philadelphia, Pa., a corporation of Delaware

Application April 28, 1944, Serial No. 533,225

6 Claims. (Cl. 179—171)

This invention relates to amplifiers, and more particularly to wide-band amplifiers which are constructed and arranged to introduce no time delay at any frequency within a predetermined transmission band.

One of the recognized effects produced by the conventional amplifier stage is that the phase of the amplifier's output signal is shifted with respect to the phase of the input signal. The phase shift produced by a given amplifier is, in general, a function of the signal frequency. This phase shift increases with the number of stages. In many applications phase shift is not disadvantageous so long as the phase shift produced by the amplifier increases linearly with frequency. This condition is difficult to obtain, however, particularly in wide-band multi-stage amplifiers, and consequently efforts in this direction have not always been satisfactory. In other instances, the presence of any phase shift whatever, whether linear or not, is disadvantageous. The present invention is directed toward novel means for preventing the occurrence of time delay or phase shifts in amplifiers.

Accordingly it is a principal object of the present invention to provide an amplifier which is capable of transmitting a predetermined band of signal frequencies without substantial time delay.

It is another object of the present invention to provide an improved coupling impedance for use between vacuum tube stages, which impedance is constructed and arranged to present a pure resistance at all frequencies within a predetermined transmission band.

It is a further object of the invention effectively to overcome the deleterious effects of the plate-output and grid-input capacities of vacuum tubes.

It is another object of the invention to provide a novel coupling impedance, which impedance is capable of "absorbing" certain undesired shunt capacitances inherently associated with the circuits to be coupled.

It is still another object of the invention to provide a novel load network for use with vacuum tubes, which network shall have a substantially constant resistive impedance throughout a desired or predetermined transmission band.

Other objects and purposes of the invention will be apparent to those skilled in the art from the following description and the accompanying drawing, in which:

Fig. 1 is a schematic wiring diagram of a pair of vacuum tube amplifier stages coupled by means of an impedance Z;

Fig. 2 is a block diagram of an improved form of the impedance Z of Fig. 1;

Fig. 3 is a schematic diagram of the load impedance of the present invention in a basic and highly developed form;

Fig. 4 is an explanatory diagram which represents graphically certain of the impedance-versus-frequency characteristics of elements of the present invention;

Fig. 5 is a schematic diagram of a more practical form of the invention;

Fig. 6 is a schematic circuit diagram of a simplified coupling network; and

Fig. 7 is a schematic circuit diagram of a highly simplified coupling circuit.

Reference is first made to the circuit of Fig. 1 in which the environment of the invention is illustrated. This circuit comprises a pair of vacuum tubes V_1 and V_2 which are coupled, in conventional manner, by means of the plate load impedance Z and the coupling condenser C_2. Plate current may be supplied to the amplifier tube V_1 by means of a suitable battery or other source (not shown) connected to the terminals designated B— and B+. The present invention relates to an improved impedance Z, the terminals of which are designated $x — x$ in Fig. 1. In the interest of simplicity the vacuum tube amplifier circuit will not be repeated in the subsequent figures, but the terminals of the improved coupling network, which forms the basis of the present application, will also be designated $x — x$, and it will be understood that such coupling networks may be connected in the circuit of Fig. 1 in place of the generalized coupling network Z.

Fig. 2 shows, diagrammatically, an improved plate load or coupling network constructed in accordance with the principles of the present invention. According to the invention the improved load impedance comprises the parallel combination of the mid-series input impedance, Z_1, of a filter terminated in its characteristic impedance, and the mid-shunt input impedance, Z_2, of a second filter terminated in its characteristic impedance. Preferably both filters should be constructed and arranged to have like characteristic impedances, and like cut-off frequencies. As will be shown hereinafter the parallel combination of such a pair of impedances Z_1 and Z_2, may be a nearly constant pure resistance throughout a predetermined transmission band.

The basic schematic form, or prototype, of the improved impedance illustrated diagrammatically

in Fig. 2, is illustrated in detail in Fig. 3. It will be understood that more complex types, such as the *m*-derived types, may also be used to advantage. In Fig. 3 the portion of the system to the left of the terminals *x*—*x* represents, schematically, the impedance Z_1, while the portion of the circuit to the right of the terminals *x*—*x* represents, schematically, the impedance Z_2. The impedance Z_1 consists, it will be observed, of a conventional low pass filter having a conventional mid-series input section. That is, the input section includes a series inductance element whose inductance is half that of the other series inductance elements. The filter may be of the constant *k* type and there may be as many sections, each comprising series inductance L and shunt capacity C, as may be desired. The filter, if it is not infinitely long, may be terminated conventionally, in its characteristic impedance, through the agency of a conventional terminating section 2.

The portion of the load impedance to the right of the terminals *x*—*x* comprises a conventional low-pass filter section having a conventional mid-shunt input section. That is, the input section includes a shunt capacitance of half the capacity value of the other shunt capacitance elements. This filter may also be of the constant *k* type, and there may be as many sections comprising series inductance L and shunt capacity C as may be desired. This filter may also be terminated conventionally, through the agency, for example, of any suitable terminating section 4.

It is emphasized that the individual filters utilized in the embodiments of Figs. 2 and 3 are, in themselves, entirely conventional, and consequently it is deemed unnecessary to repeat here any of the highly developed and well-known filter theory which will be used by those skilled in the art in the practice of the present invention. The filters employed may, of course, consist of any desired number of sections, each having a nominal characteristic impedance Z_0 equal to the square root of L/C. Both the mid-series input filter Z_1 and the mid-shunt input filter Z_2 should be designed to have the same nominal characteristic impedance, Z_0, and both should have the same cut-off frequency, f_c. As used in the specification and in the claims, the term Z_0, or "nominal characteristic impedance," refers to the input impedance of a properly terminated filter network at or near zero frequency (see Fig. 4).

The basic concepts of the invention, as embodied in Figs. 2 and 3, are best described with reference to the explanatory diagram of Fig. 4. The impedance characteristic 6—6 shows how the "mid-series image impedance" of a filter having a mid-series input section varies with frequency between the limits of zero frequency (direct current) and a frequency well above the cut-off frequency, f_c, of the filter. Within the range $f=0$ to f_c the impedance of such a filter is purely resistive, being equal to Z_0 at zero frequency, falling off gradually to zero at the cut-off frequency, f_c, at which point the series input inductance resonates with the first shunt capacitance. Beyond this frequency the filter exhibits an inductive reactance, the impedance rising generally as shown.

The impedance characteristic 8—8 shows how the "mid-shunt image impedance" of a filter having a mid-shunt input section varies with frequency. Within the range from $f=0$ to the cut-off frequency, f_c, the impedance of such a filter is also purely resistive, and rises from the characteristic impedance Z_0, approaching infinity at f_c. Beyond f_c the filter exhibits a capacitive reactance, and the impedance of the filter drops off as shown, approaching zero impedance asymptotically.

By the present invention an improved plate load, or coupling, impedance is provided by connecting in parallel the input terminals of a pair of filters having characteristics of the type illustrated at 6—6 and 8—8 in Fig. 4. The parallel combination of two such filters results in a load network having a zero-frequency impedance of one-half Z_0. Since the impedance of the two filters individually is purely resistive below the cut-off frequency, it follows that the impedance of the two filters in parallel is also purely resistive in this range. Moreover, since the individual input impedances of the two filters deviate in opposite senses from their zero-frequency impedance as f_c is approached, it also follows that the input impedance of the two filters in parallel will be much more nearly constant throughout the pass-band. This desirable effect is clearly shown in Fig. 4 by the combined impedance characteristic 10—10—10. Beyond the cut-off frequency f_c, the impedance of the network becomes reactive, approaching infinity at the frequency where the impedance characteristics 6 and 8 intersect. In the drawing this frequency is designated f_r. At the latter frequency the impedance of the network may be so high as to produce "singing" of the amplifier system, and consequently it is usually desirable to limit this impedance and thus to forestall such tendency by damping the network. This may be readily accomplished by shunting a suitable damping resistor 12 across the input terminals *x*—*x* of the network. In addition it may be desirable to insert a series damping resistor 14 in the connection to the inductance element L/2 of the mid-series input section of the filter extending to the left of the terminals *x*—*x*. Preferably the resistance of the shunt damping resistor 12 should be high compared to the qsuare root of L/C. The resistance of the series damping resistor 14 should, on the other hand, be low compared to the square root of L/C. It will be evident that, if desired, the shunt damping effect may be taken care of by the grid leak resistor 18, Fig. 1, in which case the resistor 12 may be omitted.

The load impedance Z presented by the network of Fig. 3 is evidently a substantially constant resistance over the frequency band extending from zero frequency (direct current) to some upper limit just below the cut-off frequency f_c of the individual filters. Accordingly a signal voltage, whose frequency lies within this range, will experience no time delay in passing through an amplifier employing plate load impedances of this type.

Returning to Fig. 1, the load impedance Z is, in practice, inevitably shunted by a capacitance which is due to the distributed capacitance to ground of the leads and of the associated tube elements. This deleterious shunt capacity is represented in Fig. 1 by the dashed-line condenser 16. According to the present invention this deleterious capacity may be effectively "absorbed" by simply reducing the value of the input condenser C/2 of Fig. 3 by the capacity of the deleterious capacity 16. If, perchance, the capacity 16 should just equal the capacity C/2 of Fig. 3, the latter may be omitted entirely.

It will be understood, of course, that where D. C., or very slowly varying, voltages are to be transmitted by the amplifier of Fig. 1, the cou-

pling condenser C_2 must be removed, and resort had to a conventional conductive coupling arrangement.

In general it is possible to approach the ideal form of the invention to a sufficient degree of accuracy by means of networks which are much simpler than that illustrated in Fig. 3. Such a simplified network is illustrated in Fig. 5. The filter network extending to the right of the input terminals x—x consists of a conventional mid-shunt input section, followed by a half-section constant k filter, and terminated in a conventional m-derived termination. The filter network extending to the left of the terminals x—x is provided with a conventional mid-series input section, followed by a half-section constant k filter terminated in a conventional m-derived mid-series terminating section. The terminations of both filters include the customary shunt resistor R whose resistance is equal to the square root of L/C. It may be observed that in the circuits of Fig. 5 (et seq.) the mid-series input filter and the mid-shunt input filter are terminated differently. Thus in Fig. 5 the former is provided with a conventional mid-series terminating section, while the latter is provided with a conventional mid-shunt terminating section. It will be evident to those skilled in the art, however, that both filters may be similarly terminated, it being necessary only to adhere to the usual filter design conventions.

The plate load impedance illustrated schematically in Fig. 6 represents a further simplification of the system of Fig. 3. In Fig. 6, as well as in certain of the other figures, not all of the reactance elements have been specifically dimensioned. In general only certain key dimensions which will serve to identify the system to those skilled in the art have been set forth in the drawing. It will, of course, be understood that the invention is not limited to the specific values designated in the drawing.

The embodiment of Fig. 7 represents a still further simplification. While this modification will give an impedance which is fairly constant and approximately resistive over the entire pass-band, its performance is less desirable than that of the previously described embodiments.

It will be evident that the invention is not limited to the specific forms and embodiments illustrated, since further modifications falling within the spirit and scope of the present invention will be apparent to those skilled in the art.

I claim:

1. In a vacuum tube amplifier, a pair of vacuum tubes, a two-terminal coupling impedance connected as a load impedance in the output circuit of the first of said tubes, and means coupling the input electrodes of the other of said tubes to the two terminals of said load impedance, said load impedance comprising the parallel combination of a first filter network provided with a mid-shunt input section and a second filter network provided with a mid-series input section.

2. In a wide-band vacuum tube amplifier, a pair of vacuum tubes, a two-terminal coupling impedance connected as a load impedance in the plate circuit of the first of said tubes, and means connecting the input circuit of the other of said tubes in shunt with said load impedance, said load impedance comprising a mid-series input filter connected in parallel with a mid-shunt input filter, whereby said coupling impedance presents a purely resistive, substantially constant impedance over a predetermined wide range of frequencies.

3. In a vacuum tube amplifier, a pair of vacuum tubes, a two-terminal coupling impedance connected as a load impedance in the plate circuit of the first of said tubes, and means coupling the input electrodes of the other of said tubes to the two terminals of said load impedance, said load impedance comprising a pair of terminated low-pass filters having their input circuits connected in parallel, said parallel-connected input circuits providing the two terminals of said coupling impedance, the first reactive element of one of said filters being a series inductive element, the first reactive element of the other of said filters being a shunt capacitive element, the capacitance of said capacitive element being less than the normal computed value by substantially the magnitude of the deleterious capacitances in shunt with the associated tube elements.

4. In a vacuum tube amplifier, a pair of vacuum tubes, a two-terminal coupling impedance connected as a load impedance in the plate circuit of the first of said tubes, and means connecting the input electrodes of the other of said tubes to the two terminals of said load impedance, said load impedance comprising the parallel combination of the mid-series input impedance of a first filter terminated in its characteristic impedance, and the mid-shunt input impedance of a second filter terminated in its characteristic impedance.

5. A vacuum tube amplifier as claimed in claim 4, characterized in the application of dissipative means to at least one of said filters to prevent "singing" at frequencies outside the pass-band of said filters.

6. A vacuum tube amplifier as claimed in claim 4, wherein both filters have substantially the same nominal characteristic impedances, and both have substantially identical pass-bands.

WILLIAM E. BRADLEY.