

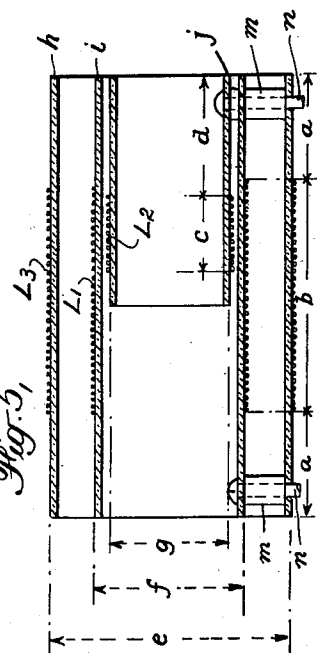
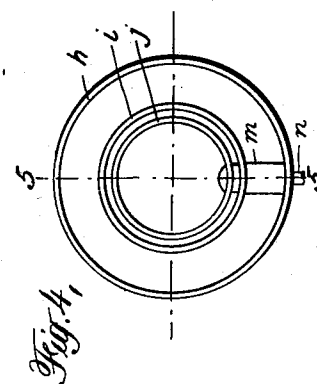
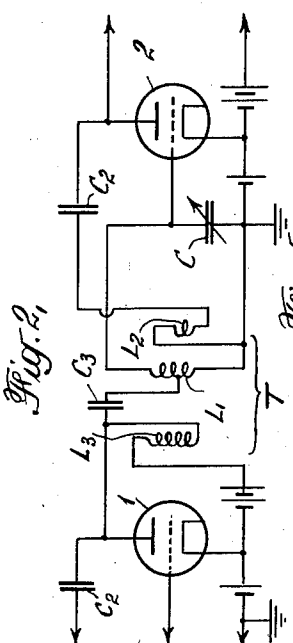
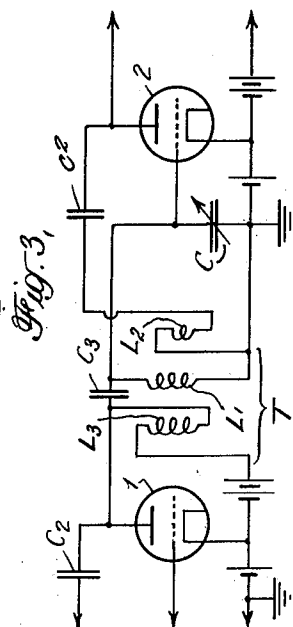
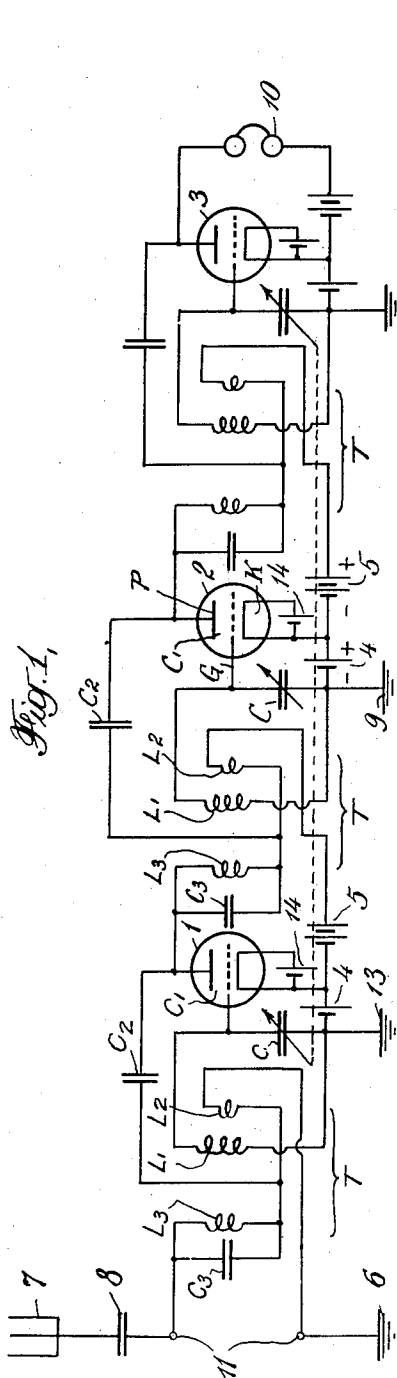
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RADIO COUPLING SYSTEM

Filed June 20, 1929



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RADIO COUPLING SYSTEM

Application filed June 20, 1929. Serial No. 372,275.

This invention relates to high-frequency thermionic amplifiers and more particularly to tunable amplifiers of this type wherein by the utilization of suitable coupling networks containing capacitive and inductive impedance elements associated with the input sections of the successive amplifier stages, the amplification may be caused to vary in a preselected manner, as the tuning is varied over a desired frequency range.

An object of the invention is to embody in an amplifier having the above characteristics, neutralizing means for minimizing any feedback of energy from the output to the input sections of the individual amplifier stages during operation, which energy transfer usually occurs as a result of the interelectrode capacities of the thermionic tubes and tends to set up sustained oscillations with resultant signal distortion, squeals and whistles.

A second object of the invention is to provide an amplifier of the type specified adapted for use in radio receiving systems and characterized by the feature that the effective output impedance of the successive amplifier stages is predominantly capacitive over the range of operating frequencies, whereby the effective antenna capacity may be quite simply adjusted to approximate the capacitive impedances of the successive amplifier stages thereby permitting the use of a coupling network between the antenna and first amplifier stage which is identical both in construction and tuning characteristics with the networks associated with the succeeding stages.

A further object of the invention is to furnish specific design data for a high-frequency transformer structure the use of which as a part of the coupling networks will result in a high and substantially uniform degree of amplification over a desired radio frequency range.

Other objects will become apparent from the subsequent detailed description.

It is a well known fact that by interposing between successive amplifier tubes a coupling network having a primary transformer winding across the output terminals of the first tube and a tuned secondary winding

across the terminals of the succeeding tube, an amplifier is obtained wherein the overall amplification and also the impedance across the output of the first tube increases as the frequency of tuning is increased. The increased amplification with frequency is undesirable since it prevents the amplifier from being uniformly sensitive and free from oscillations over a wide range of frequencies. The increase with frequency of the primary impedance is the cause of the corresponding increase of amplification and of feedback currents from plate to grid.

In order to overcome the drawbacks of the above standard type of coupling system, C. E. Trube in application for United States Letters Patent, Serial No. 120,045, filed July 2, 1926, and Patent No. 1,763,380 issued June 10, 1930, has disclosed improved types of coupling systems, by the proper design of which the amplification of a system may be caused to vary in a preselected manner as the tuning frequency is adjusted over a desired range. These coupling systems are in general characterized by the additional feature that the total primary impedance connected thereby across the output terminals of a tube may be substantially constant or even decreasing with increased frequency thereby minimizing the tendency for the setting up of sustained oscillations at the higher frequencies due to the regenerative feedback action of the tubes.

To accomplish the above results, the mentioned Trube coupling systems employ a coupling network one portion of which has a capacitive reactance and another portion an inductive reactance over a desired high-frequency range. The impedance, and hence the voltage across the capacitive element, of course, decreases with increase in frequency while for the inductive element the same factors increase with frequency. By suitably proportioning the capacitive and inductive elements relatively and suitably coupling the same with the input terminals of the succeeding tube, it is apparent that the resultant effect on the tube input can be caused to vary in a preselected manner with frequency over a desired range. Likewise, if the capacitive

and inductive elements be suitably connected across the output terminals of the preceding tube as, for example, by connecting them in series, then the impedance across the tube output can likewise be caused to vary in a desired manner with frequency, for as the impedance of one element increases, that of the other element decreases and any desired resultant effect may be obtained.

Despite the improvements introduced by the Trube coupling systems, the amplification obtainable is still limited by the feedback action of the tubes at the higher frequencies, due to the fact that the coupling between grid and plate circuits due to the interelectrode tube capacity increases with increase in frequency. The present invention, therefore, embodies in an amplifier utilizing the Trube coupling networks, suitable neutralizing means for minimizing transfers of energy from the output to the input of the successive tubes. With such an arrangement all the advantages of the Trube system are available and in addition a much higher degree of amplification over a desired frequency range is obtainable.

When utilizing high-frequency amplifiers in radio receiving systems, it is desirable that the antenna system have the same impedance characteristics over the operating frequency range as the output impedance of the successive amplifier stages, since such an arrangement permits the same type of coupling network to be efficiently utilized between the antenna and the first amplifier stage as is used to interconnect the successive stages.

For effective operation, the coupling networks must be designed to work efficiently between the impedances which they interconnect. Thus, if, as is generally the case, the antenna impedance is quite different from the output impedance of the successive amplifier stages, optimum design would call for a different type of coupling network between the antenna and the first amplifier tube than that utilized for interstage coupling.

Such a non-uniform arrangement is, of course, undesirable from a manufacturing standpoint since cheaper set construction could be obtained with the same type of coupling networks utilized thruout the receiving set. Also from an operating standpoint, the above described arrangement is undesirable since the first coupling network would tune at a different adjusting position from the others, which would prohibit the use of unitary control means including gang condensers and the like for tuning purposes.

The present invention provides a neutralized high-frequency amplifier wherein the output impedances of the successive amplifier stages are capacitive over the operating frequency range, due to the use of a relatively large neutralizing condenser connected to each plate. Thus, by suitably proportioning

the antenna structure or associating a fixed capacity of proper magnitude with the antenna circuit, the resultant antenna capacity can be made to approximate the neutralizing capacities of the amplifier stages. As a result, the same type of coupling network may be utilized for coupling the antenna and first tube as is utilized interstage and, furthermore, such networks will be identically tunable, thereby embodying in the amplifier the advantages of uni-controlled tuning pointed out above.

Referring now to the drawing:

Fig. 1 shows a circuit diagram of a complete radio receiving system embodying a uni-controlled tuned high-frequency amplifier constructed in accordance with the present invention.

Figs. 2 and 3 show modified circuit arrangements which are approximately equivalent to the circuit of Fig. 1.

Figs. 4 and 5 disclose the structural details of a special three-winding high-frequency transformer which is suitable for use in the coupling networks of Figs. 1, 2 and 3.

Referring now to Fig. 1, the receiving system comprises thermionic tubes 1 and 2 operating as amplifiers and tube 3 operating as a detector. Each tube has a grid G, a filament or cathode K constituting an input section commonly referred to as the grid circuit, and a plate P cooperating with the cathode K to form an output section commonly termed the plate circuit of the tube. The batteries 4 supply the necessary negative bias on the grids of the amplifier tubes, while the batteries 5 supply the necessary direct current voltages for the plate circuits of the successive tubes. Batteries 14 furnish the necessary energy for heating the cathodes, K.

Associated with the input to each tube is a coupling network comprising capacities C and C₃ together with a three-winding transformer T having a single secondary and two primary windings. The secondary winding L₁ shunted by the variable capacity C constitutes a tunable resonant circuit connected between grid and filament of the succeeding tube. The primary circuit connected between plate and filament of the preceding tube, or to the antenna system terminals 11, comprises the winding L₃, effectively shunted by the fixed capacity C₃, and winding L₂, connected in series with L₃ but in the reverse direction. A neutralizing capacity C₂ which serves to neutralize feedback of energy from the plate to the grid circuit of the tube is in each case connected from the plate to a point between the primary windings L₂ and L₃.

The capacity C is adapted to tune the secondary circuit over a desired frequency range, say from 550 to 1500 kilocycles under present broadcasting conditions in the United States. The capacity C₃ is selected to

tune the parallel circuit L_3C_3 to a frequency somewhat lower, usually but slightly lower, than the lowest frequency of tuning. Under the above assumption L_3C_3 would be resonant at about 400 kilocycles. Over the operating range of frequencies the circuit L_3C_3 thus has a capacitive reactance; which means that the impedance decreases continuously as the frequency increases. On the other hand, winding L_2 being substantially purely inductive, its impedance increases proportionally with increased frequency. Due to the small inductance and small distributed capacity of coil L_2 , its resonant frequency is so much higher than the upper limit of the tuning range of the coupling system, that L_2 may be considered by itself as untuned or effectively non-resonant. The coefficient of coupling between L_1 and L_2 is, however, such that L_2 is tuned by L_1C_1 .

Since the oppositely varying impedances are serially connected between plate and filament of the tube, the resultant impedance may be adjusted to vary as desired with frequency, preferably decreasing with increase in frequency.

Coming now to the effect produced by the primary on the secondary circuit L_1C_1 , since the coupling between L_1 and L_2 is constant over the frequency range, the voltage induced in L_1 by L_2 increases with frequency due to the increasing impedance and hence proportionally greater voltage drop across L_2 . On the other hand, the effect produced in L_1 by L_3 decreases with frequency, since as the frequency goes up an increasing percentage of the total primary current flows thru the capacity C_3 . In effect, the capacity C_3 shunting L_3 provides a means for automatically reducing the coupling between L_3 and L_1 as the frequency increases.

Thus there are two factors operating on the secondary circuit, one of which increases and the other of which decreases as the frequency of tuning is varied. By suitably proportioning these factors relatively, the resultant effect produced in the secondary circuit can be caused to vary in a preselected manner with frequency. In general, it is desirable to have a design such that the over-all amplification of the system remains substantially constant over the operating frequency range. Due to the presence of capacity C_3 , the current in winding L_2 is in phase opposition to that in L_3 over the operating frequency range. Hence it is necessary to connect windings L_2 and L_3 series opposed in order to obtain additive effects in winding L_1 .

The winding L_2 in addition to its function as forming part of the primary circuit of the coupling network in the manner explained above, also cooperates with the capacity C_2 to neutralize the coupling effect occurring between the plate and grid circuits of a tube as a result of the interelectrode capacity C_1 .

Regenerative feedback occurring between the plate and grid circuits of a thermionic tube, as is well known, is prevented when the circuit arrangements are such that a voltage active in the plate circuit of the tube can produce no effect in the grid circuit thereof. This condition is commonly referred to as neutralization. Referring to Fig. 1, if the winding L_2 is connected in opposite open-circuit polarity to winding L_1 , no regenerative feedback will occur when the following relation obtains:

$$(1) \frac{C_2}{C_1} = \frac{L_1}{M_{1-2}}$$

where M_{1-2} is the mutual inductance between windings L_1 and L_2 . Consider a voltage active across the primary circuit associated with the output of tube 2. Such a voltage will cause two capacity currents to flow to ground. The first capacity current flows from plate to grid of tube 2 thru the interelectrode coupling capacity C_1 and thence thru winding L_1 to ground at 9. The second capacity current will flow from plate P thru the neutralizing condenser C_2 , thru the winding L_2 , and in series thru batteries 5 and 4 associated with the tube 1 to ground at 13. If the elements are so proportioned that Equation (1) above is satisfied, then the current thus flowing thru winding L_2 will induce a voltage in winding L_1 , which is equal and opposite to the self-induced voltage in winding L_1 due to the current flowing therein. The resultant induced voltage in winding L_1 will therefore be zero and hence no voltage will be impressed between grid and filament of the tube.

In order that the neutralization obtained in this manner be effective at all frequencies, it is necessary that the coupling between windings L_1 and L_2 be as close as practicable. The coupling coefficient between these two windings in this case should be about 50% or greater if possible. If the coupling coefficient is too low, the capacity C_2 required for exact neutralization will vary considerably with frequency.

In order that the amplifier have a uniform gain over the operating frequency range, it is required that the inductance L_3 be relatively large and L_2 be relatively small as compared to L_1 . In practice, L_2 amounts to only a few turns of wire. This means, of course, that the mutual inductance between windings L_1 and L_2 will be quite small as compared to the self-inductance of winding L_1 , and if reference be had for a moment to Equation (1) above, it will be seen that under such conditions the neutralizing capacity C_2 required will be very large as compared to the plate-to-grid interelectrode capacity C_1 . In an actual design neutralizing capacities of the order of 130 mmf. (micro-microfarads) have been used.

Now referring for a moment to tube 2 of Fig. 1, it will be noted that the capacity C_2 is connected from the plate P thru the winding L_2 to ground, and is thus effectively in parallel with the output circuit of the tube. Owing to the large value of capacity C_2 , its impedance over the operating frequency range is relatively small as compared to the filament-to-plate resistance of the tube and also as compared to the impedances introduced between plate and filament thereof due to the interelectrode tube capacities occurring between the plate and grid, and plate and filament electrodes, all of which impedances are effectively in parallel with the impedance of the neutralizing capacity C_2 . In general, the impedance of C_2 over the operating frequency range is about 1000 ohms, as compared to a filament-plate resistance of about 10,000 ohms, a filament-plate interelectrode capacity negligibly small, and a grid-to-plate interelectrode capacity C_1 of 3 to 10 mmf. The apparent output impedance of the tube is, therefore, approximately that of the capacity C_2 throughout the operating frequency range. More accurately, this apparent output impedance of the tube is represented by the total capacity $C_2 + C_1$ plus that introduced by leads and wiring.

The usual capacity of an antenna used with ordinary commercial receiving sets is of the order of 200 mmf. Referring to Fig. 1, by connecting a suitable capacity 8 of say 250 mmf. in series with such an antenna having a capacity of about 200 mmf., the resultant capacity of antenna and wiring is of the order of 130 mmf., so that the antenna circuit will have a capacitive impedance over the operating frequency range which simulates the apparent output impedances of the successive tubes as approximately determined by the capacity C_2 . The advantage of such a design, of course, lies in the fact that the same type of coupling network may be utilized between the antenna circuit and the first tube 1 as is utilized for interconnecting the successive tubes, with the resultant advantages in construction and operation pointed out above.

The fixed capacity 8 is optional, and may be omitted if the antenna used in a specific case has a low capacity value, say of the order of 130 mmf. In practice, it has been found sufficient to provide a single capacity 8 of approximately 250 mmf. If the antenna impedance happens to be high, the capacity 8 is connected in series therewith, and if it happens to be low, the capacity 8 is short-circuited.

It will become apparent from the discussion given above that the circuit arrangement disclosed in Fig. 1 is very efficient and economical in that the winding L_2 serves a double purpose, i. e., as a portion of the primary circuit and also as a portion of the

neutralizing circuit. Likewise, the capacity C_2 serves a double purpose, i. e., as a portion of the neutralizing circuit and as a means for furnishing a capacitive output reactance, thereby permitting identically constructed and identically tunable coupling networks to be utilized thruout the receiver.

It has been found that best results are obtained when the coupling between windings L_1 and L_3 is not too loose. The coupling under such conditions might be termed moderate and will be so referred to in the appended claims. A moderate coupling, in this case, is one wherein the coupling coefficient has a value lying between the limits of about 10% and 50%. On the other hand, the coupling between windings L_2 and L_3 should be loose, i. e., having a value less than about 30 percent, while still fulfilling other requirements. In actual coil construction, the above conditions can usually be met due to the fact that the coupling between windings L_2 and L_3 can be as loose as is consistent with the necessary degree of couplings between windings L_1 and L_3 and between windings L_1 and L_2 . The ideal condition is attained when the coupling coefficient between windings L_2 and L_3 equals the product of the coupling coefficients between windings L_1 and L_2 and between windings L_1 and L_3 , i. e., when

$$(2) \quad K_{2-3} = K_{1-2} K_{1-3}$$

where K represents the coupling coefficient, and the subscripts denote the windings between which the coefficient is given. This equation is approximately satisfied by the design shown in Figs. 4 and 5, as will be seen from the description below.

Fig. 2 shows an alternative circuit arrangement which is a modification of that shown in Fig. 1, and may therefore, be substituted for the arrangement of Fig. 1 either as an antenna coupling system or as an inter-tube coupling system. In Fig. 2, the primary circuit is both inductively and conductively connected to the secondary circuit. The capacity C_3 is connected from the plate of the preceding tube to an intermediate tapping point on L_1 , while the winding L_3 is connected in a reversed sense between plate and filament of tube 1 as compared to its mode of connection in Fig. 1. The tapped portion of winding L_1 in Fig. 2 takes the place of winding L_2 in the primary circuit of Fig. 1, and in Fig. 2 the winding L_2 serves as a neutralizing winding only. The circuit of Fig. 2 is electrically equivalent to that of Fig. 1. The only difference consists in combining the separate primary and secondary windings L_2 and L_1 of Fig. 1 into the auto-transformer arrangement of Fig. 2. At the lower frequencies, the capacity C_3 is, in Fig. 2, effectively in shunt with the winding L_3 because the reactance of the tapped portion of L_1 is negligibly small at such frequencies. The

circuit L_3C_3 is resonant at a frequency slightly below the minimum frequency of the tuning range of the condenser C , as was the case for Fig. 1.

the receiving system thru reduction of undesired couplings.

Fig. 3 shows a circuit arrangement similar to that of Fig. 2 with the exception that the condenser C_3 is connected from the plate of the preceding tube to the upper terminal of winding L_1 . By suitably selecting the value of C_3 this circuit may be made electrically equivalent to that of Figs. 1 and 2. In this case the circuit $L_3C_3L_1$ is tuned to a frequency slightly below the tuning range covered by the condenser C . In Figs. 2 and 3, the capacity C_3 is decreased and the inductance L_3 is increased when the tap on coil L_1 is moved upward to include more turns.

The structural details and design data of a transformer which has been successfully used in the circuit arrangement of Fig. 1 will be given with reference to Figs. 4 and 5. Referring more particularly to Fig. 5, the windings L_3 , L_1 and L_2 are of cylindrical form, each comprising a single layer of wire uniformly wound about the tubular sections h , i and j , respectively, of insulating material, preferably bakelite. The tubular sections are of successively decreasing diameter as shown, and are positioned coaxially one within another in fixed spacial relationship by means of the bolts n and spacing member m . The secondary winding L_1 being of intermediate diameter is positioned between the primaries with the larger primary L_3 surrounding the same and the small primary L_2 on the inside.

The diameter of section j is only slightly less than that of i in order to provide the highest practicable coefficient of magnetic coupling between the windings L_1 and L_2 . The diameter of section h is considerably greater than that of section i in order to provide moderate coupling between the large primary L_3 and the secondary L_1 . By positioning the primary windings L_2 and L_3 on opposite sides of the secondary L_1 , a small degree of magnetic coupling is obtainable between the two primaries, while at the same time providing the necessary coupling between the primaries and the secondary. The loose coupling between L_2 and L_3 is further enhanced by positioning L_2 toward one end of L_3 .

There are several advantages in placing the large primary L_3 on the outside of windings L_2 and L_1 . It will be recalled that the large primary has connected in shunt therewith a capacity of relatively low reactance over the frequency range of tuning. As a result, the winding L_3 acts in effect as an electrostatic and electromagnetic shield substantially surrounding windings L_1 and L_2 , with resultant minimization of the external fields set up by the currents in these windings and consequent improved operation of

The shielding action of winding L_3 does not increase the effective resistance of winding L_1 over its value with L_3 on open circuit, for the reason that with L_3 on open circuit, the magnetic flux distribution due to a current in winding L_1 is such as to crowd the current in the turns of wire toward the axis of the coil, causing the same to flow thru only a portion of the conducting cross-sectional area, thereby increasing the total effective resistance in the path of the current flow. With winding L_3 short-circuited by capacity C_3 , however, there occurs a redistribution of flux caused by a current flowing in winding L_1 , since owing to the presence of the shield the flux external to the coil L_1 tends to flow between the coils L_1 and L_3 . This flux redistribution of L_1 causes the current to be more uniformly distributed over the cross-sectional area of the turns of wire, with resultant decrease in total coil resistance. On the other hand, the magnetic field set up by the current in L_1 causes a dissipation of energy in L_3 which appears as an added resistance in L_1 . The net effect, therefore, is that the effective resistance of L_1 is about the same whether L_3 is on open or short circuit, or entirely removed. This same advantage is obtained also when L_3 has the form of a multilayer coil surrounding L_2 . As contrasted with the above arrangement, if L_3 were of smaller diameter and thus placed inside of L_1 , the total resistance of winding L_1 would be increased because both of the above described effects would increase the apparent resistance of L_1 , i. e., the current in L_1 would be crowded in the portion of the conducting cross-section toward the axis, and in addition the flux set up by the current in L_1 would cause a dissipation of energy in L_3 .

In an actual embodiment of the present invention which operated in a very satisfactory manner the following dimensions were utilized in the construction of coils of the type shown in Figs. 4 and 5. The dimensions are indicated by the letters in Fig. 5 and were as follows:

$a=1$ inch
 $b=2.42$ inches
 $c=.688$ inch
 $d=1.25$ inches
 $e=2.5$ inches
 $f=1.5$ inches
 $g=1.25$ inches

cylinders h , i and j were each of insulating material having a wall thickness of $\frac{1}{16}$ ".

Winding L_3 comprised 200 turns of #30 B. & S. gauge enameled copper wire, uniformly wound 80 turns per inch; winding L_1 comprised 126 turns of #26 B. & S. enameled wire, wound 52 turns per inch; while wind-

ing L_2 comprised 11 turns of #26 B. & S. enameled wire, wound 16 turns per inch.

Measurements made at 1,000 cycles to determine the electrical constants of the various windings gave the following results. The self-inductances of the windings measured in microhenries were:

$$\begin{aligned} L_3 &= 1710 \text{ mh.} \\ L_2 &= 5.4 \text{ mh.} \\ L_1 &= 294 \text{ mh.} \end{aligned}$$

The mutual inductances were as follows:

$$\begin{aligned} M_{1-3} &= 375 \text{ mh.} \\ M_{2-3} &= 25.2 \text{ mh.} \\ M_{1-2} &= 18.5 \text{ mh.} \end{aligned}$$

where M is the mutual inductance, and the subscripts represent the windings between which the mutual inductance is measured as, for example, M_{1-3} refers to the mutual inductance between windings L_1 and L_3 . The coefficients of magnetic coupling between the windings, in percent, were as follows:

$$\begin{aligned} K_{1-3} &= 53 \text{ percent} \\ K_{2-3} &= 26 \text{ percent} \\ K_{1-2} &= 46 \text{ percent} \end{aligned}$$

In a radio receiving system of the type shown in Fig. 1 utilizing type UX-201-A tubes, and coils of the type shown in Fig. 4 having the constants given above, the following values were used for the remaining electrical elements. The capacity C_3 was of 250 mmf.; for the neutralizing capacity C_2 a value of 130 mmf. was found satisfactory; for use in the antenna circuit the fixed capacity 8 had a value of 250 mmf.; and the variable condenser C was continuously adjustable between the limits of 30 and 400 mmf.

I claim:

1. The combination with a thermionic tube having input and output sections, of an electrical coupling network having a secondary circuit tunable over a range in frequency connected to said input section, a primary circuit coupled with said secondary circuit and including an impedance capacitively reactive thruout said frequency range, and means independent of said impedance including a portion of said coupling network for reducing substantially to zero transfers of energy from the output to the input section of said tube during operation thereof, whereby a uniformly high degree of stable amplification is obtainable thruout said frequency range.

2. The combination with a thermionic tube having input and output sections, of an electrical coupling network having a secondary circuit tunable over a range in frequency connected to said input section, a primary circuit coupled with said secondary circuit and with said output section, said primary circuit including an impedance capacitively reactive thruout said frequency range, and means independent of said impedance but

otherwise including said primary and secondary circuits for reducing substantially to zero transfers of energy from said output to said input sections thruout said range in frequency during operation of said tube.

3. The combination with a thermionic tube having input and output sections, of an electrical coupling network having a secondary circuit tunable over a range in frequency connected to said input section, a primary circuit coupled to said secondary circuit and to said output section, said primary circuit including a coil resonant at a frequency below said tunable frequency range, and means independent of said resonant coil, but otherwise including said primary and secondary circuits for reducing substantially to zero transfers of energy from said output to said input section thruout said range in frequency during operation of said tube.

4. The combination with a thermionic tube having input and output sections, of an electrical coupling network having a secondary circuit tunable over a range in frequency connected to said input section, a primary circuit coupled with said secondary circuit and further coupled thru a neutralizing condenser to said output section, said primary circuit including an impedance capacitively reactive thruout said frequency range, said neutralizing condenser cooperating with said primary and secondary circuits independently of said capacitively reactive impedance to reduce substantially to zero transfers of energy from said output to said input sections thruout said range in frequency during operation of said tube.

5. The combination with a thermionic tube having an input section including grid and cathode electrodes and an output section including said cathode and a plate electrode, of a tunable secondary circuit associated with said input section, primary circuit comprising a pair of serially connected windings with a capacity connected in parallel with a first said winding and a conductive path between the free end of the second said winding and said cathode, said primary circuit elements being proportioned relatively and said windings being suitably coupled inductively with said secondary circuit to produce upon said input section a combined reaction which varies in a preselected manner as the frequency of tuning is varied over a desired high frequency range, a capacity connected from said plate electrode to a point between said serially connected windings, said capacity being suitably proportioned and said second winding being suitably poled and coupled to said secondary circuit for substantially neutralizing undesired coupling effects due to the interelectrode capacity occurring between said grid and said plate.

6. A high-frequency amplifier system comprising input and output sections with a

plurality of thermionic tubes connected in cascade therebetween, each tube having input and output electrodes, a plurality of identical electrical networks individual to said tubes and interposed between the input electrodes thereof and the preceding portion of said system, each said network comprising a tunable secondary circuit connected to the input electrodes of the corresponding tube, and a primary circuit comprising a pair of serially connected windings with a capacity connected in shunt with one said winding, said primary circuit elements being relatively proportioned and suitably coupled with said secondary circuit to cause therein a combined reaction adapted to produce a preselected variation in the ratio of output to input energy for said system as the frequency of tuning is varied over said frequency range, one or more of said tubes having a capacity connected from the plate thereof to a point between said primary circuit windings of the associated network, said capacity being suitably proportioned and said non-shunted primary winding being suitably poled relative to said secondary circuit for substantially eliminating any tendency for the setting up of undesired oscillations between the output and input of a given such tube due to the coupling effect of the inherent capacity between said input and output electrodes thereof.

7. A high-frequency amplifier comprising a thermionic tube having grid, cathode and plate electrodes, a three-winding high-frequency transformer comprising a secondary and two primary windings, means connecting said secondary winding in shunt with a variable capacity between said grid and said cathode, means serially connecting said primary windings in opposite magnetic polarity, a capacity shunting one said primary winding for resonating the same at a frequency slightly below the tuning range of said variable capacity, a conductive path from the free end of the other said primary to said cathode, and a neutralizing capacity connected from a point between said primary windings to said plate and proportioned to minimize transfers of energy from the plate to grid circuits of said tube.

8. The combination with a thermionic tube having grid and cathode electrodes comprising an input section, and a plate and said cathode electrode comprising an output section, of a high-frequency transformer having a tunable secondary associated with said input section, and inductively coupled therewith a pair of serially connected primary windings, one of which is resonant at a frequency slightly below the tunable frequency range, and the other of which is effectively non-resonant, and a condenser connected from said plate to a point between said primary

windings proportioned to substantially neutralize undesired coupling due to interelectrode capacity of said tube.

9. A high-frequency amplifier comprising a thermionic tube having grid, cathode and plate electrodes, a high-frequency transformer comprising three magnetically coupled windings positioned one within another in fixed relation, means connecting the intermediate winding thereof shunted by a variable capacity between said grid and cathode, means serially connecting the outer and inner windings in magnetic opposition, a capacity shunting said outer winding for resonating the same at a frequency slightly below the tuning range of said variable capacity, a conductive path between the free end of the inner primary winding and the secondary circuit, and a neutralizing capacity connected from a point between said primary windings to said plate proportioned to minimize transfers of energy from plate to grid circuits of said tube.

10. A high-frequency amplifier comprising a thermionic tube having grid, cathode and plate electrodes, a high-frequency transformer having a tunable secondary winding connected between the grid and cathode, and a pair of primary windings serially connected in magnetic opposition, one said primary winding having a large inductance and the other a small inductance relative to said secondary winding, a capacity shunting said large primary for resonating the same at a frequency slightly below the tuning range of said secondary winding, said primary windings being suitably proportioned and coupled with said secondary winding to produce therein a combined reaction which varies in a preselected manner with the frequency of tuning said secondary, and a neutralizing capacity connected from said plate to a point between said primaries so proportioned and cooperating with said small primary so poled relative to said secondary as to minimize transfers of energy from plate to grid circuit of said tube.

11. A high-frequency amplifier comprising, a thermionic tube having input and output sections, a high-frequency transformer comprising three coaxial windings two of which are positioned in fixed spacial relation within an outer winding, means connecting one said inner winding shunted by a variable capacity to said input section, means serially connecting the remaining two windings in magnetic opposition, a capacity shunting said outer winding for resonating the same at a frequency below the tuning range of said variable capacity, said windings being suitably proportioned and coupled for impressing upon said input section a combined reaction which varies in a preselected manner with the frequency of tuning for a voltage impressed across said serially connected

windings, said outer winding shunted by said capacity being adapted further to act substantially as an electrical shield effectively surrounding said inner windings, and means including one of said serially connected windings for minimizing transfers of energy from the output to the input sections of said tube.

12. A high-frequency amplifier comprising a thermionic tube having grid, cathode and plate electrodes, a three-winding high-frequency transformer having a secondary shunted by a variable tuning capacity connecting said grid and said cathode, a relatively small inductance primary closely coupled magnetically to said secondary, and a relatively large inductance primary moderately coupled magnetically to said secondary, a capacity shunting said large primary for resonating the same at a frequency below the frequency range of said tuning capacity, means serially connecting said primaries in magnetic opposition, the proportioning of said primary elements being such as to produce upon said secondary a combined reaction which varies in a preselected manner with the frequency of tuning, neutralizing means including said small primary and a capacity connected from said plate to a point between said primaries for minimizing transfers of energy from plate to grid circuits of said tube.

13. A high-frequency amplifier comprising a thermionic tube having grid, cathode and plate electrodes, a secondary circuit tunable over a desired frequency range connecting said grid and cathode, a primary circuit containing inductive and capacitive elements suitably proportioned and coupled with said secondary circuit to produce therein a combined reaction which varies in a preselected manner with the frequency of tuning, neutralizing means connected between said plate and cathode including a neutralizing capacity in series with a properly poled winding coupled to said secondary circuit for minimizing transfers of energy from plate to grid circuits of said tube, said neutralizing capacity being adapted further to render the apparent output impedance of said tube capacitive within said frequency range.

14. In combination, a high-frequency amplifier comprising a plurality of thermionic tubes each having input and output sections, a plurality of identical tunable electrical networks coupling said tubes in cascade, means individual to said tubes for minimizing energy transfers from the output to the input sections thereof, each said means including a relatively large neutralizing capacity effectively in shunt with the output section of the corresponding tube for rendering the apparent output impedance thereof approximately that of said capacity over a desired frequency range, an antenna having

a capacity approximating said neutralizing capacity and an electrical network identical with said plurality of networks coupling said antenna with the first tube of said amplifier.

15. A high-frequency amplifier comprising a plurality of thermionic tubes each having an input and an output section, a plurality of identical tunable coupling networks interconnecting said tubes in cascade, means individual to said tubes for minimizing transfers of energy from the output to the input sections thereof, each said means including a relatively large neutralizing capacity effectively in shunt with the corresponding tube output section for rendering the apparent output impedance thereof approximately that of said capacity, a first coupling network identical with said plurality associated with the input section of the first amplifier tube, and a capacity associated therewith for adjusting the capacity of an antenna connected thereto to approximate said neutralizing capacity whereby the said first coupling network is identically tunable with said inter-stage networks.

16. In combination a thermionic tube having anode, cathode and control electrodes, input and output circuits operatively associated therewith, and means for neutralizing the inter-electrode capacity of said tube including a neutralizing condenser having an impedance relatively small in comparison with the anode-cathode impedance, connected from said anode to a point of said input circuit such that the effective output impedance of said tube is substantially that of said neutralizing condenser.

17. In combination a thermionic tube having anode, cathode and control electrodes, input and output circuits operatively associated therewith, and means for neutralizing the inter-electrode capacity of said tube including a neutralizing condenser having an impedance relatively small in comparison with the anode-cathode impedance, connected from said anode through a relatively small inductive winding included in said input circuit to said cathode, whereby the effective output impedance of said tube is substantially that of said neutralizing condenser.

18. A high-frequency amplifier comprising a thermionic tube having anode, cathode and grid electrodes, a secondary circuit tunable over a range in frequency connecting said grid and cathode, a primary circuit containing inductive and capacitive elements suitably proportioned and coupled with said secondary circuit to produce therein a combined reaction which varies in a preselected manner with the frequency of tuning, neutralizing means connected between said anode and cathode including a neutralizing condenser having an impedance relatively small in comparison with the anode-cathode impedance, in series with a properly poled small induct-

tive winding coupled to said secondary circuit for minimizing transfers of energy from the anode to the grid circuit of said tube, said neutralizing condenser being adapted further to render the effective output impedance of said tube substantially that of said condenser.

In testimony whereof I affix my signature.
HAROLD A. WHEELER.

19. In combination, a high-frequency amplifier comprising a plurality of thermionic tubes each having input and output sections, a plurality of identical tunable coupling circuits connecting said tubes in cascade relation, means individual to said tubes for minimizing transfers of energy from the output to the input sections thereof, said means including a neutralizing condenser having an impedance relatively small in comparison with the impedance of the output section of the associated tube and effectively in shunt therewith for rendering the effective output impedance thereof substantially that of said condenser over the tunable frequency range, an antenna circuit adapted to have an effective capacity approximating that of said neutralizing condensers, a coupling circuit identical with said plurality of circuits connecting said antenna circuit with the input section of the said first tube, and uni-control means for simultaneously adjusting said plurality of tunable circuits.

20. The combination with a thermionic tube having anode, cathode and grid, of a high-frequency transformer having a tunable secondary connecting said grid and cathode, and inductively coupled therewith large and small serially connected primary windings, said large primary winding being resonant at a frequency slightly below the tunable range, the small primary winding being joined at its free end to said cathode, and a large neutralizing condenser proportioned to minimize transfers of energy from the anode to the grid circuit of said tube connected from said anode to a point between said primary windings whereby the effective output impedance of said tube is substantially that of said neutralizing condenser.

21. A high-frequency amplifier comprising a thermionic tube having anode, cathode and grid electrodes, a three-winding high-frequency transformer comprising a secondary and two primary windings, means connecting said secondary winding in shunt with a variable tuning condenser between said grid and cathode, means serially connecting said primary windings in opposite open-circuit polarity, a capacity shunting one said primary winding for rendering the same resonant at a frequency below the tuning range of said variable condenser, a conductive path from the free end of the other said primary winding to said cathode, and a neutralizing condenser connected from said anode to a point between said primary windings for minimizing transfers of energy from the

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