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AMPLIFICATION SYSTEM

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This invention relates to the neutralizing of capacity couplings between the grid and plate circuits of a vacuum tube, which couplings result in an undesirable reaction of the plate circuit on the grid circuit.

More particularly this invention has for its object to provide a more simple, efficient and exact neutralizing circuit arrangement which may be readily adapted for use in any type of vacuum tube and which prevents the feed back of energy from output terminals of the tube to the input terminals of the tube. This circuit may be readily adapted for use with any form or type of vacuum tube which has heretofore been used without a neutralizing arrangement for neutralizing the feed back effects. This may be done with a minimum of changes and a maximum of efficiency in the result obtained.

It is well known that a vacuum tube operates on the principle of capacity effect within an enclosed envelope in which a substantial quantity of all the gas has been removed. The purpose of the removal of this gas has been to enhance the capacity and electronic effects produced by electrical discharges. Usually these discharges are increased by the use of a filament or other heated body to throw off electrons in the direction of the elements.

Where a plurality of elements are used within an enclosed and evacuated envelope a plurality of effects occur, and oftentimes some of these effects are disadvantageous to the result desired, because they increase the amplification of the circuit to such a point that the tube becomes overloaded.

Ordinarily within the envelope of a three or four element vacuum tube, a control element has been used in capacity relation to a second element which is used in the load circuit. The variation of conductivity between these two elements necessarily varies the capacity between one of these elements and a third or fourth element thereby affecting the relative ratio of voltage tension between them and thereby causing variations in amplification.

It is an object of this invention to retain to a sufficient extent the feed back effects

of a vacuum tube to produce a reasonable amplification and to counteract the feed back effects of the vacuum tube such as would produce an over-abundant amplification caused from feed back from the output circuit to the input circuit of the vacuum tube and also to substantially maintain this amplification constant regardless of frequency.

Another object of this invention is to provide a vacuum tube with a neutralizing circuit coupled to both the input and the output circuits of the vacuum tube, and having a ratio of coupling therewith which differs from unity whereby the amplification is kept more nearly constant in respect to frequency. This difference is determined by the ratio of current of one of the circuit coils to the current in the neutralizing coil. This invention relates to the application of a neutralizing circuit which is coupled with but has a different number of turns in its coupling coil than there is in the input coil of the vacuum tube and a different capacity than the capacity in the vacuum tube. This same proportion, having a ratio differing from unity or one hundred percent coupling, would also be present in connection with the output coil if the neutralizing coil coupled thereto were composed of strands of wire having a different number of convolutions.

This invention relates also to the application of a neutralizing circuit to a vacuum tube in which the voltages and currents induced therein are different from the feed back voltages and feed back currents which circulate in both the output and input circuit simultaneously, differing according to the ratio of couplings between the input and output coils respectively to those of the input and output neutralizing coils coupled therewith. This ratio may be adjusted to the point where any variation of coupling due to variation of frequency may be compensated for.

Another object of this invention is to embody the desirable features of a separate neutralizing or counter feed back circuit with a plurality of vacuum tubes. Thus a

maximum efficiency results and proper adjustment for the preventing of undesirable feed backs at one frequency will automatically produce a neutralization of inherent feed backs at all frequencies at which the apparatus is used.

A further object of this invention is to improve the operation of a vacuum tube when used with a second circuit coupled therewith and to overcome the difficulties encountered due to variations in the amount of coupling and due to variations of frequencies. It has been found that in an ordinary coupling arrangement different ratios of energy couplings result when different frequencies are impressed upon the couplings. It is an object of this invention therefore to reduce such variations in couplings to a minimum by proper arrangement and proportioning of circuits, and to compensate for their variation.

Further and more definite objects will be observed in connection with the following specifications, claims and drawings, in which,

Fig. 1 represents a simple schematic arrangement of an ordinary three electrode amplifier and the simplified neutralizing circuit coupled thereto.

Figs. 2 shows an analytical circuit corresponding to the diagram of Fig. 1.

Fig. 3 shows a plurality of devices such as is shown in Fig. 1 coupled in cascade for use as radio frequency amplifiers in connection with a detector.

Fig. 4 shows a method of winding wires to form a coupling coil, and

Fig. 5 shows another method of winding the wires.

As is well understood by those skilled in the art, ordinary neutralizing circuits are ineffective in certain conditions and at such frequencies will not neutralize to sufficient extent the energy which finds its way from the output circuit back into the input circuit unless additional adjustments are made besides those which occur during the act of tuning. Difficulty is encountered when mechanically arranging the values and parts so that a complete neutralization will occur at all frequencies at which the apparatus is desired to be used.

Such a difficulty occurs in a circuit of the vacuum tube 1 with input circuit 2 composed of a coil or impedance 3, and output circuit 4 composed of impedance 5. The filament 6 is of the customary type forming a common return in this case for the output circuit 4 and the input circuit 3. A source of potential is shown at 7 in the output circuit. Capacity 8 represents the inherent grid-plate capacity of the tube.

Feed back is prevented by coupling the circuit 9 to the vacuum tube circuit. Coils 10 and 11 are coupled with coils 3 and 5 re-

spectively and a series condenser 12 is properly proportioned to capacity 8.

In order to overcome the difficulty encountered when using one of the coils 3 or 5 to constitute a tuned circuit and thereby establish cause for variations of energy circulating through these circuits, the tuned circuit 14 is coupled as nearly as possible equally to these two circuits. This tuned circuit 14 is made up of a variable capacity 15 and the coil 16. It might well be made up of a variable coil 16 and a fixed capacity 15, or both elements might be made adjustable. In any event it is desirable to have coils 3, 10 and 16 as closely coupled as possible. A method of obtaining this result is to be described below. The same is true of the coupling circuit 17 which is shown as coil 18 and variable capacity 19 coupled as closely as possible and equally to coils 15 and 11. From these two tuned circuits and the manner of coupling to the vacuum tube and neutralizing circuit it will be seen that any energies existing in tuned circuits 17 will affect equally the coils 5 and 11 to thereby feed back energy in an equal amount to coils 2 and 10 where each will be substantially counteracted by the other. The same will be true of any energy which is stored in the circuit 14 which may tend to react through the capacity 8 on energy or voltage applied to the coil 5 to cause undesirable oscillations. The terminals 20 of coil 16 may be connected to the source of alternating current energy desired to be amplified either in the form of an antenna or in the form of another amplifying circuit or other device. The terminals 21 of the tuned circuit 17 may be connected to apparatus in which it is desired that the amplified signals will circulate.

In order to accomplish this result where all frequencies within a wide range may be impressed upon the amplifier, it is necessary that these circuits, be correctly proportioned in all their elements and details. All of the elements must be proportioned in proper ratio with each other. Heretofore it has been considered that it is only necessary to have one of the coils in the amplifier in the correct ratio with relation to one of the coils in the counter feed back circuit. It has been found that this prior method of proportioning the circuit is inaccurate and does not hold for all conditions and all frequencies which are impressed upon these circuits.

These two circuits may be proportioned so that all of the different elements will have exactly the same value, that is, that coil 2 will have exactly the same diameter and the same number of turns as coil 10, coil 5 will have exactly the same diameter and the same number of turns as coil 11, and the capacity 12 will be exactly the same size as

the inherent capacity 8 between the grid and plate of the vacuum tube 1. This provides a means of neutralizing the inherent effects between the output and the input circuits of the vacuum tube for a small range of frequencies provided the coils 5 and 11, and 2 and 10, are coupled with a coupling factor which is substantially unity. In order to neutralize for all frequencies, direct conductive relations between the two circuits have been eliminated and the two circuits have been separately coupled as shown in Fig. 1. This provides means whereby the effects of the tuned circuits on the capacity of the plate and grid of the vacuum tube are the same as the effect of these circuits upon the condenser 12 in the counter feed back circuit and therefore undesirable oscillations are prevented in the vacuum tube circuit. This permits the variation of all the constants of the circuits in the correct ratios.

It is also obvious from this arrangement that no direct contact is made with either the input circuit or the output circuit and that energy is taken off from both these circuits by means of inductive couplings. Therefore, in case the condenser 12 breaks down or there is a short circuit between any part of the neutralizing circuit, no difficulty will be encountered such as the burning out of the filament as would be the case particularly when the filament resistance switch 22 is in the "off" position as shown in Fig. 1. It is necessary that the insulation between coils 3 and 10, as well as the insulation between coil 5 and coil 11 be broken down at the same time, in the present arrangement to burn out the filament. This is very unlikely to happen and therefore this additional factor of safety results. Where unusually high voltages are used in place of the battery 7 an additional capacity could be added in the connection 23 which when added to the capacity at 12 would give a total capacitance effect in the proper proportion to the capacity 8 of the vacuum tube.

In Fig. 2 is shown a simplified circuit of the arrangement in Fig. 1. All of the equivalent parts are indicated by the same numbers except that they are primed.

The proper relation between the coils and the constants of the various circuits is determined as follows: Assuming that all coils are of the same diameter and of wire having the same resistance and that the coils are spaced the same distance apart, and preferably as close as possible, then the inductance of coil 3' in Figure 2 might be represented by A, the inductance of coil 5' by B, and the inherent capacity between these two coils by C; this would also include the other external capacities of the circuit including the tube 6'.

The inductance of coil 10' would be represented by "a", the inductance of coil 11' by "b", and capacity 12' by "c". Then the relation between capacity "C" and the capacity "c" should be equal to the following expression:

$$\frac{A+B}{a+b} \times \frac{B}{A} \times \frac{a}{b} = \frac{c}{C}$$

and not simply

$$\frac{A}{a} = \frac{c}{C} \text{ or } \frac{B}{b} = \frac{c}{C}$$

This is true because the energy factor or measure of ability to store energy of a circuit containing capacity and inductance in parallel for a given frequency is approximately the capacity times the inductance. Therefore to get the two circuits (the vacuum tube circuit and the counter-feed-back circuit) to have the same stored energies,

$(A+B)C$ must equal $(a+b)c$ or

$$\frac{A+B}{a+b} = \frac{c}{C}$$

but other factors enter into the circuits; namely, the transformation ratios of the couplings. Thus power is transmitted from B to b with the voltage ratio of

$$\frac{B}{b}$$

and from a to A with the voltage ratio of

$$\frac{a}{A}$$

and this voltage ratio is the direct measure of the throttling effect of the condensers. Therefore,

$$\frac{A+B}{a+b} \times \frac{B}{b} \times \frac{a}{A} = \frac{c}{C} \text{ or } \frac{A+B}{a+b} \times \frac{B}{A} \times \frac{a}{b} = \frac{c}{C}$$

In other words the ratio of the total impedance of the vacuum tube circuit to the total impedance of the neutralizing circuit, times the ratio of the impedance of the second coil in the vacuum tube circuit to the first coil in the vacuum tube circuit, times the first coil in the neutralizing circuit to the second coil in the neutralizing circuit should be equal to the neutralizing capacity divided by the vacuum tube circuit capacity.

Theoretically these values A, B, a, b, would simply relate to the inductance of the various elements but practically it may be assumed that the coils, if they are wound in a manner to be described further on, are concentrically arranged, then the values chosen may be stated in numbers of turns or convolutions of wire, and a result substantially approaching that obtainable with the theoretical values is approached.

If the values are arranged so that an in-

creasing amount of energy is transmitted through the neutralizing circuit at higher frequencies than at lower and this increase is properly proportioned the vacuum tube circuit will remain neutralized at all frequencies. This can be accomplished by reducing the turns in the neutralizing coils and increasing the capacity to such a point that the regeneration of the circuit is substantially the same for all frequencies thus keeping the amplification and feed back constant regardless of variations in inductive couplings and in this way efficient neutralization is maintained at all frequencies.

Referring now to Fig. 3, the above arrangement may be advantageously used in a multi-stage amplifier arrangement having input connections 24 from an antenna or other apparatus to a coil 25 which is coupled as nearly equally as possible to two coils 26 and 27. The coil 26 is connected to the input circuit of a vacuum tube and has a parallel variable condenser 28 connected across its terminals to provide proper tuning means therefor. The output of the vacuum tube is in the form of coil 29 connected between the plate element of the tube and the positive potential side of the B battery 30.

A proper A-battery 31 is used to supply power to the filaments for the vacuum tubes arranged in parallel by means of common connections 32 and 33. The neutralizing coil 27 is coupled as closely as possible to the input coil 26 and is arranged in series with the neutralizing condenser 34 and neutralizing coil 35 across which is a tuning capacity 36. The coil 35 is coupled as closely as possible to the output coil 29 as well as to the input coil of the second stage 37.

In order to maintain the circuits of the vacuum tube and of the neutralizing circuit the same, the tuning circuit is placed in the neutralizing circuit instead of in the input circuit to the second stage. This provides an arrangement whereby the constants of all the circuits are maintained substantially the same and the effective result is a perfect balance of the energy transference of both circuits and a neutralization of undesirable feed back currents at all frequencies.

In the case of the multi-stage amplifier it is preferable to keep coils 27 and 35 of the same inductance so that assuming that the inductances are measured by numbers of turns, they will have the same number of turns on both.

However the relation between the various elements of these two circuits must be maintained the same as specified in connection with Figures 1 and 2 and any variation therefrom will prevent the circuit from properly neutralizing with all frequencies impressed thereon.

The input coil 37 to the vacuum tube 38 is connected to the common return 32 from the

filament. The output from the vacuum tube 38 is in the form of a coil 39, across which is connected the variable capacity 40 so that the feed back circuit of the vacuum tube 38 is kept substantially the same as the counter feed back circuit in which coils 35 and variable capacity 36 are positioned. This counter feed back circuit includes the coil 41 and neutralizing capacity 42 for keeping the energy which is transferred through the circuits, in the same proportions, to the energies transferred in the vacuum tube circuits 38.

It is obvious from the construction of the diagram that the condensers 28, 36 and 40 control the constants in their respective feed back and counter feed back circuits. If one of these condensers is moved independently of the others then necessarily there will be a difference in the neutralizing effect produced in these respective circuits and in case they are moved too far from the point at which they are more most effectively operated, undesired oscillations will result. It is therefore desirable to mechanically couple these three condensers by a single control indicated by the dotted lines 43 and 44. These dotted lines indicate that these condensers are arranged in what is commonly known as a "Uni-control system". Slight variation of these capacities, either one way or the other has been found in actual practice not to affect greatly the neutralization of the respective circuits, but considerable variation therefrom is detrimental to the efficient operation of the circuits and cause undesirable feed back currents.

As in the case of the other coils, coil 39 and coil 41 are very closely coupled together and together are closely coupled to an input coil 46 to a detector or other tube 47 having an output coil 48 coupled to any apparatus which it is desired to couple it. Such apparatus may be connected to the secondary of the transformer 49 at terminals 50.

It will be noted in connection with these modifications described that the coupling coil or coils are so related as to provide as close as possible one hundred percent coupling. It has been found that by a carefully designing of these coils that a coupling of as high a percentage as 95% or possible slightly higher in extreme cases has been produced. To express it another way a coupling in which the leakage has been reduced to a practical minimum has been accomplished by proper proportioning the parts and improving the mechanical arrangement.

These coils may be advantageously constructed of a triple strand conductor such as is shown in Figure 4 composed of strands 51, 52 and 53 braided, twisted or otherwise combined into a single cord or cable. If these strands are wound around together in

a regular manner and as close as possible, preferably over a cylindrical form, there will result a coil having as little leakage between each section as practicable. The twisting
 5 or braiding of wire aids in the preventing of electrostatic coupling between turns to a considerable extent, it being understood that electrostatic coupling between turns permits a leakage of current between turns and
 10 therefore a leakage of magnetic flux between turns. Another common and simpler method is shown in Figure 5 where connectors 54, 55 and 56 are combined together in a single cord or cable 57 and are wound
 15 in the form of a coil as above described.

It can be seen from this disclosure that it is practically impossible to obtain a coupling having 100% efficiency or of a coupling factor of unity. Therefore, there is always
 20 a transference of energy in any type of neutralizing circuit which is applied to a vacuum tube and unless this energy finds a path which is of equal resistance, impedance and capacity, an over or under balance of
 25 the vacuum tube circuit results.

This over or under balancing can only be obviated by designing the circuit on which energy is set back as nearly as possible similar to that through which counter feed back
 30 energy is conducted. Heretofore this identity of circuits has not been maintained it being thought only necessary to produce equal and opposite voltages.

As explained above these equal and opposite voltages do not entirely neutralize the vacuum tube and particularly at all frequencies. This neutralization can only be
 35 accomplished when the parts and elements are proportioned according to the formula specified above. It has also been found that it is not entirely necessary to maintain a high value of coupling between the various coils in case the proper ratios of the elements in
 40 the circuits are maintained, through which the feed back and counter feed back currents and energies circulate.

It has been found in practice that sufficient coupling results between two or more coils, for the purposes described herein, if each
 45 one of the coils is simply wound on one of a plurality of concentric and tight fitting cylinders, either in the form of cardboard, bakelite or other material having thin rigid walls. Any coupling which approaches in
 50 value the range of 35 to 85% is usually sufficient in most low powered radio receiving circuits to produce the proper counteracting effect of the feed back current substantially throughout the broadcast range.

It is not intended to be limited to the exact method of construction and apparatus shown so long as the characteristics are confined to the principles embodied herein. A full
 55 range of equivalents is anticipated to the extent indicated in the following claims.

What I claim is:

1. In a radio frequency amplifying circuit having grid plate and cathode elements, means for neutralizing undesirable capacitive couplings between said elements consisting of an electrically independent circuit
 70 magnetically coupled to said amplifier circuit, means for tuning a portion of said independent circuit, a capacity in said independent circuit to adjust the translation of
 75 energy through said circuit, the value of said capacity being adjusted according to the ratio of total inductance of the amplifier circuit to total inductance of the independent circuit times the capacity of the undesirable
 80 capacitive couplings.

2. In a radio frequency amplifier having inherent capacity couplings between its input and output circuits, a third circuit magnetically coupled to said first circuits the
 85 coefficient of coupling being adjusted to as close to unity as practicable, means for tuning a portion of said third circuit, a capacity in said independent circuit to adjust the translation of energy through said circuit,
 90 the value of said capacity being adjusted according to the ratio of total inductance of the amplifier circuit to the total inductance of said independent circuit times the capacity of the undesirable capacitive couplings.
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3. In a cascade connected thermionic amplifier system, a plurality of thermionic amplifiers, each having input and output circuits and inherent undesirable couplings between said circuits, means for reducing
 100 this coupling consisting of an independent parallel circuit having shunt inductances and series capacities and a tuning condenser connected across one of said shunt inductances.

4. In a cascade connected thermionic amplifier system, a plurality of thermionic amplifiers, each having input and output circuits and inherent undesirable couplings between said circuits, and means for reducing
 105 this coupling consisting of an independent parallel circuit having shunt inductances and series capacities, at least one of said inductances being tuned, said capacities being proportioned according to the ratio of the total inductance associated with each
 110 amplifier stage to the total inductance in said independent circuit corresponding to said stage times the capacity of the inherent coupling.

5. In a cascade connected thermionic amplifier system, a plurality of thermionic amplifiers, each having input and output circuits and inherent undesirable couplings between said circuits, means for reducing
 120 this coupling consisting of an independent parallel circuit having shunt inductances and series capacities, said capacities being proportioned according to the ratio of the total inductance associated with each amplifier stage to the total inductance in said
 130

independent circuit corresponding to said stage times the capacity of the inherent coupling and means for tuning at least one of the inductances in said independent parallel circuit.

6. In a cascade connected thermionic amplifier system, a plurality of thermionic amplifiers, each having input and output circuits and inherent undesirable couplings between said circuits, means for reducing said coupling consisting of an independent parallel circuit having shunt inductances and series capacities, said capacities being proportioned according to the ratio of the total inductance associated with each amplifier stage to the total inductance in said independent circuit corresponding to said stage times the capacity of the inherent coupling, the input circuit of one of said amplifiers and the output circuit of the next adjacent amplifier stage each having a tuning condenser in parallel thereto and means for tuning one of the inductances in said independent parallel circuit simultaneously with the adjustment of said aforementioned tuning condensers.

7. In a cascade connected thermionic amplifier system, a plurality of thermionic amplifier stages, each having input and output circuits and inherent undesirable couplings between said circuits, means for reducing this coupling consisting of an independent parallel circuit having shunt inductances and series capacities, said capacities being proportioned according to the ratio of the total inductance associated with each amplifier stage to the total inductance in said independent circuit corresponding to said stage times the capacity of the inherent coupling, the input circuit of one stage and the output circuit of the next stage each having a tuning condenser in parallel thereto, said independent parallel circuit having alternate inductances coupled to the input circuit of one amplifier stage and to the output circuit of the next adjacent stage, means for tuning the shunt connected inductance intermediate said aforementioned inductances, said means being controlled simultaneously with the adjustment of said aforementioned tuning condensers.

8. In a cascade connected thermionic amplifier system, a plurality of thermionic amplifiers, each having input and output circuits and inherent undesirable couplings between said circuits, tuning condensers for controlling selected ones of said circuits, means for reducing said coupling consisting of an independent parallel circuit having shunt inductances and series capacities, a tuning condenser in parallel with each alternate shunt inductance, said tuning condensers being mechanically interconnected for simultaneous movement for adjusting

said circuits uniformly over a wide frequency range.

9. In a cascade connected thermionic amplifier system, a plurality of thermionic amplifiers, each having input and output circuits and inherent undesirable couplings between said circuits, means for tuning selected ones of said circuits, means for reducing this coupling consisting of an independent parallel circuit having shunt inductances and series capacities, said capacities being proportioned according to the ratio of the total inductance associated with each amplifier stage to the total inductance in said independent circuit corresponding to said stage times the capacity of the inherent coupling, means for tuning a selected portion of said independent parallel circuit, said means being controlled simultaneously with the operation of said first mentioned means for adjusting said circuits uniformly over a wide frequency range.

10. In a cascade connected thermionic amplifier system, a plurality of thermionic amplifier stages, each having input and output circuits and inherent undesirable coupling between said circuits, means for reducing said coupling consisting of an independent parallel circuit having shunt inductances and series capacities, said capacities being proportioned according to the ratio of the total inductance associated with each amplifier stage to the total inductance in said independent circuit corresponding to said stage times the capacity of the inherent coupling, the input circuit of one stage and the output circuit of the next stage each having a tuning condenser in parallel thereto, and a tuning condenser in parallel with one of said shunt inductances, said tuning condensers being mechanically associated for simultaneous movement for adjusting said circuits uniformly over a wide frequency range.

11. In a cascade connected thermionic amplifier system, a plurality of thermionic amplifier stages, each having input and output circuits and inherent undesirable coupling between said circuits, means for reducing said coupling consisting of an independent parallel circuit having shunt inductances and series capacities, at least one of said inductances having a tuning condenser connected in parallel thereto, said capacities being proportioned according to the ratio of the total inductance associated with each amplifier stage to the total inductance in said independent circuit corresponding to said stage times the capacity of the inherent coupling, the input circuit of one stage and the output circuit of the next stage each having a tuning condenser in parallel thereto, said tuning condensers being mechanically associated for simultaneous movement for adjusting

taneous movement for adjusting said circuits uniformly over a wide frequency range.

12. In a cascade connected thermionic amplifier employing two amplifier tubes, input and output circuits for each of said amplifier tubes, means for inductively coupling the output of said first amplifier tube to the input of said second amplifier tube, each of said input and output circuits having inherent undesirable couplings between said circuits, means for reducing said undesirable coupling consisting of an independent parallel circuit having three inductances connected in shunt and a condenser connected in series between one terminal of the middle of said three inductances and each of said inductances in the end position, one of said inductances being coupled to the input of the first of said amplifier tubes, said middle inductance being coupled to the output of said first amplifier tube, and said third inductance being coupled to the output of said second amplifier tube and a variable tuning condenser connected in parallel to the middle of said inductances.

13. In a multi-stage thermionic amplifier system, a plurality of thermionic amplifier stages, each having input and output circuits and inherent undesirable couplings between said circuits, means for reducing said undesirable couplings consisting of an independent parallel circuit having shunt inductances and series capacities, said capacities being proportioned according to the ratio of the total inductance associated with each amplifier stage to the total inductance in said independent circuit corresponding to said stage, times the capacity of said inherent undesirable couplings of said amplifier stage, one of said shunt inductances being coupled to the input coil of the first tube of said amplifier, each of the other of said shunt inductances being coupled to the output coil of one amplifier stage, and a variable tuning condenser connected in parallel, across the common connecting wires, between each pair of shunt inductances.

In testimony whereof I affix my signature.
EDWARD W. FEARING.