Dec. 4, 1928. 1,693,898

L. C. F. HORLE

AMPLIFICATION SYSTEM

Filed Jan. 24, 1923 2 Sheets-Sheet 1

Fig. 1.

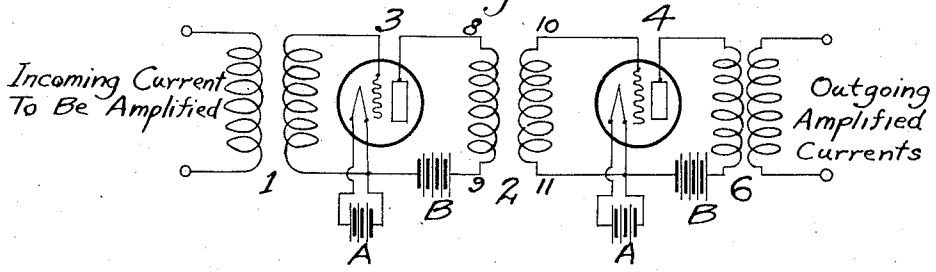


Fig. 2.

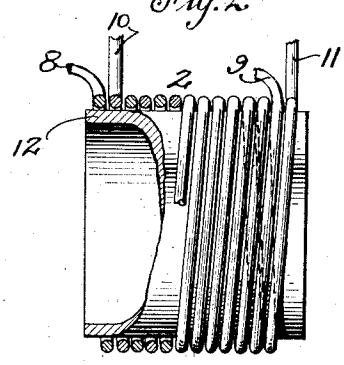


Fig. 3.

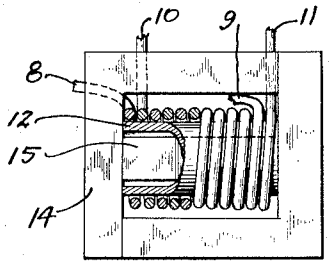


Fig. 4.

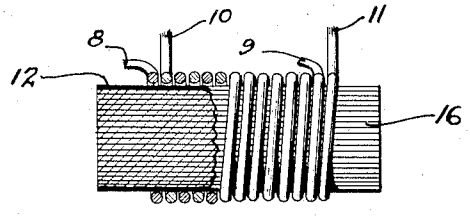
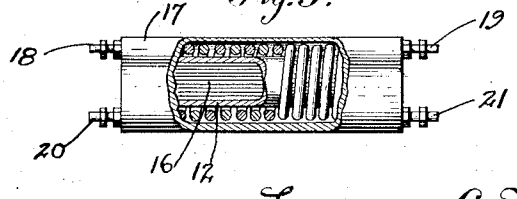


Fig. 5.



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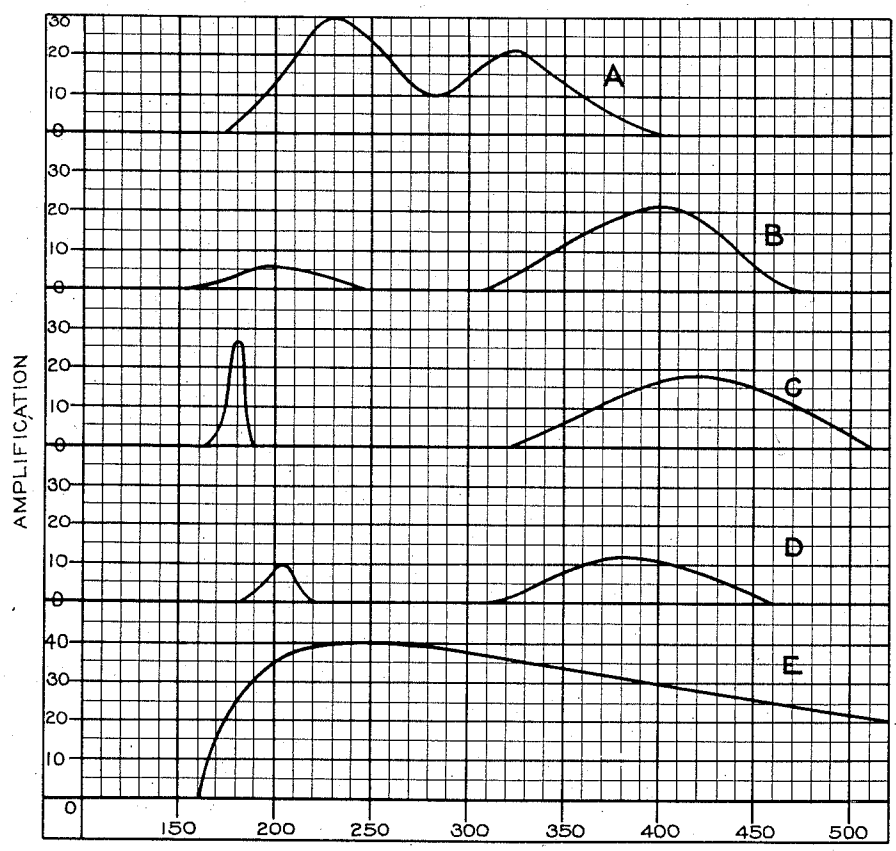


Fig. 6.

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UNITED STATES PATENT OFFICE.

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AMPLIFICATION SYSTEM.

Application filed January 24, 1923 Serial No. 614,608.

My invention relates broadly to the amplification of feeble electric currents, and more particularly to means for coupling the input and output circuits of amplifiers operating over broad bands of alternating current frequencies.

One of the objects of my invention is to provide means for coupling a plurality of electric circuits for particular kinds of current while isolating the circuits from one another for other types of currents.

Another object of the invention is to provide a means for interconnecting electrical circuits which are to be coupled for alternating current and are to be insulated from one another for direct currents or for interconnecting such circuits which are to be coupled for a band of alternating current frequencies and to be substantially insulated from one another for all other bands of frequencies.

Another object of the invention is to provide a transformer for coupling the input and output circuits of an electron tube amplifier, the coupling means being designed to secure substantially pure magnetic coupling with substantially no capacity coupling.

A still further object of the invention is to provide a type of duplex winding for the circuits of the coupling device and the amplifying means.

Another object of the invention is to provide a simplified construction of coupling device which may be manufactured in quantity production where the characteristics of the coupling device must not vary between specimens manufactured under similar conditions and with materials which vary no more than do the materials that are commonly available for their fabrication.

My invention will be more clearly understood from the following specification by reference to the accompanying drawings in which:

Figure 1 is a wiring diagram of an electron tube amplification circuit employing my invention; Fig. 2 is a view of an air core transformer employing the duplex winding of my invention; Fig. 3 is a view of a closed core transformer employing the duplex winding of my invention; Fig. 4 is a view of an iron core transformer with primary and secondary windings in duplex arrangement in accordance with my invention; Fig. 5 is a view partially broken away showing the transformer mounted within an insulated cylindrical casing with terminals for the windings brought out at opposite ends of the case; and Fig. 6 is a curve sheet showing the characteristics of the transformer of my invention compared with the characteristics of transformers heretofore available in the art.

My invention finds application in such laboratory apparatus as bridges for radio frequency use, coupling systems for duplex telephony and for intertube couplings for electron tube amplifiers.

Heretofore in the art several types of radio frequency transformers for coupling the circuits of an electron tube amplifier have been employed, including the multilayer open core transformer in which the windings are wound adjacent each other in grooves in a form of insulating material; the iron core multilayer transformer in which the windings are mounted inside a closed iron core; the single layer air core transformer with windings arranged along the periphery of an insulated tubular member; and the single layer closed iron core transformer. The characteristics of each of these prior types of transformers have been represented by curves A, B, C and D, respectively, in Fig. 6.

It will be observed that in every case shown in the drawings the range over which amplification can be accomplished is very narrow and that the degree of amplification varies rapidly with wavelength. This is seriously objectionable since it means that in the use of apparatus in which these transformers are included every minute change of wavelength must be accompanied by readjustments of other controls to maintain the amplifier at its best amplification and make the operation of the equipment both cumbersome and requiring expert operation. It will be noted as well that each of these transformers have two bands of frequencies throughout which they show amplification. The lower band, however, is generally one of lower amplification and has much more rapid change of amplification with change of frequency. This results in an exceptionally high degree of instability when in operation and makes the amplifier useless in that region.

With the transformer of my invention I secure a characteristic curve represented at

E in Fig. 6. My transformer consists of two windings, a primary winding and a secondary winding, the conductors of which are laid on the winding from parallel and separated from one another only by the thickness of the insulating material on the conductors. It will be observed in Fig. 6 that only one wavelength band occurs in this transformer and that the amplification changes only vary slowly with frequency change. The actual amplification at any wavelength throughout this band is considerably in excess of the other transformers and because of its change, the stability of operation is very great.

Referring particularly to Fig. 1 of the drawings, a representative electron tube amplification circuit is shown consisting of means for applying the incoming power which is to be amplified to the vacuum tube 3 which in this case is the transformer 1; the vacuum tube 3; the device for interconnecting the vacuum tube 3 with the vacuum tube 4 which in this case is the transformer of my invention 2; and the means 6 for applying to the system to which the amplifier is connected the power made available by the amplifier unit. In addition to these essential elements there are the batteries A for supplying the filaments, and the batteries B for supplying the exciting current of the tube.

The transformers 1 and 2 are of such a nature that they most efficiently accommodate the tubes to the incoming and outgoing lines and will therefore depend in their characteristics upon the nature of the lines. The transformer 2 however must accommodate the output characteristics of the tube 3 to the input characteristics of the tube 4, and it must be so designed that any wave form which exists in the grid circuit of tube 3 will be reproduced very faithfully in the plate circuit of tube 4, and this must be done with the very maximum gain of energy in the transfer.

Where such an amplifier is devised for amplifying currents of low frequency—200 to 2000 cycles—as in telephony, it is quite easily possible to build a transformer which will approximate the ideal characteristics described above; namely, high efficiency and faithfulness of reproduction by the use of the commonly available materials of the telephone art and with the commonly used telephone transformer design methods. But where such an amplifier is to be used for the amplification of exceedingly high frequency currents—500,000 to 5,000,000 cycles—the difficulty of obtaining high efficiency is multiplied many fold and the difficulty of securing faithfulness of reproduction over a wide band of frequencies becomes almost insurmountable.

Fortunately for the art, however, where such amplifiers are used for the amplification of high frequencies, as in a radio telephony and similar work, the same broad frequency band of faithfulness of reproduction is not required as it is in amplification common to the telephone art. In this latter case, for instance, it is found that if an amplifier is to be used for the amplification of voice frequency currents of the kind that are used in the broadcasting of music and the like by radio the amplifier must be capable of amplifying currents of all frequencies lying between only a few per second up to, perhaps, 10,000 per second, and it must amplify all these frequencies to the same degree. If this absolute equality of amplification is not obtained the quality of the sounds as they are reproduced by devices, such as telephones or loud speakers, supplied by the amplifier depart greatly from the quality of the sound which is applied to the system of which the amplifier is a part and the amplifier is said to be one of low quality. But since the characteristics of the vacuum tubes that are available are such that the characteristics are practically the same over this band of frequencies, the problem of building such an amplifier reduces itself to the design of a transformer which has the desirable and constant characteristics over this band of frequencies. And since the action of the materials common to the telephone art are reasonably independent of frequency this problem has been solved, as have other transformer problems of the telephone art.

Its best solution is accomplished through the recognition of the fact that the most efficient and satisfactory amplifier is that one which will make the greatest voltage available to the grid of electron tube 4 for a given voltage available in the plate circuit of tube 3. The only limiting condition which is set for making the ratio of the highest possible value at voice frequencies is the fact that both the plate circuit of tube 3 and the grid circuit of tube 4 are essentially resistances and are independent in their values of the frequencies. There are certain capacities existent in these circuits of the tube, and since the impedance of any capacity depends upon the frequency the capacity impedances of the tube depend upon the frequency and might be expected to cause the action of the amplifier to vary with frequency. The impedances which result from these capacities, however, are found to be so extremely high at the frequencies which are used for this type of amplification that when compared with the resistances of the tube circuits they influence the operation of the amplifier in only a very minor way, and if proper provision is made for their use they may be made to correct a contrary variation of the other characteristics of the tube circuits.

When the frequencies to be amplified are exceedingly high, however, the impedances of the tube become predominantly those of the associated capacities and the problem of

amplification is multiplied many times. This is quite evident when it is remembered that for faithfulness of reproduction over a wide band of frequencies that the characteristics of the tube and the transformers must be independent of the frequencies, and since the impedance of a capacity as that of the tube depends directly on the frequency it becomes quite impossible to secure constancy of amplification over such a wide band of frequencies as is usual in low frequency amplification. Thus, while it is quite common practice to secure amplification of voice frequency currents between 200 and 2000 cycles—a range of ten to one—it is a more difficult feat if uniformity of amplification can be accomplished between 500,000 and 5,000,000 cycles—a range of only two to one. In the amplification of radio frequency currents such as are used in radio telephony, however, the band over which uniform amplification must be accomplished in order that faithfulness of reproduction may be assured may be very small. When reception of broadcast signals is to be done with the amplifier, for instance, if uniformity of amplification can be gotten over a range of frequencies of 1.2 to 1, satisfactory quality of reproduction will be obtained. But where such an amplifier is to be used for stations operating on widely differing wavelengths it must be capable of about the same degree of amplification on these several wavelengths. In order that a radio frequency amplifier be absolutely universal in its application to radio reception it would be required that it permit amplification on all wavelengths between 200 meters and 20,000 meters—1,500,000 and 15,000 cycles. This is practically impossible of accomplishment and the art has had to make use of devices whose characteristics depart very greatly from these ideal conditions. Heretofore radio frequency amplifiers have been greatly limited in range, but because of the fact that no amplifier installation is required in actual practice to be used for the many different types of radio service, which are represented by the very wide band of wavelengths, the comparatively narrow band amplifier has found a very important place in the field of radio.

The radio frequency amplifier commonly used also suffers greatly from instability, a condition that either makes it inoperative at some frequencies or makes it necessary that it be carefully and critically adjusted for every frequency at which it is used. That is, whenever the frequency at which it is used is changed it usually requires a change in the constants of the associated apparatus and thereby makes its use rather cumbersome and not easily accomplished.

In addition to the above objections to the forms of radio frequency amplifiers in common use is the fact that efficiency of these devices is usually low. Unless the transformers which are used in such equipment are of low resistance the degree of amplification must of necessity be low. The resistance of such a device is not limited to the conductor which constitutes its windings, but is often due, in a major way, to losses in the magnetic or dielectric material of its structure. Whatever the losses and hence the resistance may be, its effect is the same, namely, to limit the amplification that can be secured through the use of the device.

In Fig. 2 I have illustrated the construction of radio frequency transformer by which I secure the advantages herein set forth and particularly shown by the characteristic curve E in Fig. 6. The turns of wire comprising the transformer 2 have been shown in greatly exaggerated size in all of the views in order to clearly bring out the principle of my invention, and it will be understood that the transformer winding comprises fine wire turns where the turns are represented by the large size conductors. An air core is formed by winding the turns upon an insulated form 12. The primary winding begins as indicated by reference character 8. The secondary winding commences as indicated by reference character 10. The twin conductor is wound upon the form 12, the turns of the primary winding being indicated in section by cross-hatching slanting to the right while the turns of the secondary winding are indicated by cross-hatching slanting to the left. The transformer windings continue along the core 12, the primary winding ending at 9 and the secondary winding finishing at 11. The same characters of reference have been used to indicate corresponding connections in the wiring diagram Fig. 1.

Fig. 3 shows a closed iron core transformer wherein the coil supporting member 12 is mounted upon core member 15 within the closed core 14.

In Fig. 4 the transformer winding is illustrated disposed on insulating member 12 forming an envelope for an iron core 16.

The turns of the primary winding are wound closely adjacent to the turns of the secondary winding and are parallel throughout the entire length of the winding. The turns are separated by the dielectric formed by the insulation enveloping each of the conductors.

The transformer may be suitably mounted as illustrated in Fig. 5 within an insulated cylindrical casing 17, bearing posts 18—19—20—21 on the exterior of the casing. The primary winding beginning at 8 is connected interiorly of the case with post 18 and at the end 9 the primary winding is connected within the case with post 19. The secondary winding 10 is connected inside of the casing with binding post 20 while the end of the secondary winding 11 connects inside of the case with binding post 21. This arrangement per-

mits external connections to be made between the binding posts and the electron tube circuits.

In the operation of an electron tube amplifier employing my invention, the power is transferred from tube 3 of Fig. 1 to tube 4 by means of the magnetic flux which interlinks the two windings of the transformer. Where these two windings and their associated capacity which, for the most part resides in the tube, are so chosen that they are tuned to the same wavelength as those shown in Fig. 2, that is, the primary of the transformer and the output capacity of the tube are tuned to the same wavelength as are the secondary winding and the input capacity of the tube and the power is transferred only at the frequency at which they are tuned. If the resistance of the windings were kept very low it would be found that the band over which the transformer could be depended upon to give amplification would be even narrower than are the transformers shown, and that the transformer would be so very unstable as to be entirely unusable. There are two methods by which this band may be broadened; one of them consists in inserting resistance in the transformer winding or its associated material and thereby broadening the band of operation. This, of course, results in a reduction in the degree of amplification in order to gain breadth of band, and results in such amplification characteristics as are shown by curves A, B, C and D in Fig. 6. The other method is by increasing the coupling between the windings as is secured with my transformer. This is accomplished by placing the windings in the closest proximity to one another and results in a broadening of the band without any sacrifice in the degree of amplification and with a degree of stability that cannot be secured by any other means. It is to be observed that this same result cannot be accomplished by the expedient of merely placing the windings of the transformers of the prior and usual construction in close proximity. This would result in an increase of coupling, of course, but it would also result in bringing into being much dielectric flux and great dielectric loss with a consequent reduction of the degree of amplification. In the transformer construction of the present invention this increased coupling is secured without increased dielectric loss by the fact that while the conductors of the two windings are extremely close to one another those parts of the conductors that are most closely adjacent are always at the same potential and therefore no dielectric flux exists and hence no loss. It is essential for the successful operation of the transformer of my invention that the conductors be laid on parallel and that they be closely adjacent, and that they be closely and permanently fixed relative to one another so that no dielectric loss as above described may be brought into being, for such loss will be fatal to the operation of the device. To this end it is found advisable to impregnate the entire device in wax or varnish. This cannot be done in prior constructions, since the dielectric field that always accompanies these prior types of construction would result in tremendous losses.

By reason of this arrangement of the windings the reactance gradients along all portions of the two conductors closely adjacent to one another must be substantially equal. The currents in closely adjacent portions of the conductors are substantially equal in magnitude.

The transformer is particularly effective for quantity production since by its construction all its electrical characteristics may be easily reproduced. Since its inductance depends only on the size of conductor, number of turns, and the diameter of the form, the coupling depends only on the position of the windings relative to one another, and hence only upon the insulation thickness; and since coupling capacity is eliminated by the type of winding, it is found quite possible to build these devices by using only ordinary care with resultant variations in the constants in the transformers of a degree considerably less than it is possible to secure in the manufacture of the associated equipment of electron tube amplifiers such as the electron tubes per se.

In the claims hereinafter following I have used the term "inductance element" as embracing the two windings parallel side by side substantially throughout their length.

While I have described the transformer of this invention with particular reference to radio frequency currents, it is to be understood that my construction is applicable to audio frequencies and that no limitations are intended other than are imposed by the scope of the appended claims.

Having thus described my invention, what I claim and desire to secure by Letters Patent of the United States is:

1. An amplification system comprising in combination a plurality of electron tubes each having a heated cathode, an anode and a grid, input circuits including said grid and cathode of each tube, output circuits including said anode and cathode of each tube, and coupling means between the output circuit of one tube and the input circuit of another tube comprising conductors connected in the respective circuits and fixed immediately adjacent and parallel side by side to one another throughout the entire length thereof in such manner that the reactance gradients along all portions of the two conductors are substantially equal.

2. An amplification system comprising in combination a plurality of electron tubes each

having a cathode, an anode and a grid, input circuits including said grid and cathode, output circuits including said anode and cathode, and coupling means between the output circuit of one tube and the input circuit of another tube comprising conductors connected in the respective circuits and wound upon a core, said conductors being located adjacent each other separated by dielectric between turns and parallel to one another side by side throughout the entire length thereof in such manner that adjacent points on said conductors are at the same relative potential.

3. An amplification system comprising in combination a plurality of electron tubes each having a cathode, an anode and a grid, input circuits including said grid and cathode, output circuits including said anode and cathode, and coupling means between the output circuit of one tube and the input circuit of another tube comprising conductors connected in the respective circuits and wound upon an iron core, the conductor in one circuit being located immediately adjacent the conductor in the other circuit and insulation material for spacing said conductors parallel side by side throughout the length thereof, the potential of those portions of the conductors which are closely adjacent being substantially equal for preventing dielectric flux therebetween.

4. An amplification system comprising in combination a plurality of electron tubes each having a cathode, an anode and a grid, input circuits including said grid and cathode, output circuits including said anode and cathode, and coupling means between the output circuit of one tube and the input circuit of another tube comprising conductors connected in the respective circuits, the conductors being wound upon a core, the turns of one conductor being located alternately between the turns of said other conductor and immediately beside said conductor, whereby the reactance gradient along all portions of the conductors is substantially equal.

5. In an amplification system a plurality of electron tubes each having a heated cathode, an anode and a grid, input circuits including said grid and cathode, output circuits including said anode and cathode and coupling means between the output circuit of one tube and the input circuit of a succeeding tube, said means consisting of a twin conductor wound upon itself with one of the conductors connected in said input circuit and the other of said conductors connected in said output circuit.

6. In an electrical system, a grid, a plate, an inductance element comprising two windings wound parallel side by side throughout their length, the coefficient of coupling of said windings being substantial unity, a circuit including said grid and inductance element, a circuit including said plate and inductance element, adjacent points along the respective windings being at the same potential, the potential gradient along any given portion of one winding being the same as the potential gradient along a corresponding portion of said other winding.

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