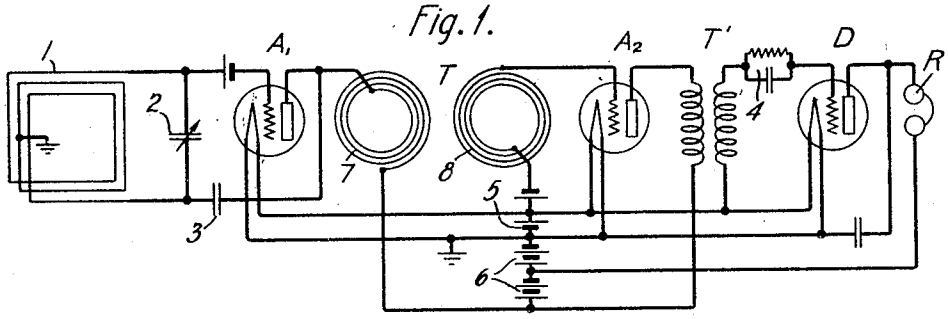
May 24, 1932. H. T. FRIIS ET AL 1,859,867

WAVE TRANSMISSION CIRCUITS

Original Filed Nov. 20, 1923

Fig. 1.



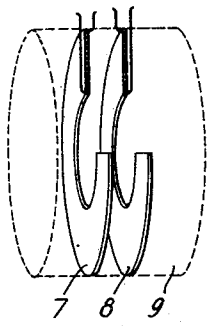
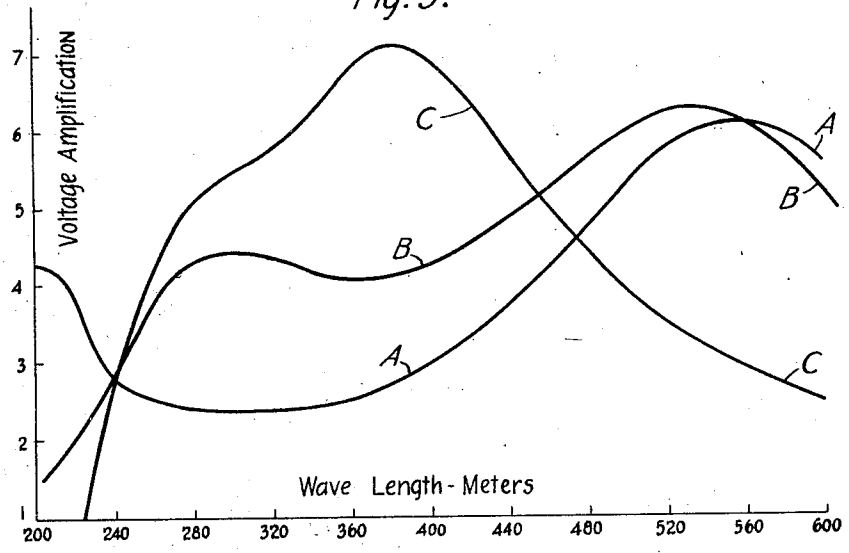


Fig. 2.

Fig. 3.



Inventors:
Harald T. Friis
Axel G. Jensen
by F. P. Reville Atty

Patented May 24, 1932 1,859,867

UNITED STATES PATENT OFFICE

HARALD T. FRIIS AND AXEL G. JENSEN, OF RED BANK, NEW JERSEY, ASSIGNORS TO WESTERN ELECTRIC COMPANY, INCORPORATED, OF NEW YORK, N. Y., A CORPORATION OF NEW YORK

WAVE TRANSMISSION CIRCUITS

Original application filed November 20, 1923, Serial No. 675,816. Patent No. 1,727,010, dated September 3, 1929. Divided and this application filed March 2, 1928. Serial No. 258,475.

The present invention relates to transmission circuits for electrical wave energy in signaling or similar systems, and is a division of application Serial No. 675,816 filed November 20, 1923, Patent 1,727,010, September 3, 1929.

The invention has particular application to wave amplifying systems and will be described in connection with a radio receiving system although it is not limited to reception nor to use in the radio art.

It is an object of the invention to obtain improved high frequency amplification over a range of wave lengths.

A feature of the invention comprises a high frequency transformer associated with an amplifying system to give improved high frequency amplification over a wide range of wave lengths.

Radio frequency transformers have been proposed in which an attempt has been made to reduce the losses between primary and secondary windings by dividing the primary and secondary windings each into a number of separated coils and associating each secondary coil in inductive relation with a respective primary coil. This form of construction requires considerable space and necessitates the use of more wire in order to obtain the same value of mutual inductance that can be obtained between a single primary coil and a single secondary coil. Also this mode of construction, comprising as it does, several distinct units, provides a greater number of parts which have to be duplicated, if duplicate transformers are to be built, than in the case where the transformer comprises only two windings. This is a matter of considerable importance in the manufacture on a quantity production basis of transformers having the same characteristics to a high degree of accuracy.

The high frequency transformer of this invention comprises a two-winding transformer of small mechanical dimensions and of a construction to give the desired mutual inductance with small capacity losses.

The transformer employed in the embodiment of this invention herein shown comprises, disk-shaped coils, that is, coils of large total diameter and of large depth of winding (measured from the innermost turns to the outermost turns) compared with the other dimension, which will be termed the width of the winding, corresponding to the thickness of the disk. It has been found that a marked improvement in the general efficiency of the coil for repeating high frequency waves over a considerable wave length range is realized if the total diameter of the coil is kept above a certain minimum value, and if the thickness of the winding and the separation between the primary and secondary coils is kept below a certain maximum value.

It has also been found, in accordance with this invention, that the transmission characteristic of the transformer, that is, the relation between the amplitude of the wave transmitted through the transformer and the length of the wave transmitted is greatly influenced by the manner of connecting the transformer in the circuit. With one manner of connecting the transformer, a single-peaked characteristic is obtained, giving high transmission at certain wave lengths at the expense of small or practically no transmission at neighboring wave lengths. With the type of connection of the invention, however, the characteristic is less peaked and the transformer exhibits efficient transmission over a much greater wave length range.

Reference will now be had to the drawings which, in connection with the detailed description to follow will afford a more complete understanding of the nature and objects of the invention.

In the drawings: Fig. 1 is a schematic representation of a radio receiving circuit embodying the invention; Fig. 2 is a view partly in section of a transformer in accordance with the invention, and Fig. 3 shows characteristic curves illustrative of the effect of connecting the transformer into the circuit in the manner provided by the invention as compared with the effect of any other manner of connection.

In Fig. 1, a loop antenna 1 has the center of its inductance grounded and the terminals of the loop are connected across a tuning condenser 2 and to the radio frequency amplifier

A_1 in the manner disclosed in the U. S. patent to H. T. Friis, No. 1,678,183, July 24, 1928. That is, the grid of the tube is connected to one loop terminal, and the plate of the tube is connected to the other loop terminal through a small balancing condenser 3 having a capacity of the same order of magnitude as the grid-to-plate capacity of the tube, the purpose of this condenser being, as explained in the above mentioned patent of Friis, to stabilize the circuit against the building up of sustained oscillations due to the grid-to-plate capacity.

The plate of the radio frequency amplifier A_1 also is connected to the primary winding of the radio frequency transformer T, the secondary of which is connected in the grid circuit of a second stage radio frequency amplifier A_2. Other stages of radio frequency amplification may be provided as required and may be connected in tandem with amplifier A_2 in the same manner that that amplifier is associated with the amplifier A_1. Following the radio frequency amplifier stages is a detector D, which may be of the usual type and preferably is provided with a grid-leak resistance and condenser circuit 4. The output circuit of the amplifier A_2 is coupled to the detector through a radio frequency transformer T', which may be of the same type as the transformer T. One or more stages of audio-frequency amplification (not shown) may be provided following the detector in accordance with known practice. The receiver R which is illustrated as the usual ear-phones may in practice be any type of receiver, for example, a loud speaker.

The cathodes of all the tubes are connected together and to ground, and are, therefore, connected to the center of the loop inductance. This has the effect of impressing on the grid of tube in the first amplifier A_1 only half the voltage developed in the loop, but the advantages resulting from this mode of connection in stabilizing the circuit and sharpening its frequency selectively more than outweigh the loss in amplitude, as is fully explained in the application of Friis referred to above.

Heating current is supplied to the cathodes of all the tubes from the source 5, and space current for all the tubes is supplied from source 6 which, as shown, may be provided with a tap for supplying a smaller plate voltage to the detector than to the amplifiers.

The operation of the circuit in receiving radio signals will be obvious from the circuit description already given. Loop 1 is properly oriented and condenser 2 is properly adjusted to render the set selective, as to direction and wave length, of the particular waves to be received. Amplifiers A_1 and A_2 amplify the received energy at the radio frequency level and so secure the well known advantages in signal amplification, which is substantially as the square of the radio frequency amplification. After such amplification, the signal is detected in the detector D and is impressed on the receiver R. To accommodate the set to waves having any one of a wide range of wave lengths, it is essential that transformers T and T' transmit any of the waves within this range, and if anything like uniform results are to be secured at the different wave lengths, it is necessary that these transformers give substantially uniform transmission throughout this wave length range.

The construction of the radio frequency transformer of the invention and the manner of its association in the circuit in accordance with the invention to secure uniformity of transmission over a wide wave length range will now be described.

Referring to Fig. 2, the transformer windings 7 and 8 are illustrated partly in section to show the manner of winding. These coils are disk-shaped and have an inner and outer diameter and a depth of winding (i. e. measured between the inner and the outer diameter) all of which are large compared with the width of winding. In practice these dimensions are conveniently determined by accurately cutting grooves having these dimensions into a block or spool of suitable material such as hard rubber or wood, and winding the coils in the grooves. The outline of the spool is indicated at 9. It is not necessary to construct the transformer in this manner, however, since the windings may be made self-supporting or may be supported in any other manner, as desired.

It has been found that when coils are wound in this manner and are mounted co-axially and parallel with each other with a spacing within certain limits, and with the proper circuit connections, the transmission characteristic of a receiving set such as that illustrated in Fig. 1 as measured and plotted between wave length and amplitude of the wave transmitted through the set, will, in general, comprise the well known double-humped curve characteristic of coupled circuits. The primary of the transformer together with the tube A_1 and its associated circuits form a primary of definite inductance and capacity values, and the secondary and the elements of tube A_2 form in like manner, another circuit having its own characteristics. The transformer furnishes a coupling between these circuits which consists partly of inductance and partly of capacity, the latter being due to the capacity between the transformer windings.

It has been found that as the dimensions of these transformer windings and their separation are varied the transmission characteristic of the set varies markedly. By keeping the width of winding very small and increas-

ing the depth a corresponding amount, the shunt capacity of each winding is reduced so that the reactance of each winding is more nearly pure inductance. It has been found that as the two coils are brought nearer to each other the two humps of the characteristic are separated farther apart. Thus, in Fig. 3, curve A represents a measured characteristic of a particular circuit similar to that shown in Fig. 1. If windings 7 and 8 were moved closer together and another set of readings taken these would be found to define a characteristic with two humps spread farther apart. Conversely, as the windings are spaced apart farther the two humps of the characteristic approach each other more closely. Accompanying this effect, there is a definite variation in the central or "valley" region of the characteristic. This portion and also the humped portions of the curve are controlled to a large extent by the capacity between the windings, which varies not only with their distance of separation but also with their areas. As the capacity between windings changes, it influences both the relative height of the valley portion of the curve with respect to the humped portions and the distance apart of the humped portions. It will be noted that the area of a winding of given depth increases as the respective inner and outer diameters increase, so that the capacity between windings varies not only with their spacing but also with the coil diameter, assuming constant depth of winding.

Furthermore, the sense of this capacity in the external circuit, whether (depending on the coil connections) the capacity between certain elements of the circuit or between other elements, has a marked effect on the characteristic.

It has been found by experiment that all of the factors which control the shape of the characteristic curve can be reduced to the shape, the mechanical dimensions, the separation between the windings, and the manner of connection of the coils in the external circuits.

Taking up first the diameter of the coils, curve A in Fig. 3 is a measured characteristic of a circuit employing a transformer having a width of winding of 3/64 inch, a separation between windings of 1/16 inch, an inside diameter of 1 inch, and a winding depth of 1/2 inch. It is found that as the diameter is increased, the other dimensions remaining the same, there is a marked increase in the distance between the humps and also a heightening in the valley portion of the curve, for dimensions in the vicinity of 1 inch internal diameter. For example, in the typical set of measurements there was found to be an increase in the distance between the humps of the order of 25% in passing from a 3/4 inch internal diameter to a 1 inch internal diameter coil, whereas in passing from a 1 inch to a 1¼ inch internal diameter coil the increase in distance between the humps of the characteristic was only about one-half this amount, an observed case being about 14%, the other dimensions being the same. There was only a very slight relative heightening in the valley portion of the characteristic in changing from the 3/4 inch internal diameter to the 1 inch internal diameter coil, while there was a marked heightening of the valley portion in passing to the 1¼ inch internal diameter coil. There is seen, therefore, to be a marked advantage in increasing the internal diameter of the coils in the vicinity of the one inch internal diameter, for the same depth of winding.

This effect on the characteristic of increasing the coil diameter for the same depth of winding is probably due to the increase in the area of the face of each coil. It is also found that increasing the depth of the winding for the same inner diameter has similar effects on the characteristic.

Taking up now the effect of the width of the winding, it is found that, other dimensions being the same and being of the order of those stated hereinbefore, a winding width of 1/16 inch gives a characteristic of principally one hump with possibly a minor hump superposed and displaced at a slight distance from the center of the principal hump of the curve, so that as this winding width is reached in the scale of decreasing widths, the coil begins, at least for wave lengths of the order of 200 to 500 meters, to give the broader characteristic due to the development of the two humps.

The development of two humps representing the same order of amplification proceeds rapidly as the width is narrowed from 1/16 inch to 3/64 inch, and somewhat less rapidly as the width is changed from 3/64 inch to 1/32 inch. In the region of 1/16 inch to 3/64 inch, therefore, a value for the width of winding is obtained which gives a marked improvement in the characteristic in that it represents a broader wave length range over which substantially the same order of amplification is obtained.

As pointed out above, the separation between the windings has a marked effect on the characteristic. With the diameter and width values of the order of magnitude hereinbefore stated, it is found that for greater separations than about 1/4 to 1/2 inch the two humps of the characteristic begin to merge into one, and that the effect of changing from a separation of 1/4 inch to a separation of 3/16 inch is very marked, at least in the wave length region of 200 to 500 meters. Curve B may be referred to, to show the type of curve obtained with a separation of 3/16 inch between windings. Curve A is not directly comparable with curve B since in the case which it represents, two differ-

ences occur in dimensions, namely, the internal diameter of the coil in the case of curve A was 1 inch while, as stated, that in the case of curve B was 1¼ inches, and the coil separation in the case of curve A was 1/16 inch, while that in the case of curve B was 3/16 inch. This separation effect, however, is more strikingly shown by curves A and B than would be the case if they were directly comparable, since the lesser diameter of coil A would, as stated above, tend to bring the humps of the curve closer together than they would be for a 1¼ inch internal diameter, so that in general, the effect on the spread between the peaks of the characteristic will be greater in changing from a separation of 3/16 inch to a separation of 1/16 inch than that shown by comparing curves A and B. It has not been thought necessary or desirable to encumber the drawings with other curves showing the effect of each individual condition discussed.

Curve B represents a desirable characteristic since it shows an amplification which only varies between the extreme limits of about 3.7 and 6.3 (arbitrary units) or about 25% from the mean value over the total range of 260 meters to 600 meters, and within the range of 260 meters to 460 meters, the greatest variation is only about 15% from the mean.

As stated above, it is advantageous to increase the diameter beyond the minimum limits given.

Since all the dimensions above discussed are to an extent dependent upon each other, it follows that if any one dimension is changed very materially there can be somewhat of a relaxation in the limits set for the other dimensions. For example, it is shown above that increasing the diameter of the winding, other dimensions remaining the same, broadens the characteristic. Increasing the width of the winding, on the other hand, gives a narrower characteristic. Hence, if the winding diameter be considerably increased in a given case, the width of the winding can also be increased to some extent without giving any narrower characteristic than that possessed originally in the assumed case.

In other words, while the actual limiting dimensions above given are the preferred dimensions, especially in short-wave radio receivers, the invention is not limited to those actual dimensions but only by the relative dimensions, and the invention can therefore be embodied in transformers of much larger actual dimensions than are given above, so long as the relative dimensions given are preserved. For example, it is found that if the depth of the winding be increased from 1/2 inch to 1 inch, the inner diameter remaining the same, the width of winding can be increased in about the same proportion, and 3/32 of an inch has been found to give the desired form of characteristic with the 1 inch depth of winding.

The effect of connecting the coil of the invention into the circuit in the manner in accordance with the invention is illustrated by curves A and C which represent the characteristics observed with the same coil connected respectively in accordance with the invention (curve A) and in the manner which would ordinarily be thought to be the proper manner (curve C). It will be noted that the two manners of connection give entirely different shaped characteristics.

Curve A results from connecting the plate and grid to respectively opposite terminals of the two windings, that is, if the inner terminal of the primary is connected to the plate, as indicated in Fig. 1, the outer secondary terminal is connected to the grid. This means, of course, that the terminals which are connected to the filaments (through the necessary batteries) are in the case of one winding the outer, and in the case of the other winding the inner terminal. Connecting the coil in this manner, therefore, gives a much broader characteristic than connecting homologous terminals to the plate and grid, respectively.

This is on the assumption that both windings are made with the same direction of winding. If one of the two windings is turned so as to present its opposite face to the other winding or if the coil is made up by winding the wire in opposite directions in the two coils, then the homologous terminals can be connected to the plate and grid, respectively.

It is probable that reversing the direction of winding of one coil and connecting homologous terminals of the coils to the plate and grid elements will result in a characteristic which is not exactly identical with that obtained by the preferred method of winding the coils in the same direction, and connecting respectively non-homologous terminals to the plate and grid elements. This is for the reason that there is a somewhat different distribution of capacity between corresponding portions of the respective windings in the two cases.

It is, of course, more convenient in practice to wind both coils in the same direction, particularly where they are formed by building up the windings in grooves in a spool or the like.

The reason for the difference in characteristic obtained with the two general types of connection between the coil terminals and the tube elements appears, from present information, to be that in the one case there is such a relation between the capacity coupling between the transformer windings and the inductive coupling between them, as to increase the wave length range throughout which substantially the same amplification is

obtained; while in the other case the two kinds of coupling do not cooperate in this manner. This appears to be due to the phase relations between the electromotive forces set up due to the respective kinds of coupling. That is, with the connections shown in Fig. 1 the capacity and inductive couplings are in aiding relation while with the reversed connections they are opposed.

Regardless of the particular theory upon which the actions depend, the coil and terminal relations determine to a large extent the shape of the characteristic, and the proper relations for obtaining a broad characteristic are those above given.

Each of the curves A, B and C was obtained in an amplifier circuit using the so-called "peanut" type of vacuum tubes. These tubes were in particular the Western Electric Company Type N tubes, which have very small grid-to-plate capacity, the plate consisting of a cylinder about 9/16 inch long and 5/32 inch internal diameter, and the grid consisting of a spiral forming a cylindrical surface of about 5/8 inch length and 7/64 inch external diameter. The coil which gave the characteristic curve B contained 200 turns of No. 36 Brown and Sharpe gauge double silk covered copper wire in each of the windings.

While each of the curves given in Fig. 3 was taken with transformers having a 1:1 ratio, it is to be understood that the invention is not to be limited to transformers having this ratio but that any desired ratio of turns may be employed. In general, if the transformer is inserted between tubes having different capacities between the tube elements to which the transformer terminals are connected, it is found advantageous to use a transformer ratio different from unity and to include the greater number of turns in the coil connected to the tube of the smaller capacity.

In Fig. 1 the transformer T′ is merely indicated in conventional manner, but it is to be understood that this transformer is of the same type of construction as transformer T.

While the invention is herein illustrated in an embodiment employing a particular type of transformer the invention is not limited thereto. As described above, substantially uniform amplification of a wide band of frequencies is obtained by provided capacity and inductive couplings properly proportioned and phased relative to each other. Obviously such couplings may be obtained by employing other types of structures.

What is claimed is:

1. In an electrical system, means for transferring energy throughout a range of frequencies from an exciting circuit to an absorbing circuit, one of said circuits being tunable, said means including a coupling between said circuits comprising means having capacity reactance and inductive reactance so related to one another as to transfer energy in aiding phase, said reactances being adjusted to produce a combined reactance which varies in a predetermined way as the frequency of the transferred energy varies.

2. Means for transferring electrical energy of superaudible frequency from one electrical circuit to a second electrical circuit, one of said circuits being variably selective to waves of super-audible frequency, comprising coupling means having a capacity reactance and an inductive reactance common to the two circuits, the respective phase of said reactances and the relative values of the capacity and inductive coupling produced thereby being so chosen that the inductive and capacity couplings respectively transfer energy with substantially reversed transfer-frequency characteristics as the selectivity of said one circuit is varied to vary the frequency of the transferred electrical energy.

3. In an electrical system, means for transferring energy throughout a range of frequencies from an exciting circuit to an absorbing circuit, one of said circuits being tunable, comprising a coupling between said circuits having capacity reactance and inductive reactance of such relative phase as to transfer energy in aiding phase, said reactances being proportioned to produce an energy transfer which remains substantially constant with frequency variations as said tunable circuit is tuned.

4. An electrical system comprising an exciting circuit, an absorbing circuit, one of said circuits being tunable over a range of frequencies, and means for providing an electrostatic and an electromagnetic coupling between said circuits, said couplings being so poled and relatively adjusted that for such adjustment their combined energy transfer remains substantially constant with frequency as said tunable circuit is variably tuned over said range of frequencies.

5. In combination, a plurality of electric discharge devices having input and output circuits, and means for coupling the output circuit of one of said deivces to the input circuit of another to provide substantially uniform transmission for waves of a wide range of frequencies representing a series of signal modulated waves, said means having capacity and inductive coupling effects of such relative phase as to transfer energy in aiding phase from said output circuit to said input circuit.

6. In combination, two space discharge devices each having a cathode and another eletrode and a transformer having primary and secondary windings each of said windings consisting of a flat disk-shaped coil having an inner diameter of at least one inch and a dimensional ratio of at least 8 to 1 between the radial depth of each winding and the

width of the winding, said coils being associated in parallel and co-axial relation with each other and separated by a distance at least as small as 1/2 inch, said coils terminating in an end on the inner layer and another end on the outer layer, the inner end of one winding being connected to the cathode of one device, the outer end of the other winding being connected to the cathode of the other device and the other ends of the respective windings being connected to the respective other electrodes of said devices.

7. In combination, two space discharge devices each having a cathode and another electrode, and a transformer having primary and secondary windings in the form of circular coils arranged coaxially, each winding consisting of a single spiral coil conductor, terminating in an end on the inner layer and in another end of the outer layer and having its dimensions in such a fixed relationship to the dimensions of the other and to the distance separating the windings as to give substantially uniform transmission for waves of a wide range of frequencies, the inner end of one winding being connected to the cathode of one device, the outer end of the other winding being connected to the cathode of the other device and the other ends of the respective windings being connected to the respective other electrodes of said devices.

8. In an electrical wave transmission system, an exciting circuit, a load circuit, adjustable means in one of said circuits for selecting any of a plurality of waves in a wide superaudible frequency band, and means having capacity and inductive reactance for coupling said circuits, said means comprising a transformer having primary and secondary windings so proportioned, spaced and poled with respect to each other that the inductive and capacity couplings are additive in effect and cooperate to substantially uniformly transmit all waves in said wide superaudible frequency band.

In witness whereof, I hereunto subscribe my name this 6th day of February, 1928.

HARALD T. FRIIS.

In witness whereof, I hereunto subscribe my name this 20th day of February, 1928.

AXEL G. JENSEN.