March 10, 1931.

H. WHITTLE ET AL

1,795,914

AMPLIFYING SYSTEM

Filed Oct. 26, 1927

FIG. 1

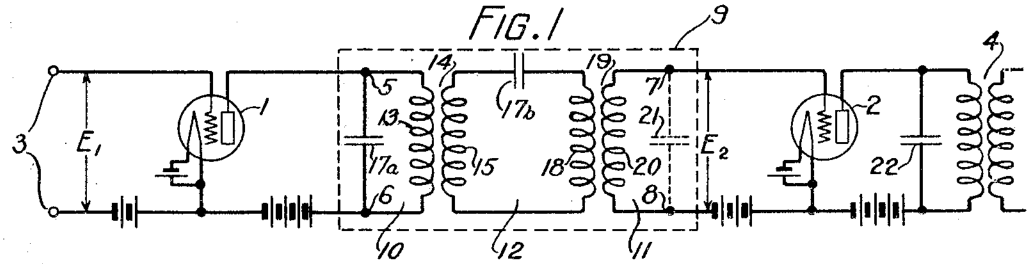
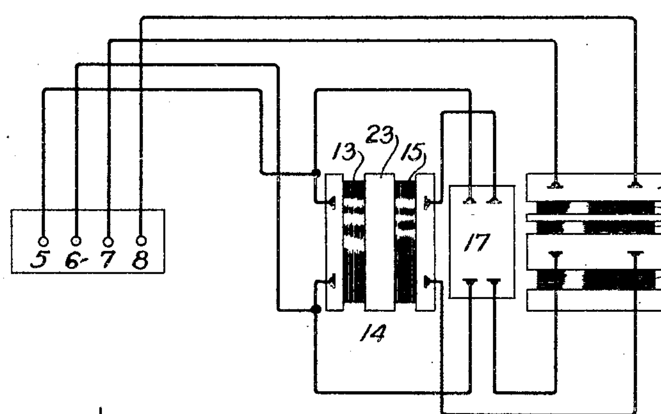


FIG. 2



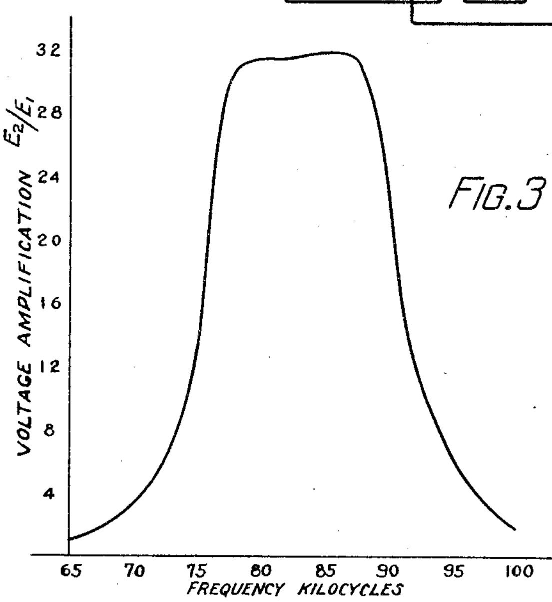


FIG. 3

INVENTORS HORACE WHITTLE
ARTHUR J. CHRISTOPHER
BY H. A. Burgess
ATTORNEY

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UNITED STATES PATENT OFFICE

HORACE WHITTLE, OF MAPLEWOOD, NEW JERSEY, AND ARTHUR J. CHRISTOPHER, OF YONKERS, NEW YORK, ASSIGNORS TO BELL TELEPHONE LABORATORIES, INCORPORATED, OF NEW YORK, N. Y., A CORPORATION OF NEW YORK

AMPLIFYING SYSTEM

Application filed October 26, 1927. Serial No. 228,727.

This invention relates to amplifying systems and particularly to networks used therein to couple two space discharge devices in tandem.

An object of the invention is to secure a uniform voltage transformation of waves within a prescribed band of frequencies with a sharp attenuation of frequencies immediately outside of the prescribed band.

Another object is to increase the overall amplification by a space discharge amplifier of waves within a prescribed band of frequencies to the maximum degree consistent with uniform amplification throughout the band and a high degree of selectivity.

The above objects are accomplished in accordance with the invention by utilizing for coupling two space discharge devices in a multi-stage amplifier, a network comprising two tuned transformers coupled in tandem through a series condenser, so that the complete network comprises three coupled tuned circuits, the first and last being shunt anti-resonant circuits and the intermediate being a closed series resonant circuit. These circuits are all tuned alike to the same frequency, which is preferably near the center of the selected band. By properly selecting the relative values of the elements of the coupled circuits and proportioning the coupling coefficients of the network in accordance with the present invention, it is found that all waves within a predetermined band of frequencies can be transformed and transmitted by the network with maximum amplification and in a substantially uniform degree, while waves of frequencies outside the limits of the band will be strongly attenuated.

The coupling circuit of the invention besides combining the features of high amplification and great selectivity is advantageous from the standpoint of its simplicity, small size and low cost of manufacture, as it comprises a small number of elements which may be economically made commercially, and which are arranged to take up a minimum of space.

The nature of the invention and the manner of its application is explained more fully in the following description in connection with the accompanying drawings in which:

Fig. 1 shows conventionally in schematic form a portion of the circuit of a space discharge amplifier embodying the invention;

Fig. 2 is a detailed view of one embodiment of the coupling circuit used in the circuit of Fig. 1, showing the detail features and arrangement of the parts making up the coupling circuit; and

Fig. 3 shows an actual voltage amplification characteristic obtained with a circuit such as shown in Fig. 1 embodying the invention.

The portion of the amplifier circuit shown in Fig. 1 comprises a space discharge amplifier tube 1 and a space discharge tube 2, acting as a grid bias detector, both of the well-known three-electrode type, connected in tandem between input terminals 3 and an output transformer 4. The output circuit of space discharge amplifier tube 1 is connected to the input circuit of space discharge detector tube 2 by a coupling network 9.

The network 9 comprises a shunt anti-resonant circuit 10 connected between points 5 and 6 in the output circuit of amplifier tube 1, another shunt anti-resonant circuit 11 connected between points 7 and 8 in the input circuit of detector tube 2, and a closed series resonant circuit 12 magnetically and electrically coupling the anti-resonant circuits 10 and 11. The anti-resonant circuit 10 comprises the primary winding 13 of transformer 14 and a condenser 17_a in shunt therewith. The closed series resonant circuit 12 comprises the secondary winding 15 of transformer 14, the series condenser 17_b and the primary winding 18 of transformer 19. The anti-resonant circuit 11 comprises the secondary winding 20 of transformer 19 and the total capacity effectively in shunt therewith, as indicated by the dotted condenser 21, which comprises the effective input capacity of detector tube 2 plus the distributed capacity between the terminals of secondary winding 20 of transformer 19. The amplifier tube 1 and the detector tube 2 have the usual space current supply, grid polarizing and filament heating batteries.

The condenser 22 connected across the primary winding of output transformer 4 is provided to serve as a low impedance to the carrier frequencies in the output circuit of detector tube 2.

The method of selecting the actual values of the various elements in coupling circuit 9 to obtain the desired high amplification with uniform transmission efficiency for a given band of frequencies, and sharp attenuation for the frequencies immediately outside the given band, will be explained hereinafter.

In Fig. 2 is shown the detailed features and general arrangement of one embodiment of the coupling network 9 of Fig. 1, the elements therein corresponding to the elements shown schematically in the circuit of Fig. 1 bearing corresponding designation characters.

Referring to Fig. 2, it will be noted that the windings 13 and 15 of transformer 14 are wound side by side in parallel grooves of a wooden spool 23. The primary winding 13 and the secondary winding 15 of transformer 14 are approximately equal electrically, that is, they have approximately the same inductance and distributed capacities, and each is designed to obtain maximum ratio of reactance to resistance over the transmitted band, such as by using stranded wire in place of a solid conductor of equivalent cross-section.

The windings 18 and 20 of transformer 19 are wound side by side in parallel grooves of a wooden spool 24. The primary winding 18 and the secondary 20 of transformer 19 are electrically unequal, the primary winding 18 being substantially equal electrically to the secondary winding 15 of transformer 14. The secondary winding 20 of transformer 19 is wound in two sections in two narrow grooves in spool 24. Since the object of the coupling network 9 is to increase the amplification of the selected band of frequencies as much as possible, it is desirable to reduce to a minimum the distributed capacity and dielectric losses of winding 20 operating into the input circuit of detector 2. This is done in this particular case by winding secondary winding 20 in the two separated narrow grooves in spool 24. The electromagnetic coupling between transformers 14 and 19 is reduced to a minimum by arranging the spools 23 and 24, as shown in Fig. 2, so that the magnetic fields of the transformer windings wound thereon are at right angles with each other. The condenser box 17 consists of two individual capacities 17_a and 17_b separated electrically from each other, the capacity 17_b being connected in series with secondary winding 15 of transformer 14 and the primary winding 18 of transformer 19, and the capacity 17_a being connected in shunt with the primary winding 13 of transformer 14, as indicated in the schematic circuit of Fig. 1. The network 9 may be shielded from other apparatus in the circuit by placing it in a copper case (not shown).

The method of designing coupling circuit 9 to accomplish the objects of the invention as set forth above will be clear from the following theoretrical considerations.

It will be noted that the coupling network 9 of Figs. 1 and 2 is similar to, and for purposes of design may be considered equivalent to two-half-section confluent band pass filters. The following filter formulæ, therefore, may be applied in determining the constants of network 9.

The preferred frequency to which the three coupled circuits are to be tuned is

$$f=\frac{\sqrt{2}F_1F_2}{\sqrt{F_1^2+F_2^2}} \quad (1)$$

and the effective capacity C_1 in shunt to the primary winding 13 of transformer 14 is

$$C_1=\frac{1}{2\pi(F_2-F_1)R} \quad (2)$$

where R equals the impedance looking into the filter for waves of the frequency f, and is assumed to be equal or preferably a little less than the impedance from which the filter operates; and F_2 and F_1 are respectively the upper and lower cut-off frequencies of the filter.

Actually, in such a filter structure the position of the upper and lower cut-off frequencies will occur outside of the flat portion of its attenuation-frequency characteristic. In the particular case for which the circuit of the invention was designed, it was desired to transmit with substantially uniform transmission efficiency and maximum amplification, a frequency band ranging from 78 kilocycles to 88 kilocycles, the mid-frequency of the band being 83 kilocycles. It was assumed, therefore, that the upper cut-off of the filter structure should be set at approximately 91 kilocycles and the lower cut-off at approximately 75 kilocycles. The impedance looking into the filter at mid-frequency was assumed to be 17,000 ohms, which is the plate circuit impedance of a particular type of vacuum tube having such characteristics as to be suitable for the amplifier tube 1 feeding into the coupling network 9. Substituting the values given in Equation (1), it is found that

$$C=\frac{1}{2\pi(91000-75000)\ 17000}=585\text{ mmf.} \quad (3)$$

Let it be assumed that a standard condenser of 500 mmf. capacity is available and is utilized as condenser 17_a connected in shunt with primary winding 13 of transformer 14 in the circuits of Fig. 1. In an actual transformer designed as indicated, it was found that the distributed capacity of the primary winding plus the shunt capacity of 500 mmf.

was such as to make the total effective capacity approach the theoretical capacity as computed above. The inductance, L_1, of the primary winding 13 of transformer 14 which will resonate with the 500 mmf. condenser in shunt therewith plus the distributed capacity of the winding at the frequency f of the band to be transmitted, may be computed from the formula

$$L_1=\frac{1}{(2\pi f)^2 C_1} \quad (4)$$

where C_1 equals $C+C_0$, or the capacity 500 mmf. plus the distributed capacity of the winding 13.

As stated above, the inductances of the secondary winding 15 of transformer 14 and the primary winding 18 of transformer 19, which in the following equations will be referred to respectively as L_2 and L_3, are equal. Their combined inductance should be such as to resonate with a capacity equal to

$$\frac{C}{2}$$

at the frequency f. Therefore, a condenser having the capacity of

$$\frac{C}{2}$$

or 250 mmf. may be utilized for condenser 17_b connected in series with windings 15 and 17 in coupling network 9. The distributed capacity of windings 15 and 17 may be neglected in high time constant coils provided it is not too large.

The inductance, L_4, of the secondary winding 20 of transformer 19 is adjusted so that it will resonate with the total capacity, C_3, effectively in shunt therewith, which comprises the effective input capacity of detector tube 2 plus the distributed capacity between the turns of winding 20, at the frequency f of the selected band. This inductance may be computed from the following formula

$$L_4=\frac{10^{12}}{(2\pi f)^2 C_3} \quad (5)$$

where f is in kilocycles, and C_3 equals the effective input capacity of tube 2 plus the effective distributed capacity of winding 20 in mmf.

The electromagnetic coupling between transformers 14 and 19 should be reduced to a minimum. One way of doing this is to mount these transformers so that their fields are at substantially right angles to each other.

The desirable coupling factor K for the transformers 14 and 19 may be determined experimentally or may be computed from the following formula:

$$K=\frac{F_2^2-F_1^2}{F_2^2+F_1^2} \quad (6)$$

Substituting the values for the upper and lower cut-off frequencies as assumed above when the value of C_3 was determined, of 91 kilocycles for F_2 and 75 kilocycles for F_1, it is seen that

$$K=\frac{91^2-75^2}{91^2+75^2}=19.4\% \quad (7)$$

The derivations of the above formulæ used in designing the coupling network 9 are given in a previous Patent, No. 1,714,149, issued to the applicants on May 21, 1929. Combining Equations (2) and (4), the following equation is obtained:

$$\frac{L_1}{C_1}=\frac{R^2(F_2-F_1)^2}{F_2F_1} \quad (8)$$

Combining Equations (6) and (8), it is found that

$$\frac{L_1}{C_1}=\frac{R^2}{F_2F_1}\left(\frac{F_2^2-F_1^2}{K}-2F_2F_1\right) \quad (9)$$

The voltage step-up Z of network 9 is

$$Z=\frac{L_4}{L_1} \quad (10)$$

Then, since networks 10, 11 and 12 are all tuned to the same frequency

$$\frac{L_1}{C_1}=\frac{L_2+L_3}{4C_2}=\frac{L_4}{ZC_3}=\frac{R_2}{F_2F_1}\left(\frac{F_2^2-F_1^2}{K}-2F_2F_1\right) \quad (11)$$

It is desirable, and has been found to be commercially possible, to adjust the inductances of the windings in the coupling network 9 to ± 1% and the capacities of the condensers in network 9 to ± 2% in order to insure the proper location of the frequency band as well as uniform voltage amplification over the band.

The coupling coefficients for network 9 can be kept within the desired limits by placing limits on the dimensions of the separations between the windings of transformer 14 and of transformer 19.

An actual voltage amplification characteristic obtained with a circuit such as shown in Fig. 1 in which the values of the elements of the coupling network 9 and their relative positions were determined by the method of design given above, is shown in Fig. 3 of the drawing. Referring to Fig. 3, it will be noted that the voltage amplification E_2/E_1 between the input of tube 1 and the input of tube 2 of the circuit of Fig. 1, is approximately 32 times over a frequency band ranging from 78 to 88 kilocycles, that the variation over this band corresponds to less than 1 TU, and that the voltage amplification outside the operating range decreases rapidly and uniformly, the gain at points approximately 12,500 cycles from the mid-frequency of the band being approximately 20 transmission units (TU) below that at mid-frequency, which corresponds to a reduction in the voltage amplification of approximately one-tenth at these points. (A transmission unit (TU) is defined by specifying that the number of transmission units corresponding to a power ratio of P_1/P_2 is equal to $10 \log_{10} P_1/P_2$.)

The coupling network 9 of the invention, as described above, is particularly adaptable for use in amplifier systems designed to amplify selectively waves of a band of frequencies. For example, in radio telephone receiving systems of the super-heterodyne or successive detection type, or in carrier systems, where relatively uniform transmission is desirable over a narrow band of frequencies with a high attenuation outside the transmission band, it may be applied to the amplification of the intermediate frequency waves.

It is to be understood that the various details of the construction of the apparatus as described above have been given merely as examples, and that while the invention has been illustrated and described with particular reference to a specific circuit arrangement, it is understood that it is not to be limited to the particular circuit shown as a whole or to the specific details described, but only by the scope of the appended claims.

What is claimed is:

1. A wave transmission system comprising in combination with a wave source and a wave receiver having unequal impedances, means for transmitting from said source to said receiver waves of a predetermined band of frequencies with a maximum voltage amplification for the frequencies in said band consistent with a desired quality of transmission, said means comprising a coupling network consisting of a pair of anti-resonant circuits and an intermediate closed series resonant circuit coupled in tandem between said source and said receiver, the constants of said network being related to each other and to the band of frequencies to be amplified in accordance with the equation

$$\frac{L_1}{C_1}=\frac{L_2+L_3}{4C_2}=\frac{L_4}{ZC_3}=\frac{R^2}{F_2F_1}\left(\frac{F_2^2-F_1^2}{K}-2F_2F_1\right)$$

where L_1 is the inductance and C_1 the capacity effectively in shunt therewith in the anti-resonant circuit connected to said source, L_2 and L_3 the inductances and C_2 the capacity in said intermediate resonant circuit, L_4 the inductance and C_4 the capacity effectively in shunt therewith in the anti-resonant circuit connected to said receiver, Z is

$$\frac{L_4}{L_1},$$

R is the impedance of said source, K is the coupling factor for the coupling between each of said anti-resonant circuits and said intermediate circuit, and F_1 and F_2 are the limiting frequencies of said band.

2. A system in accordance with claim 1 and in which the values of the constants of said coupling network are such that the network produces a high degree of attenuation in the frequencies received from said wave source lying outside the range of said band.

3. A system in accordance with claim 1, and in which the values of the constants of said network are such that said band of frequencies has a width of approximately ten kilocycles.

4. A system in accordance with claim 1, and in which the values of the constants of said network are such that said band of frequencies extends from a frequency of approximately 78 kilocycles to a frequency of approximately 88 kilocycles.

5. In a wave transmission system for transmitting waves of a plurality of frequencies comprising an amplifying circuit consisting of two space discharge devices and a coupling network therebetween comprising an anti-resonant circuit connected to the output of one of said devices, a second anti-resonant circuit connected to the input of the other of said devices, and a closed series resonant circuit magnetically and electrically coupling the anti-resonant circuits, said anti-resonant circuits and said resonant circuit being tuned to substantially the same frequency, the coupling and impedance coefficients of said network being proportioned with respect to each other and a predetermined band of frequencies to be amplified extending on either side of said same frequency so that said network transmits with substantially uniform transmission efficiency and with maximum amplification said band of frequencies and produces a high degree of attenuation in the frequencies outside said band.

6. A wave transmission system in accordance with claim 1, and in which the values of the constants of the said network and its associated circuits are such that said network transmits with substantially uniform transmission efficiency a band of frequencies having a range of approximately ten kilocycles, and in which the attenuation produced by said network on the transmitted frequencies outside said range and approximately twelve kilocycles from the mid-frequency of said band is at least twenty transmission units (TU) below the attenuation produced by said network on said mid-frequency.

7. A wave transmission system comprising in combination with a source of waves having a wide range of frequencies, and a wave receiver having a substantially capacitive input impedance, a coupling network therebetween of elements comprising a transformer having a primary winding of inductance L_1 connected to the output of said source, and a secondary winding of inductance L_2, a capacitive impedance element in shunt with said

primary winding and forming therewith a shunt anti-resonant circuit, a second transformer having a primary winding of inductance L_3, and a secondary winding of inductance L_4 connected to the input of said wave receiver and forming with the capacitive input impedance thereof a second shunt anti-resonant circuit, a second capacitive impedance element of value C_2, said second capacitive element being connected in series in a closed circuit with the secondary winding of the first mentioned transformer and the primary winding of said second transformer and forming therewith a series resonant circuit, the constants of said network being related to each other and to the frequencies of a predetermined band of frequencies to be transmitted by said network in accordance with the equation

$$\frac{L_1}{C_1}=\frac{L_2+L_3}{4C_2}=\frac{L_4}{ZC_3}=\frac{R^2}{F_2F_1}\left(\frac{F_2^2-F_1^2}{K}-2F_2F_1\right)$$

where C_1 and C_2 are the capacities respectively in shunt with said primary winding of the first mentioned transformer and the secondary winding of said second transformer, Z is

$$\frac{L_4}{L_1},$$

R is the effective impedance of said source, and F_2 and F_1 are the limiting frequencies in said predetermined band, said network transmits between said source and said receiver with maximum amplification for a given quality of transmission for said predetermined band of frequencies, while producing rapidly increasing attenuation to the frequencies adjacent to said band.

8. A system in accordance with claim 5 and in which said anti-resonant circuits are arranged with respect to each other so as to reduce the electromagnetic coupling between said anti-resonant circuits.

In witness whereof, we hereunto subscribe our names this 24 day of October, A. D. 1927.

HORACE WHITTLE.
ARTHUR J. CHRISTOPHER.