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D. A. QUARLES ET AL

ELECTRIC CURRENT TRANSMISSION

Filed April 30, 1923

Fig. 1.

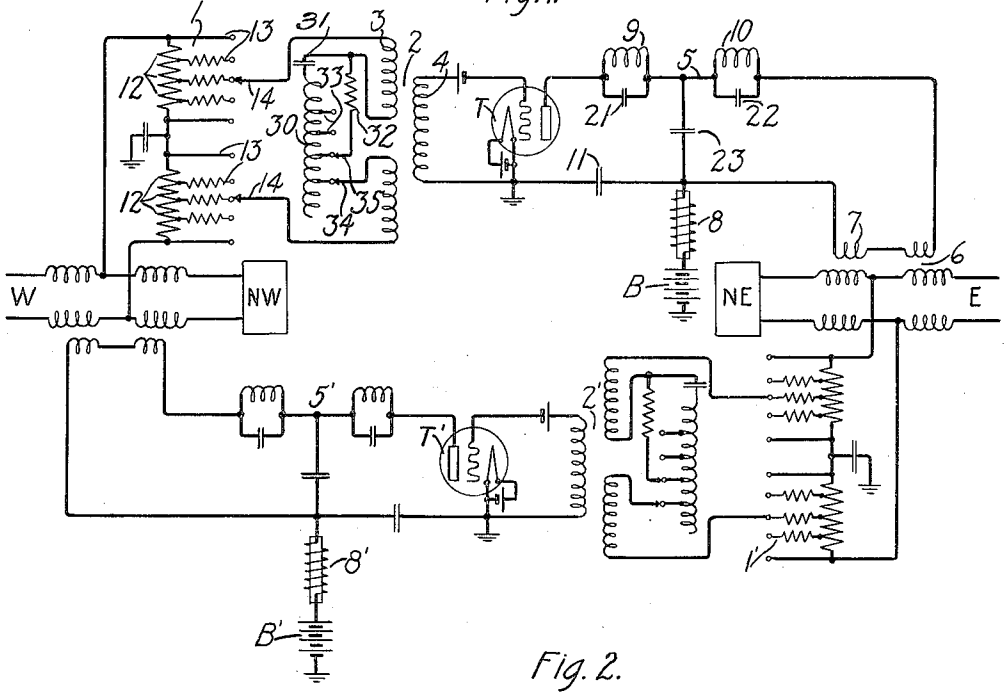
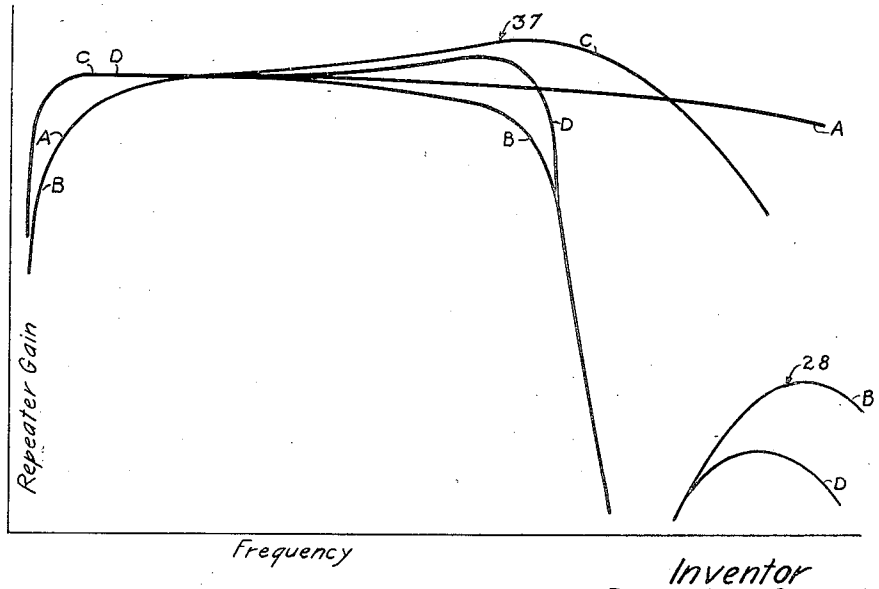


Fig. 2.



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UNITED STATES PATENT OFFICE.

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ELECTRIC-CURRENT TRANSMISSION.

Application filed April 30, 1923. Serial No. 635,419.

To all whom it may concern:

Be it known that we, DONALD A. QUARLES and FRANKLIN MOHR, citizens of the United States, residing at Englewood, in the county of Bergen, State of New Jersey, and East Orange, in the county of Essex, State of New Jersey, have invented certain new and useful Improvements in Electric-Current Transmission, of which the following is a full, clear, concise, and exact description.

This invention relates to electric current transmission, especially to repeating telephone currents, and aims to accomplish such repeating efficiently and without undue distortion.

In accordance with the invention there is associated with a transformer, such for instance as the input transformer of an electron tube repeater, a compensating reactance for resonating with the effective reactance across the secondary winding of the transformer, to prevent that effective reactance from unduly attenuating currents of high frequency, for instance, the higher frequencies of the voice range, and the degree of compensation effected is controlled by effectively shunting a part of the compensating reactance with a resistance to control the sharpness of the resonance. Over compensation may be effected when desired, as for the purpose of correcting for distortion due to unequal attenuation of currents of different frequencies in the line, or for the purpose of correcting for the attenuation effected by the repeater filter at frequencies in the transmitted range but close to the range of highly attenuated frequencies; and the repeater may be adapted for use with lines and filters having various cut-off frequencies by making the compensating reactance variable, to provide for varying the frequency at which the resonance occurs. Moreover, the provision for adjusting the frequency of resonance and the provision for adjusting the degree of damping of the resonance adapt the repeater for use with filters, characterized by considerably lower attenuations at frequencies well above the cut-off frequency than in the neighborhood of the cut-off frequency, since the resonance frequency may be made sufficiently low, with respect to the cut-off frequency of the particular filter to be used, to insure that the repeater will not sing above the cut-off frequency and yet, because of the low resonance frequency, in spite of the damping of the resonance the repeater gain will be maintained high for the frequencies below but in the neighborhood of the cut-off frequency.

There is also associated with the transformer a second compensating reactance, for resonating with the reactance presented by the primary winding of the transformer, to prevent this reactance so presented from unduly attenuating currents of low frequency, for instance, frequencies in the neighborhood of 135 cycles, and the degree of compensation so effected, or the sharpness of this resonance is determined by having the resistance mentioned above effectively shunted across the second compensating reactance.

Fig. 1 of the drawings is a circuit diagram of a repeater embodying the invention; and Fig. 2 shows curves for facilitating explanation of the invention.

In Fig. 1 an amplifier T is connected to repeat frome line W to line E. Interposed between line W and the input electrodes of the amplifier is a potentiometer 1 and an input transformer 2 having a primary winding 3 and a secondary winding 4. Interposed between the output electrodes of the amplifier and the line E is a filter 5 and an output transformer 6 having a primary winding 7. The filter, in the form shown, comprises coils 9 and 10 and condensers 21, 22 and 23. The output transformer is of the usual three-winding type, and balancing networks NW and NE balance the impedances of lines W and E, respectively, in the usual fashion. Battery B supplies D. C. plate current for amplifier T through a choke coil 8, winding 7, and coils 9 and 10 of the filter. A condenser 11 by-passes A. C. around the battery and choke coil.

The potentiometer 1 comprises a resistance 12 having tap conductors 13 leading therefrom which may be selectively connected by means of adjustable contacts 14 to the primary winding 3. In order to make the impedance facing the winding 3 the same for all of the gain settings of the potentiometer, and therefore make the damping in the input circuit independent of the potentiometer setting resistances of suitably graduated values are embodied in the tap conductors, the resistances in series with the end tap conductors being substan-

tially zero and the resistance values of the tap conductors increasing toward the center tap conductors. The potentiometer arrangement is not our invention, but is claimed in the application of D. F. Whiting, Serial No. 406,861, filed August 30, 1920.

The filter 5 used with the repeater may be any suitable filter adapting the repeater to whatever may be the degree of loading and the cut-off frequency of the particular line in which the repeater is to be used. However, in order to obtain a sharp cut-off, it is frequently desirable to employ a filter of the suppression type, due to G. A. Campbell and disclosed in British patent to Western Electric Company, Limited, No. 186,198. The filter 5 is a low pass filter of the type shown in Fig. 10 of that patent, and as explained in the patent, the use of such a filter renders it feasible to obtain a sharper cut-off than if the filter employed were, for instance, of the type shown in Fig. 7 of U. S. patent to Campbell, No. 1,227,114, May 22, 1917, which is the type customarily employed in telephone repeaters of the general description of that of Fig. 1. Since the vacuum tube amplifier is a voltage operated device, transformer 2 is arranged to step up the voltage. It may, for example, have an impedance step up ratio of 300 to 300,000 ohms. The input impedance of vacuum tube T with reference to direct current or low frequencies is usually of the order of infinity, and in any event is high relative to the impedance of the high winding of the transformer. At the higher frequencies of the voice range, however, the capacity between the tube electrodes, the capacity between the leads, and the capacity within the coil itself are appreciable. For these reasons the transformer presents an inductive reactance to the line in the lower part of the voice range and a capacity reactance in the upper part of the voice range. If no compensation for the effects of these reactances is provided, the repeater may give a desired gain in the middle portion of the frequency range, but the transmission may fall off considerably at the upper and lower ends of the range, with resulting distortion of the speech signals. This would also result in poor transmission of ringing currents, which in practice usually have a low frequency, as for example, 135 cycles.

As disclosed in the applications of W. L. Casper, Serial No. 366,581, filed March 17, 1920, and Serial No. 462,883, filed April 20, 1921, an inductance 30 is provided in series with primary winding 3 having such value that this inductance and the leakage inductance of the transformer will resonate with the capacity reactance above described at a frequency in the neighborhood of the upper part of the voice frequency range; and further, as disclosed in the application of P. H. Pierce, Serial No. 410,587, filed September 16, 1920, a condenser 31 is provided to annul the inductive reactance of the transformer at frequencies in the lower part of the voice range. As explained in the application of D. F. Whiting, Serial No. 406.861, filed August 30, 1920, it is frequently desirable to damp the resonance produced by condenser 31, so that the transmission-frequency characteristic of the transformer will not have a sharp peak or pronounced upward curve at the resonance frequency, and this damping may be accomplished by shunting a resistance across the tuning capacity. Therefore, a resistance 32 is connected in shunt relation to the capacity 31, the inductance 30 presenting negligibly low impedance at the frequency at which condenser 31 tunes with the inductive reactance of the transformer.

The inductance 30 is provided with tap conductors 33 for engagement with an adjustable contact 34, whereby the amount of the inductance 30 connected in circuit may be varied; and an adjustable contact 35 is provided, whereby the resistance 32 may be connected in shunt relation to any desired part of inductance 30, the capacity 31 presenting negligibly low impedance at the frequency at which inductance 30 resonates with the transformer and tube capacities. The value of the resistance 32 determines the degree of damping that this resistance exerts upon the low frequency resonance or resonance of capacity 31 with the inductive reactance of the transformer; but the degree of damping that the resistance 32 exerts upon the high frequency resonance, or resonance produced by inductance 30, depends not only on the value of resistance 32 but also on which of the tap conductors 33 is engaged by contact 35, the inductance 30 acting as an autotransformer feeding resistance 32 as a load. Thus, the degree of damping of the high frequency resonance can be adjusted substantially independently of the degree to which the low frequency resonance is damped. The larger the ratio of output voltage to imput voltage of the auto-transformer 30 the greater will be the damping effect of resistance 32 upon the high frequency resonance.

For repeating from line E to line W there is provided an amplifier T′ and auxiliary apparatus like that described above in connection with amplifier T, the reference characters used to designate corresponding parts of the auxiliary apparatus being the same in the case of amplifier T and the amplifier T′, except that in the latter case the characters are primed.

Fig. 2 shows gain frequency curves of the repeater. Curve A is for the repeater with-

out the filter or the tuning circuit 30, 31, 32; curve B is for the repeater with the filter but without the tuning circuit; Curve C is for the repeater with the tuning (and damping) but without the filter; and curve D is for the repeater with both the filter and the tuning (and damping) circuit.

The filter 5 being of the suppression type shown in Fig. 1, the curve B rises, as indicated at 28, at frequencies above the cut-off frequency of the filter, and therefore the repeater may tend to sing at these frequencies since the impedance unbalance between the lines and their balancing networks is likely to be greater at frequencies considerably above the cut-off frequency than at frequencies below the cut-off frequency.

To reduce this tendency of the repeater to sing, the amount of inductance 30 connected in circuit is preferably so adjusted that the high frequency resonance point or frequency of the resonance produced by inductance 30 will fall below the frequency at which the hump 28 is highest (and preferably is so adjusted that the high frequency resonance point will fall betwen the cut-off frequency of the filter and the higher part of the hump 28) in order to insure that the gain of the repeater without the filter will not be at its maximum where the filter attenuation above the cut-off frequency reaches a minimum or where the gain of the repeater and filter without the tuning circuit reaches a maximum, above the cut-off frequency. For example, referring to Fig. 2, the maximum gain shown by curve C occurs at about 2600 cycles, a point at which the filter attenuation is considerable and at which the impedance unbalance between the lines and their balancing networks is not likely to be great; and the curve C falls off considerably before reaching the frequency in the attenuated range at which the transmission efficiency of the filter and repeater without the tuning circuit, has reached the maximum indicated at the crest of the hump 28. Further, the contact 35 is so adjusted that the damping of the high frequency resonance is sufficiently great to insure that throughout whatever frequency range may be common to the humps 37 and 28 the repeater will not sing.

Within the limits imposed by these adjustments to prevent singing, the frequency of the resonance produced by the inductance 30 and the degree of damping of this resonance are so adjusted with regard to whatever types of line and filter are being used, as to compensate for variation of line and filter attenuation with frequency over the upper part of the frequency range to be transmitted so that a sharp cut-off effect, with uniform transmission up to the cut-off point, is obtained. For example, it will be noted that the rise of curve C with frequency, over the upper part of the frequency range to be transmitted, is more than sufficient to compensate for change of filter attenuation over this part of this frequency range, the excess being for the purpose of compensating for increase of line attenuation with frequency. The frequency range over which compensation for varying attenuation is to be thus effected is sufficiently close to the frequency of the resonance produced by inductance 30 to premit of obtaining the requisite degree of rise in curve C even though the damping of the resonance be high.

Although the invention has been described above with especial reference to the transmission of currents in the voice frequency range, it is not restricted to transmission of such frequencies, for its principles are applicable also to the transmission of currents of other frequencies. It may be realized in various embodiments within the scope of the appended claims.

What is claimed is:

1. In combination, a transformer having across its output terminals, an impedance substantially infinite at a given frequency, a condenser forming with the inductance of said transformer a series tuned circuit at said frequency, an inductance, said condenser and one portion of said last mentioned inductance being serially related to each other with a resistance connected in shunting relation to a different portion of said last mentioned inductance.

2. In combination, an electron tube, an input transformer therefor having a winding, and a circuit connected in series with said winding, said circuit comprising a capacity and one portion of a retard coil serially related to each other with a ressistance in shunting relation to a different portion of the retard coil.

3. In combination, a transformer having across its output terminals, an impedance substantially infinite at a given frequency, a condenser forming with the inductance of said transformer a series tuned circuit at said frequency, an inductance, said condenser and one portion of said last mentioned inductance being serially related to each other with a resistance connected in shunting relation to said condenser and a different portion of said last mentioned inductance.

4. In combination, an electron tube, an input transformer therefor having a winding, and a circuit connected in series with said winding, said circuit comprising a capacity and one portion of a retard coil serially related to each other with a resistance in shunting relation to said capacity and a different portion of said coil.

5. In combination, an electron tube repeater having input electrodes, a transformer

having output terminals connected in series with the space between said electrodes, a capacitive reactance forming with the inductive reactance presented by the input terminals of said transformer a series tuned circuit at a frequency to be repeated, and an inductance, said capacitive reactance and one portion of said inductance being serially related to each with a resistance connected in shunting relation to a different portion of said inductance.

6. In combination, an electron tube having input electrodes, a transformer having output terminals connected in series with the space between said electrodes, the input terminals of said transformer presenting an inductive reactance at a frequency in the lower part of the voice range, a condenser connected in series with the input terminals of said transformer, said condenser being of such capacity as to tune with said inductive reactance at said frequency in the lower part of the voice range, and an inductance, said condenser and one portion of said inductance being serially related to each other with a resistance connected in shunting relation to a different portion of said inductance.

7. In combination, a transformer having input terminals presenting an inductive reactance at low frequencies and a capacitive reactance at relatively high frequencies, a condenser forming with said inductive reactance a circuit tuned to a relatively low frequency, an inductance having a portion forming with said capacitive reactance a circuit tuned to a relatively high frequency, and a resistance connected in shunting relation to said condenser and a portion of said coil.

8. In combination, an electron tube having input electrodes, a transformer having output terminals connected to said electrodes, a condenser forming with the inductance presented by the input terminals of said transformer a series tune circuit, an inductance having a portion serially related to said condenser with a resistance connected in shunting relation to said condenser and a portion of said last mentioned inductance, the first mentioned portion of said last mentioned inductance forming with the capacity between the transformer winding turns and between said electrodes a circuit which is resonant at a frequency for which the impedance of said condenser is negligibly low.

9. In combination, an electron tube having input electrodes, a transformer having output terminals connected to said electrodes, a condenser forming with the inductance presented by the input terminals of said transformer a series tuned circuit, and a retard coil having a portion forming with the capacity bewteen the transformer winding turns and between said electrodes a circuit which is resonant at a frequency for which the impedance of said condenser is negligibly low, said portion of said retard coil being serially related to said condenser, with a resistance connected in shunting relation to said condenser and an adjustable portion of said retard coil whereby the degree of damping of the last mentioned resonance may be adjusted substantially independently of the degree of damping of the first mentioned tuning.

10. In combination with a transformer presenting in its primary circuit an inductive reactance at low frequencies and a capacitive reactance at relatively high frequencies, means for resonating with said inductive reactance, means for resonating with said capacitive reactance, and a resistance for damping said first mentioned resonance and adjustably connected to said second mentioned means for varying the degree of damping of said second mentioned resonance substantially independently of the degree of damping of said first mentioned resonance.

11. The combination with an electron tube, amplifier and filter in circuit therewith, said filter having a cut-off frequency and having a frequency range of free transmission below said cut-off frequency, and a frequency range of attenuation above said cut-off frequency, said filter also having practically infinite attenuation per section at a finite frequency above the cut-off frequency, and the gain frequency characteristic of said amplifier and filter having a maximum point at a finite frequency above the cut-off frequency, of an input transformer for said amplifier, having inductance effectively in series with one of its windings, said inductance being of such value as to resonate with the effective capacity presented by said transformer and the effective input capacity of said tube at a frequency below the frequency of said maximum point above the cut-off frequency.

In witness whereof, we hereunto subscribe our names this 27th day of April, A. D., 1923.

DONALD A. QUARLES.
FRANKLIN MOHR.