April 14, 1936. H. G. TASKER 2,037,285

ELECTRICAL NETWORK

Filed April 17, 1933 4 Sheets-Sheet 1

FIG 1

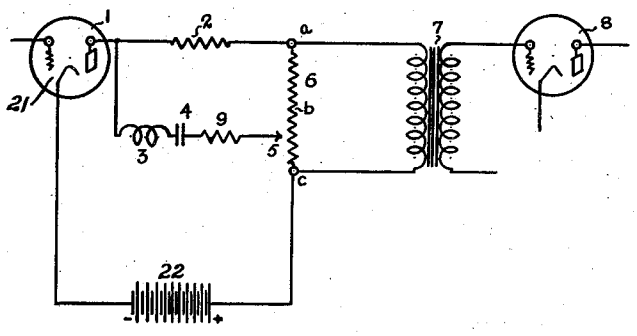


FIG 2

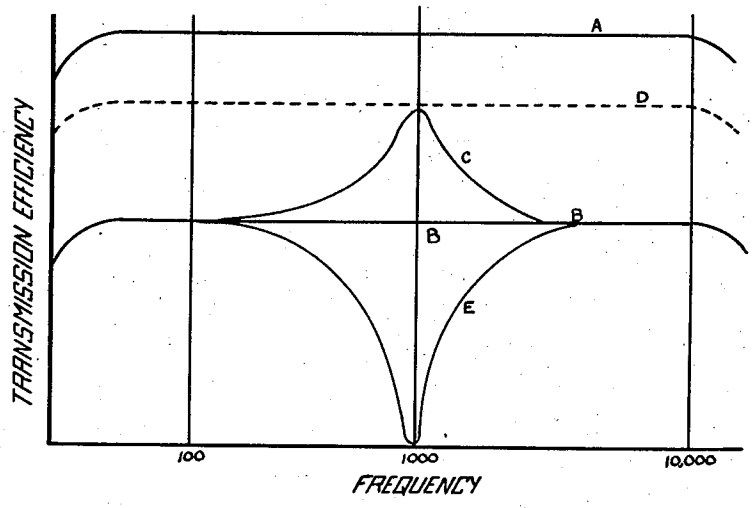
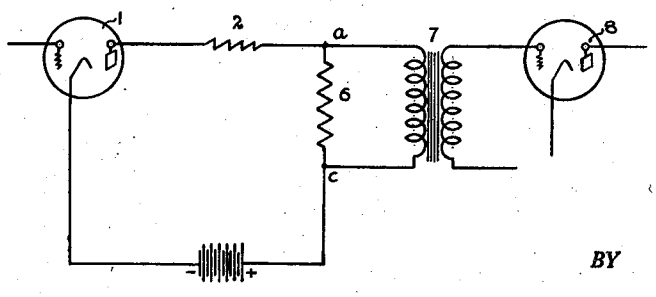


FIG 3



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April 14, 1936. H. G. TASKER 2,037,285

ELECTRICAL NETWORK

Filed April 17, 1933 4 Sheets-Sheet 2

FIG 4

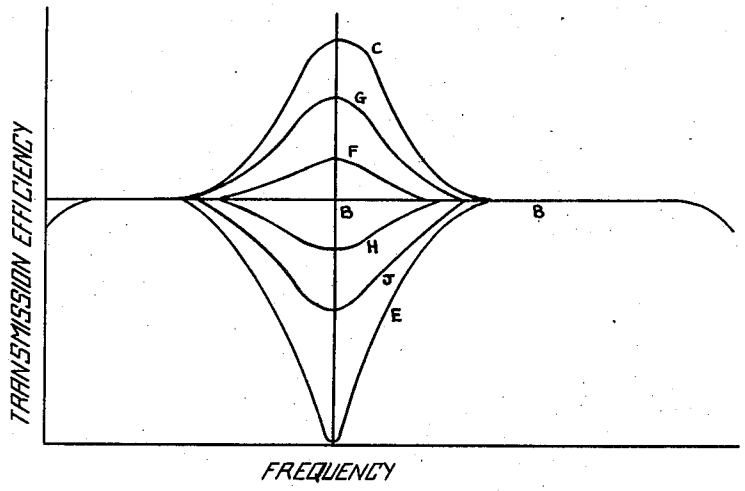


FIG 6

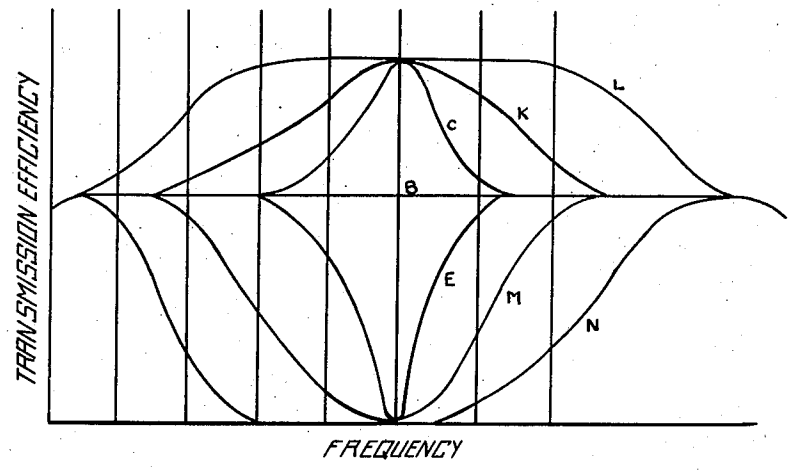
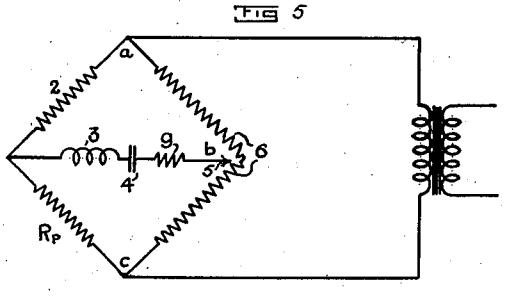


FIG 5



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April 14, 1936. H. G. TASKER 2,037,285

ELECTRICAL NETWORK

Filed April 17, 1933 4 Sheets-Sheet 3

FIG 7

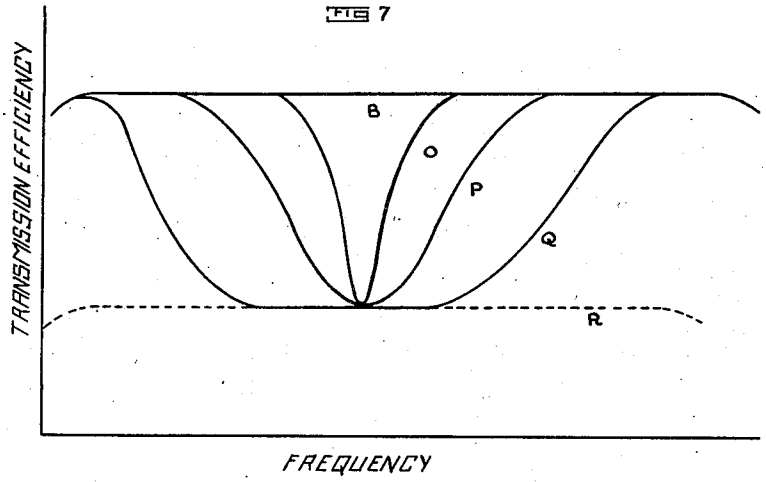


FIG 8

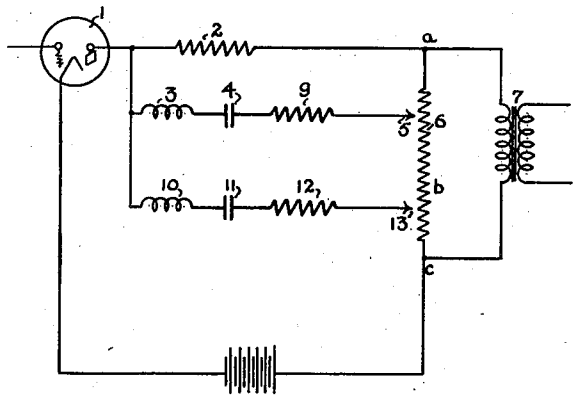
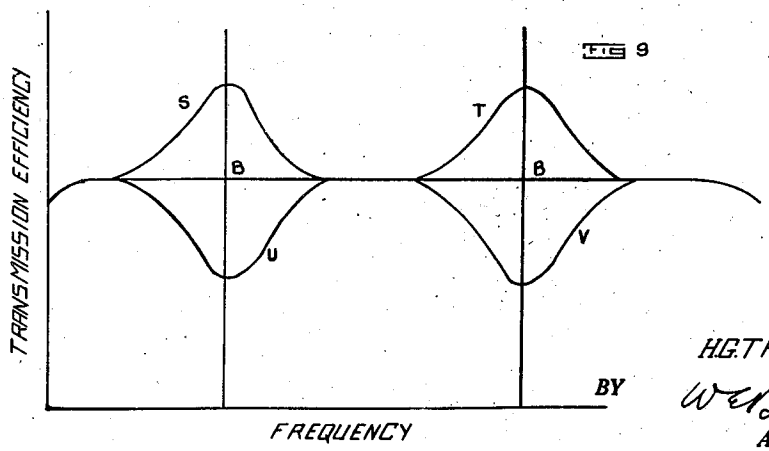


FIG 9



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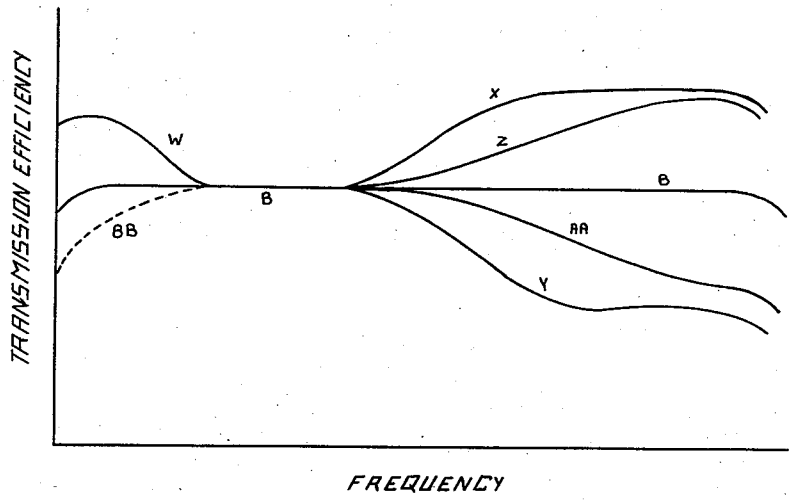
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April 14, 1936. H. G. TASKER 2,037,285

ELECTRICAL NETWORK

Filed April 17, 1933 4 Sheets-Sheet 4

Fig 10



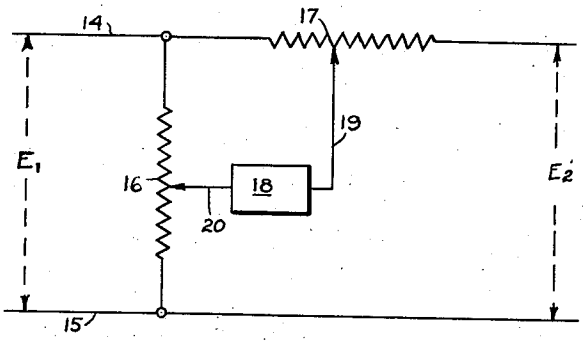


Fig 11

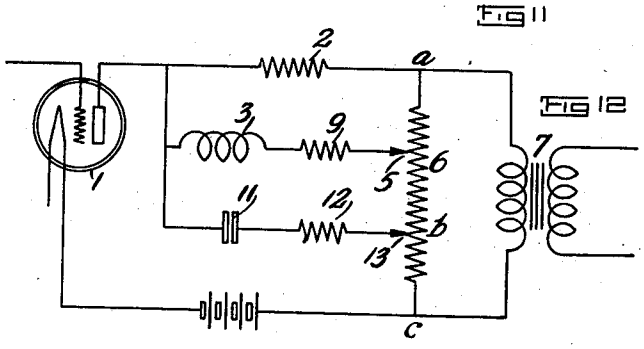


Fig 12

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Patented Apr. 14, 1936 2,037,285

UNITED STATES PATENT OFFICE

2,037,285

ELECTRICAL NETWORK

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Application April 17, 1933, Serial No. 666,439

16 Claims. (Cl. 179—1)

The invention relates to electrical networks, and particularly to a variable equalizer for controlling the frequency characteristic of an amplifying or transmission system.

Equalizers heretofore have had several defects, namely; first, adjustments affected the breadth of the selected portion of the band of frequencies; second, adjustments affected the transmission level of the remainder of the band of frequencies, and third, no provision was made for utilizing the same equalizer to either increase or decrease from normal transmission a selected frequency portion.

These defects are overcome according to the present invention which has for an object to selectively raise or lower the transmission efficiency in one portion of the frequency spectrum, without affecting other portions, and between chosen limits.

According to the invention, the transmission level of a selected portion of the band of frequencies is attenuated and continuously changed between predetermined limits of amplitude, and in either sense from the attenuated level.

The method and means for accomplishing this will be described in connection with the drawings, wherein:

Fig. 1 is a schematic circuit arrangement of an equalizer applied to an amplifier circuit.

Figs. 2, 4, 6, 7, 9, and 10 are curves illustrating the transmission efficiency for different frequencies and under circumstances to be later described.

Figs. 3 and 5 are simplified circuit arrangements for explaining the circuit in Fig. 1.

Fig. 8 is a modification of the circuit arrangement in Fig. 1.

Fig. 11 is a simplified circuit arrangement of the invention.

Fig. 12 is a schematic circuit of another modification of the invention.

Referring in detail to the drawings, Fig. 11 illustrates an elementary form of a variable equalizer according to the present invention in which a source of voltage having a characteristic impedance provides the voltage E—1 across the line 14—15, which voltage is modified by the impedance 16 in shunt to the line 14—15, by the impedance 17 which is in series in one side of that line, and by the impedance 18 which can be variably connected by slider 19 to any desired point in impedance 17, and by slider 20 to any desired point in impedance 16. The voltage on the load terminals of the line 14—15 is represented in the drawings as E—2, although it will be understood that transmission may occur in either direction.

In the case shown in Fig. 11, the frequency characteristic is modified by the elements 16, 17 and 18, 16 and 17 being resistances and 18 being a reactive impedance. The reactive impedance 18 serves to augment or diminish the attenuation effects of the resistance elements 16 and 17 by varying amounts determined by the positions of the sliders 19 and 20, and within those frequency ranges for which the numerical magnitude of the reactive impedance 18 is comparable to, or less than, the numerical values of impedances 16 and 17.

This will be further described in connection with Fig. 1, wherein: The transmission line is illustrated as comprising two vacuum tube amplifiers 1 and 8 connected in tandem by transformer 7, or by other suitable coupling means. The equalizer is here illustrated as directly connected in the plate circuit of amplifier 1, the series resistance element 17 of Fig. 11 being here illustrated as fixed resistance 2, although the latter may be variable as shown in Fig. 11. The shunt impedance of Fig. 11 is illustrated as shunt resistance 6 in Fig. 2 and the reactance represented by block 18 in Fig. 11 is illustrated by inductance 3, condenser 4 and resistance 9 which can be connected by slider 5 to any selected point in the shunt resistance 6. The plate circuit for tube 1 is completed from the cathode 21 to battery 22 and through the shunt resistance 6 and series resistance 2. This plate circuit could, with equal facility be isolated from these resistances by means of a transformer. The left-hand terminal of inductance 3 is connected to the line at a point between the anode of tube 1 and the resistance 2, although as above described, this terminal may be connected to any desired point in resistance 2 as shown in Fig. 11.

The values of inductance 3 and condenser 4 are such that the branch circuit in which they are included is tuned within the frequency range which it is desired to control and which, of course, pertains to the frequencies transmitted by the tubes 1 and 8.

The function of the equalizer in Fig. 1 may be understood in connection with Fig. 2, wherein curve A represents the frequency characteristic which would result from directly connecting the plate circuit of vacuum tube 1 to the transformer 7, and this curve is assumed to be substantially flat as shown within the useful frequency range of the transformer 7. Curve B in Fig. 2 illustrates the decrease in transmission efficiency due

only to the presence of shunt resistance 6 and series resistance 2 as illustrated in Fig. 3, the difference in values between curves A and B representing the amount of attenuation. Curve B is the same in form as curve A as the frequency in both cases will normally be attenuated alike as shown, particularly if the elements 2 and 6 are so chosen that the impedance presented to transformer 7 is the same whether these elements be presented or omitted. Other proportions may be used if deviations from the original curve A are desired.

Considering now the operation resulting from the presence of the reactive elements 3 and 4 in Fig. 1, it will be apparent that the presence of these elements will change the frequency characteristic of the amplifier as elements 3 and 4 present an impedance which changes with frequency while elements 2 and 6 do not.

Resistance 6 is of the potentiometer type having terminals *a* and *c* and a sliding contact 5 to which elements 3, 4 and 9 are connected. Suppose, for example, that resistor 9 is omitted and that inductance 3 and capacity 4 are pure reactances of such value as to be resonant at 1,000 cycles and that the reactance of either at this frequency is large compared to resistance 2. If slider 5 is at terminal *a* of the resistance 6, then near the frequency of resonance (i.e., 1,000 cycles) elements 3 and 4 will provide a low impedance path around resistance 2 as a result of which the signal strength will be increased in the manner illustrated by curve C of Fig. 2. The result will be to emphasize the frequencies in the neighborhood of 1,000 cycles, leaving undisturbed the frequencies which are remote from that value. It should be noted that even with pure reactances, the peak of curve C will not rise higher than the level to which all frequencies would be raised if resistance 2 were short-circuited. This level is shown by dotted curve D of Fig. 2. The difference between curves A and D represent the attenuation due to the shunting effect of resistance 6.

On the other hand, when slider 5 is at terminal *c* of resistance 6, the impedance elements 3 and 4 appear in shunt to the amplifying system with the result that frequencies in the neighborhood of 1,000 cycles will be greatly attenuated while those remote from 1,000 cycles will be affected but slightly, as illustrated by curve E of Fig. 2. It is obvious that as slider 5 moves continuously from terminal *c* to terminal *a*, the signal strength at 1,000 cycles will vary continuously from the lowest point of curve E to the highest point of curve C. Neighboring frequencies will likewise be more or less affected in a similar manner so that a family of curves will result, as illustrated in Fig. 4. At some point *b* on resistance 6 the effect of elements 4 and 5 will pass through zero and the frequency characteristic will be the same as if 3 and 4 were disconnected. This will be readily understood from Fig. 5 in which the circuit elements are redrawn in conventional Wheatstone bridge form. The plate impedance of vacuum tube 1 is represented by resistances R_p which comprises in this case the characteristic impedance of the incoming line, and the other elements are as in Fig. 1. The useful voltage appears across terminals *a* and *c* of resistance 6, and with respect to the Wheatstone bridge as formed, the elements 3 and 4 comprise the equivalent galvanometer circuit.

At balance (i. e. when the ratio of resistance 2 to resistance R_p equals the ratio of portion *ab* to portion *bc* of resistance 6) any current in elements 3 and 4 will be so divided in the bridge arms that it will not develop potential across the primary of transformer 7, as terminals *a* and *c* are at equipotential points. Consequently, the frequency characteristic is unaffected by elements 3 and 4 as illustrated by curve B of Fig. 4.

The curves of Fig. 2, in which the elements 3 and 4 are rather sharply resonant, may be found useful in practice but the method may be extended by proper choice of values of the circuit elements, to a broad range of requirements. These choices are dependent upon elementary considerations and approximate values of circuit elements may be quickly determined.

Consider curve C of Fig. 6 which is the same as curve C of Fig. 2. Since circuit elements 3 and 4 of Fig. 1 are assumed to be pure reactances, the resonance peak of curve C is limited in height by resistance 2 in its relation to the other circuit elements. At either side of resonance, however, the elements 3 and 4 present a reactance

$$X = 2\pi f L_3 - \frac{1}{2\pi f C_4}$$

which diminishes the shunting effect around resistance 2 with the result noted in curve C, where L_3 is inductance of 3 and C_4 is capacity of 4 and *f* is the frequency in cycles per second. Obviously, the steepness of this curve will depend on the rate at which X increases with respect to resistance 2 as *f* departs from resonance. It is also obvious that X will experience a more rapid increase with changing *f* if L_3 and C_4 are large than when small. Consequently, a whole family of curves such as C, K, and L may be obtained by proper choices of L_3 and C_4, of which curve C represents the case of reactances at resonance much greater than resistance 2; curve K represents corresponding reactances approximating resistance 2, and curve L represents reactances quite small compared to resistance 2.

When slider 5 is at terminal *c* of potentiometer 6, curves E, M and N would result from the use of reactances which in the neighborhood of resonance are respectively greater, comparable to and less than the total impedance appearing between cathode and anode of vacuum tube 1 including the vacuum tube impedance and the shunting effect of elements 2, 6 and 7.

In some of the useful applications of such an equalizer circuit, it would be objectionable to suppress any one portion of the frequency spectrum to zero as shown in curves E, M and N, Fig. 6, and for this reason resistor 9 is normally given a value which will limit the lowest point of curves E, M and N to any convenient value, such as illustrated in curves *o*, *p* and *q* of Fig. 7. This lowest point of the several curves will then correspond with the attenuation to which all frequencies would be subjected if elements 3 and 4 were short-circuited, as illustrated by the dotted curve R of Fig. 7.

The usefulness of such an equalizer may be readily extended by the introduction of additional resonant circuits, such as elements 10, 11 and 12 of Fig. 8 to control additional portions of the frequency spectrum in the manner indicated in Fig. 9. If the resonant frequencies are sufficiently separated, the one resonant circuit will not affect the other and any combination of transmission curves which lie within the areas bounded by curves *s*, *t*, *u* and *v* of Fig. 9 may be obtained by proper settings of sliders 5 and 13.

It may frequently happen that it is desired to control the entire frequency spectrum beyond a

given point rather than a comparatively narrow band. This is readily accomplished by omitting one of the elements of the resonant circuit.

Fig. 10 illustrates the result of omitting condenser 4 and inductance 10 from Fig. 8, assuming in this case that inductance 3 has a reactance comparable with resistor 2 in the low frequency portion of the spectrum, thereby affording curves W and BB. The resulting circuit is shown in Fig. 12. The effect of condenser 11 is illustrated in curves x and y for a capacity whose reactance toward the middle of the frequency spectrum is comparable to the value of resistor 2, and curves Z and AA shows the effect of a smaller value of capacity whose reactance is comparable to the value of resistor 2 only at the extreme upper end of the frequency spectrum. It is obvious from the foregoing that the elements of this equalizer may be so chosen as to accomplish a great variety of desirable results, in all of which an element of great usefulness is introduced by the use of the resistor 6 with sliding contacts 5 and 13, etc., which make it possible to continuously vary the effects produced by any of the equalizer circuits between the upper and lower limits predetermined by impedance values.

Having thus described the invention, what is claimed as new and desired to secure by Letters Patent, is:

I claim:

1. The method of successively modifying the transmission level of a line for a selective portion of a band of frequencies being transmitted which comprises uniformly attenuating the transmission level of all the frequencies of said band to a predetermined level and decreasing and increasing the attenuation of said selective portion above and below said predetermined level, the other portion of said band of frequencies remaining at said predetermined level.

2. The method of modifying the transmission level of a line transmitting a band of frequencies which comprises uniformly attenuating the transmission level of all of said frequencies to a predetermined level, and increasing and decreasing the attenuation of a certain selective portion of said frequency band above and below said predetermined level while maintaining the remainder of said band of frequencies at said predetermined level, the limit of increase being between the maximum level before attenuation and the predetermined level.

3. The combination of a line for transmitting a band of frequencies, attenuator means comprising a series impedance element and a shunt impedance element, whereby the signal level of said line is attenuated to a predetermined signal level, a reactive circuit effective at a selected portion of said frequency band, and means for connecting said reactive circuit across all of said series element and variably across said shunt attenuator element.

4. An attenuator comprising a fixed series impedance element comprising solely a resistance element and a fixed shunt impedance element, and a reactive circuit in shunt to all of said series impedance element and also in shunt to a variable portion of said shunt element.

5. The combination of a line for transmitting a band of frequencies, a fixed impedance in series in said line, an impedance in shunt to said line, a reactive circuit having a natural frequency within the range of said band, and means for connecting said reactive circuit to include in shunt therewith all of said impedance in series in the line and an adjustable amount of said shunt impedance, whereby the transmission of a band may be increased or decreased with respect to uniform transmission.

6. The combination of the output electrodes of an electron discharge device, a line connected thereto for transmitting a band of frequencies, a non-reactive impedance in series in said line, an impedance in shunt to said line, a reactive circuit comprising inductance "L", capacity "C", and resistance and wherein

$$\frac{1}{2\pi}\sqrt{LC}$$

is within said band of frequencies, a connection from one terminal of said reactive circuit to a point between one of said output electrodes and said series impedance, an adjustable connection between the other terminal of said reactive circuit and said shunt impedance, and an outgoing line connected to said shunt impedance.

7. A transmission circuit of the Wheatstone bridge type wherein a transmission line and a reactive circuit are in conjugate relation, one of the arms of said bridge comprising the internal output circuit impedance of an electron discharge device, the remaining arms comprising impedances of such values that said bridge in balanced relation does not appreciably modify the transmission efficiency of said line and when unbalanced in opposite directions, increases or decreases respectively said transmission efficiency in a selected portion of the band of frequencies transmitted by said line.

8. A transmission circuit comprising a network of the Wheatstone bridge type having a transmission line and a reactive circuit in unbalanced conjugate relationship, one of the arms of said bridge comprising the internal output circuit impedance of an electron discharge device and the remaining arms of said bridge comprising non-reactive impedances respectively, and means for adjustably connecting one end of said reactive circuit to different points on the non-reactive impedances in adjacent arms of said bridge.

9. The combination of a line having a series impedance and a shunt impedance for transmitting a band of frequencies, and a reactive circuit in shunt to said series impedance with adjustable connections for varying the amount of said shunt impedance in series with said circuit whereby the potential developed across said reactive circuit due to current from said line may in one position of adjustment add its effect to the potential of said line and in another position of adjustment may subtract its effect therefrom, whereby the transmission efficiency with respect to constant transmission over a wide band may be increased or decreased in a selected portion of said band of frequencies.

10. The combination of a line having a series impedance and a shunt impedance for transmitting a band of frequencies, and a reactive circuit therefor with adjustable connections to said shunt impedance whereby the potential developed across said reactive circuit due to current from said line may in one position of adjustment add its effect to the potential of said line and in another position of adjustment may subtract its effect therefrom, whereby the transmission efficiency may be increased or decreased in a selected portion of said band of frequencies, and means in said reactive circuit for limiting the extent to which said

transmission efficiency may be increased or decreased in said selected portion of said band of frequencies.

11. An attenuator comprising a fixed series impedance element, a fixed shunt impedance element, and a plurality of reactive circuits each having a series impedance element connectable across a portion of said shunt impedance element, the reactance of one of said reactive circuits having a different sense from the reactance of another thereof.

12. The combination of a line for transmitting a band of frequencies, attenuator means comprising a series resistance and a shunt resistance for equally reducing the signal level of all frequencies in said band to a predetermined substantially constant signal level, a reactive circuit effective at a selected portion of said band of frequencies, and means for connecting said reactive circuit in a plurality of positions to said line and to said shunt resistance whereby in one position the transmission in said portion is increased above said predetermined level, in another position said transmission in said selected portion is substantially unaffected by said reactive circuit, and in a third position said transmission in said selected portion is reduced below said predetermined level.

13. The combination of a line for transmitting a band of frequencies, attenuator means comprising a series impedance and a shunt impedance for equally reducing the signal level of all frequencies in said band to a predetermined substantially constant signal level, a reactive circuit effective at a selected portion of said band of frequencies, and means for connecting said reactive circuit in a plurality of positions to said line and said shunt impedance whereby in one series of positions the transmission in said selected portion is increased above said predetermined level, and in another series of positions said transmission in said selected portion is reduced below said predetermined level.

14. The method of modifying the transmission level of a line transmitting a band of frequencies which comprises uniformly attenuating the transmission level of all of said frequencies to a predetermined level, and increasing and decreasing the attenuation of certain selective portions of said band of frequencies above and below said predetermined level while maintaining the remainder of said band of frequencies at said predetermined level.

15. A transmission circuit for a band of frequencies comprising a fixed series impedance, a fixed shunt impedance, said impedances uniformly attenuating all the frequencies of said band, and a plurality of reactive circuits each of which is connectable across different amounts of said shunt impedance, each of said reactance circuits increasing and decreasing different respective selective portions of said band of frequencies in accordance with the amount of said shunt resistance connected thereto, the remaining frequencies of said band being un-attenuated.

16. A circuit having input and output terminals for transmitting a band of frequencies comprising a fixed series resistance, a fixed shunt resistance connected across said output terminals, a reactive impedance having one terminal connected to one of said input terminals, and a resistance having one terminal connected to the other terminal of said reactive impedance and the other terminal thereof to a variable contact on said shunt impedance, one extreme position of said variable contact placing said reactive impedance in shunt to said fixed series resistance and the other extreme position of said variable contact placing said reactive impedance in shunt to said fixed shunt resistance.

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