July 25, 1944. D. E. NORGAARD 2,354,537

WIDE BAND COUPLING FOR TRANSMISSION LINES

Filed March 17, 1943

Fig. 1.

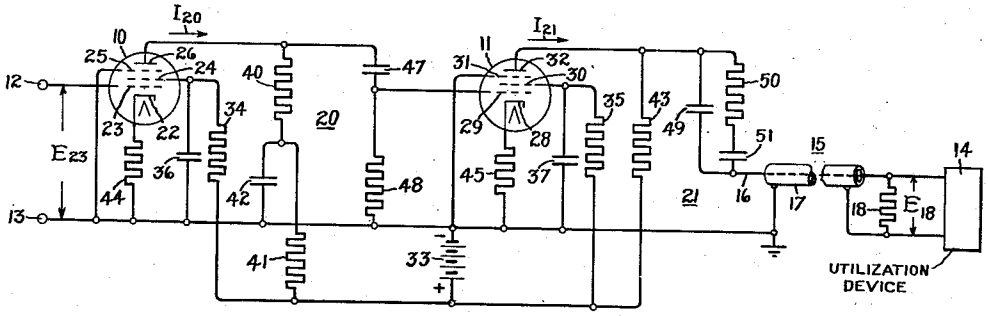


Fig. 3.

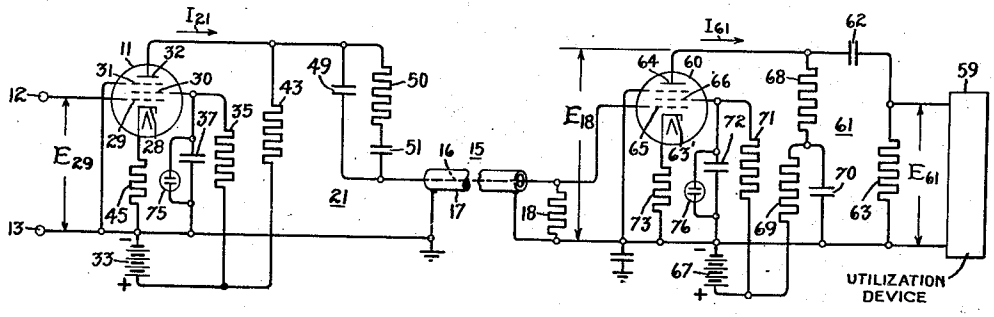
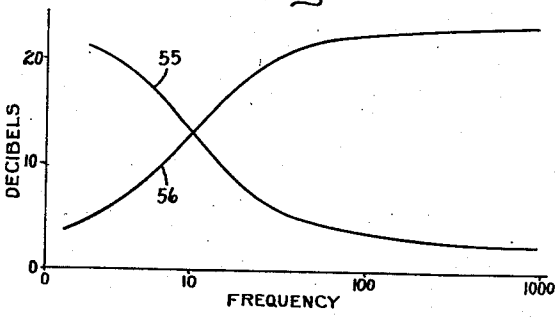


Fig. 2.



Inventor:
Donald E. Norgaard,
by Harry E. Dunham
His Attorney.

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WIDE BAND COUPLING FOR TRANSMISSION LINES

Donald E. Norgaard, Schenectady, N. Y., assignor to General Electric Company, a corporation of New York

Application March 17, 1943, Serial No. 479,412

4 Claims. (Cl. 179—171)

My invention relates to circuits for coupling apparatus such as electronic amplifiers to transmission lines and particularly to such circuits which maintain linearity of the transmitting signal over a wide band of frequencies.

In apparatus for transmitting signals within a wide band of frequencies such, for example, as television transmitters and receivers, it frequently becomes necessary to employ portable units which must be connected by low impedance transmission lines. These lines are commonly of the concentric conductor type and are made flexible so that they may be handled easily. One method for connecting such a transmission line is to arrange it in the cathode circuit of an electronic amplifier tube so that the terminating resistance of the line is in the cathode circuit; an objection to this connection is that it necessitates the passing of a substantial amount of direct current through the transmission line. When the transmission line is coupled to the plate circuit of an electronic amplifier tube a series coupling condenser may be provided which prevents the passage of direct current through the line; however, unless a very large condenser is employed, the signal may be attenuated objectionably in the low frequency end of the band of frequencies to be transmitted. The cost and size of the large coupling condenser are too great for the requirements of many types of apparatus. Furthermore, even with a very large coupling condenser some slight phase shift at low frequencies is unavoidable. In circuits where even this slight phase shift is objectionable it becomes necessary to provide some coupling arrangement which will provide true linearity over the entire band width.

Accordingly, it is an object of my invention to provide an improved coupling arrangement for transmission lines utilized to transmit signals over a wide band of frequencies and which insures linearity of signal transmission throughout the band.

It is another object of my invention to provide a circuit for coupling a low impedance transmission line to an electronic amplifier device through a series capacity and which includes an improved arrangement for preventing attenuation of the transmitted signal in the low frequency portion of the band.

The novel features which I believe to be characteristic of my invention are set forth with particularity in the appended claims. My invention itself, however, both as to its organization and method of operation together with further objects and advantages thereof may best be understood by reference to the following description taken in connection with the accompanying drawing in which Fig. 1 represents an embodiment of my invention, Fig. 2 represents certain characteristics pertaining to the operation of my invention, and Fig. 3 illustrates another embodiment of my invention.

In general, the coupling apparatus shown in the drawing comprises an electronic amplifier provided with an input network for supplying a signal to be amplified and an output network for coupling the amplified signal to a utilization device. The apparatus includes a low impedance transmission line, the terminating resistance of which is connected as an element in one of the networks, and the proportions of the several elements of the one network are selected with respect to certain elements of the other network so that signals are attenuated in the low frequency end of the band in one of the networks and are correspondingly accentuated in the other of the networks. The amounts of attenuation and accentuation are selected so that an overall straight line or flat characteristic results and signals throughout the entire band may be transmitted through the apparatus including the line without frequency discrimination. The network coupled to the transmission line includes a series coupling condenser shunted by relatively high resistance, and as a result, no substantial amount of direct current is passed through the transmission line. If desired, a condenser may be provided in series with the resistance to prevent the passage of any direct current through the line, this condenser, of course, being sufficiently large to pass the low frequency components of the signal.

Referring now to the drawing, the coupling apparatus shown in Fig. 1 comprises two thermionic amplifiers including electron discharge devices 10 and 11 connected in cascade. Signals to be transmitted and which lie within a predetermined wide band of frequencies are impressed upon the apparatus across input terminals 12 and 13, and the amplified signals are supplied to a suitable utilization device 14 connected to the output end of a transmission line 15. The transmission line comprises a central conductor 16 and an external concentric grounded shielding conductor 17, and is provided with a suitable terminating resistance 18 across which the utilization device 14 is connected. Between the devices 10 and 11 is connected an interstage network 20 which may be considered as an input network with respect to the device 11. In the output circuit of the device 11 is connected a network 21 which includes the terminating resistance 18 of the line 15.

The device 10 is provided with a cathode 22, a grid or control electrode 23, screen grid 24, suppressor grid 25, and anode 26. The device 11 includes a cathode 28, control grid 29, screen grid 30, suppressor grid 31, and an anode 32. Anode and screen voltages for both devices are obtained from a suitable direct current source such as a battery 33. The screen grids 24 and 30 are connected to the battery by resistors 34 and 35 respectively and provided with by-pass condensers 36 and 37. The anode 26 is connected to the battery through a resistance comprising portions 40 and 41, the portion 41 being by-passed by a condenser 42. The resistances including the portions 40 and 41 in series constitute a shunt resistance in the input network of the device 11. The anode 32 is connected to the battery 33 through a suitable resistance 43 in the output network 21. Resistances 44 and 45 are connected in the circuits of the cathodes 22 and 28 respectively. These resistances are not provided with by-pass condensers so that the resultant degeneration is constant at all frequencies and produces no frequency discrimination over the band of frequencies of the impressed signals.

Signals impressed across the terminals 12 and 13 are amplified by the device 10 and appear across the shunt resistance 40, 41, and these signals are coupled to the grid 29 of the device 11 through a suitable coupling condenser 47 and a grid leak resistor 48. The device 11 amplifies the signal which appears across resistor 43 and is coupled to the transmission line through a condenser 49. The condenser 49 is shunted by a relatively high resistance 50, and a blocking condenser 51 may be provided in series with resistance 50 if it is desired to prevent any direct current from flowing through the transmission line.

During the operation of the apparatus, the coupling condenser 49 tends to produce attenuation of the signals in the low frequency portion of the band to be transmitted. At the same time, it is essential that the signal be transmitted through the line 15 without so-called phase distortion due to changes in the reactance of the condenser 49 with frequency. It has been found that a flat characteristic may be obtained by proper selection of the several components of the input network 20 and the output network 21. The relative sizes of the resistance portions 40 and 41 and the capacity of the condenser 42 are selected with respect to the values of the resistances 18, 43, and 50 and the condenser 49 so that attenuation of the low frequency portion of the signal in the network 21 is completely compensated by the accentuation produced in the network 20 in order that a flat characteristic is provided throughout the band of frequencies to be transmitted. The loss of the transmission line 15 is negligible, and the resistance 18 may be considered as connected directly to the condensers 49 and 51. In the two networks 20 and 21, the ratio of the sum of the resistances 18 and 43 to the resistance 40 is made equal to the ratio of the resistance 50 to the resistance 41 and to the ratio of the capacity of the condenser 42 to the capacity of the condenser 49. When these ratios have been obtained, the characteristic for the circuit becomes flat over a wide band of frequencies. It should be understood, of course, that the screen grid circuits of the devices 10 and 11 are adequately by-passed by the condensers 36 and 37. The time constants of the condenser 47 and resistance 48 in series and the resistance 50 and condenser 51 in series should be made greater than the period of one cycle of the lowest frequency of the band to be transmitted. In addition, resistance 48 should be much larger than the sum of resistances 41 and 40; and the plate resistance of device 10 should also be much larger than this sum.

In Fig. 2, I have illustrated the characteristic curves of the networks 20 and 21 at 55 and 56, respectively. The abscissa of these curves is a logarithmic scale of frequencies and the ordinate is in decibels, and since decibels are by definition logarithmic, both scales are logarithmic. For any frequency the sum of the decibel values and therefore, the product of the voltage values taken from the curves 55 and 56 is the same and provides the desired straight line characteristic.

In the foregoing, the general arrangement and the relative values of the several components of the input and the output networks of the device 11 have been described. The manner in which the linear frequency characteristic is obtained whereby signals may be coupled to and transmitted through the low impedance line 15 will be more clearly understood from the following analysis.

The network 20 is coupled to the device 11 through the condenser 47 and the resistance 48, and this coupling must be chosen so that it passes the lowest frequency within the band to be transmitted without more than a permissible amount of phase shift. Because resistance 48 must be large, this condition is easily achieved in most cases by the use of a reasonably small size of coupling condenser 47. In the analysis below, the phase shift caused by elements 47 and 48 is neglected, since it may be made negligible in practice.

The impedance of the network 21 may be expressed by the following equation:

$$Z_{21}=\frac{R_{43}\left(R_{18}-\frac{\frac{jR_{50}}{\omega C_{49}}}{R_{50}-\frac{j}{\omega C_{49}}}\right)}{R_{43}+R_{18}-\left(\frac{\frac{jR_{50}}{\omega C_{49}}}{R_{50}-\frac{j}{\omega C_{49}}}\right)} \quad (1)$$

Where Z, R, and C represent, respectively, the impedance resistance, and capacity of the elements of the drawing designated by the reference numeral written as a subscript after the respective character; ω represents the frequency expressed in radians per second and is equal to the frequency multiplied by 2π; and j represents the imaginary quantity $\sqrt{-1}$. This nomenclature will be employed throughout the following:

It should be mentioned, however, that the numerical value of R_{43} includes the shunting effect of the plate resistance of the device 11 which is in parallel with the resistance 43. In most cases the plate resistance is so high that the numerical value of R_{43} is the actual value of the resistance 43.

The voltage E_{18} across the resistance 18 at the output of the transmission line may be expressed as follows:

$$E_{18}=I_{21}Z_{21}\left[\frac{R_{18}}{R_{18}-\left(\frac{\frac{jR_{50}}{\omega C_{49}}}{R_{50}-\frac{j}{\omega C_{49}}}\right)}\right] \quad (2)$$

where I_{21} is the current flowing to the plate 32 of device 11, and the impedance of condenser 51 is negligible compared with the resistance 50 within the band of frequencies to be transmitted:

Substituting Z_{21} from Equation 1

$$E_{18}=I_{21}\left[\frac{R_{43}\left(R_{18}-\frac{\frac{jR_{50}}{\omega C_{49}}}{R_{50}-\frac{j}{\omega C_{49}}}\right)}{R_{43}+R_{18}-\left(\frac{\frac{jR_{50}}{\omega C_{49}}}{R_{50}-\frac{j}{\omega C_{49}}}\right)}\right]\left[\frac{R_{18}}{R_{18}-\left(\frac{\frac{jR_{50}}{\omega C_{49}}}{R_{50}-\frac{j}{\omega C_{49}}}\right)}\right] \quad (3)$$

Simplifying,

$$E_{18}=I_{21}\left[\frac{R_{18}R_{43}}{R_{43}+R_{18}-\left(\frac{\frac{jR_{50}}{\omega C_{49}}}{R_{50}-\frac{j}{\omega C_{49}}}\right)}\right] \quad (4)$$

The current I_{21} may be expressed in terms of I_{20}, the current flowing in the load circuit of device 10, as follows:

$$I_{21}=KI_{20}\left[R_{40}-\left(\frac{\frac{jR_{41}}{\omega C_{42}}}{R_{41}-\frac{j}{\omega C_{42}}}\right)\right] \quad (5)$$

where K is a real constant; hence:

$$E_{18}=KI_{20}\left[R_{40}-\left(\frac{\frac{jR_{41}}{\omega C_{42}}}{R_{41}-\frac{j}{\omega C_{42}}}\right)\right]\left[\frac{R_{18}R_{43}}{R_{43}+R_{18}-\left(\frac{\frac{jR_{50}}{\omega C_{49}}}{R_{50}-\frac{j}{\omega C_{49}}}\right)}\right] \quad (6)$$

Now, if $R_{18}+R_{43}=AR_{40}$, where A is a real constant; $R_{50}=AR_{41}$, and

$$C_{49}=\frac{C_{42}}{A}$$

then from Equation 6 the following is obtained:

$$E_{18}=KI_{20}\left[R_{40}-\left(\frac{\frac{jR_{41}}{\omega C_{42}}}{R_{41}-\frac{j}{\omega C_{42}}}\right)\right]\left[\frac{R_{18}R_{43}}{AR_{40}-\left(\frac{\frac{jA^2R_{41}}{\omega C_{42}}}{AR_{41}-\frac{jA}{\omega C_{42}}}\right)}\right] \quad (7)$$

Simplifying

$$E_{18}=KI_{20}\frac{R_{18}R_{43}}{A} \quad (8)$$

which contains no term dependent upon frequency. It follows that the signal will be transmitted linearly throughout the required band of frequencies, since I_{20} is proportional to the applied input voltage, E_{23}, across terminals 12 and 13.

In many cases a large voltage is available at the terminals 12 and 13 of the apparatus on the input side of the transmission line, and in some cases it may be difficult to provide ahead of device 11, as is done in the network 20 of Fig. 1, correction for the phase shift caused by the network 21. In order to obtain a flat characteristic in this case, the circuit shown in Fig. 3 may be employed; this circuit incorporates the compensating network in the output of an amplifier located at the output end of the transmission line.

The first amplifier stage illustrated in Fig. 3 and including the transmission line is the same as the second stage shown in Fig. 1 and corresponding parts or circuit components have been designated by the same numerals. The device 10 together with its associated circuits is not employed and the input terminals 12 and 13 are connected to impress the input signal directly on the grid 29 of the device 11. The characteristic curve for the first stage of the amplifier in Fig. 3 is, therefore, the same as that of the second stage in Fig. 1, and is indicated by the curve 56 in Fig. 2. The voltage appearing across the terminating resistance 18 is amplified and coupled to a utilization device 59 through an amplifier including an electron discharge device 60 having an output network 61 coupled to the utilization device through a coupling condenser 62 and across a resistor 63. The amplifying stage including the device 60 and the network 61 is connected in the same manner as the first stage shown in Fig. 1 and including the device 10 and network 20. The device 60 is provided with a cathode 63', an anode 64, a control electrode 65, and a screen grid 66. Anode and screen voltages are obtained from a suitable source such as a battery 67, the anode 64 being connected to the battery 67 through a shunt resistance comprising portions 68 and 69 in the network 61. The portion 69 is shunted by a condenser 70. The screen grid is connected to the battery 67 through a resistor 71 by-passed by a condenser 72. A resistance 73 is provided between the cathode 63' and the ground and it is of a value such that correct bias is provided for device 60. The values of the resistance portions 68 and 69 and the capacity of the condenser 70 are chosen with respect to the values of the components of the network 21 so that compensation is provided for the attenuation of low frequency currents produced by the network 21, the resulting characteristic curve being the same as the curve 55 in Fig. 2. The values of the components of the networks 61 are chosen so that the ratio of the sum of the resistances 18 and 43 to the resistance 68 is the same as the ratio of the resistance 50 to the resistance 69 and also the same as the ratio of the capacity of the condenser 70 to the capacity of the condenser 49. The coupling condenser 62 and the resistance 63 are chosen so that they do not cause low frequency phase shift within the band of frequencies to be transmitted.

The mathematical analysis of the circuit shown in Fig. 3 is similar to that of the circuit of Fig. 1. The several components of the first stage of Fig. 3 may have the same values as those of the second stage of Fig. 1. The values of the circuit components of the second stage associated with the device 60 are chosen to compensate fully for the phase shift in the network 21 in accordance with the following analysis.

The voltage E_{61} across the network **61** at the anode **64** may be expressed as follows:

$$E_{61}=I_{61}\left[R_{68}-\left(\frac{\frac{jR_{69}}{\omega C_{70}}}{R_{69}-\frac{j}{\omega C_{70}}}\right)\right] \quad (9)$$

where I_{61} is the plate current of device **60**. This is a correct expression for E_{61} because the resistance **63** and the plate resistance of the device **60** are both very much larger than the sum of the resistances **68** and **69**. Now:

$$I_{61}=K_2E_{18} \quad (10)$$

where K_2 is a real constant of proportionality. Substituting in Equation 9

$$E_{61}=K_2E_{18}\left[R_{68}-\left(\frac{\frac{jR_{69}}{\omega C_{70}}}{R_{69}-\frac{j}{\omega C_{70}}}\right)\right] \quad (11)$$

Substituting the value of E_{18} from Equation 4

$$E_{61}=K_2I_{21}\left[\frac{R_{18}R_{43}}{R_{43}+R_{18}-\left(\frac{\frac{jR_{50}}{\omega C_{49}}}{R_{50}-\frac{j}{\omega C_{49}}}\right)}\right]\left[R_{68}-\left(\frac{\frac{jR_{69}}{\omega C_{70}}}{R_{69}-\frac{j}{\omega C_{70}}}\right)\right] \quad (12)$$

Now, if $R_{18}+R_{43}=BR_{68}$, where B is a real constant; $R_{50}=BR_{69}$, and

$$C_{49}=\frac{C_{70}}{B}$$

then substituting in Equation 12 yields

$$E_{61}=K_2I_{18}\left[\frac{R_{18}R_{43}}{BR_{68}-\left(\frac{\frac{jB^2R_{69}}{\omega C_{70}}}{BR_{69}-\frac{jB}{\omega C_{70}}}\right)}\right]\left[R_{68}-\left(\frac{\frac{jR_{69}}{\omega C_{70}}}{R_{69}-\frac{j}{\omega C_{70}}}\right)\right]=\frac{K_2I_{18}R_{18}R_{43}}{B} \quad (13)$$

But $I_{18}=K_1E_{29}$, where K_1 is a real constant, and E_{29} is the voltage across the input terminals **12** and **13** of Fig. 3. Substituting:

$$E_{61}=\frac{K_1K_2E_{29}R_{18}R_{43}}{B} \quad (14)$$

Equation 14 contains no term which is dependent upon frequency, and it follows that linear transmission of the signal is attained throughout the desired frequency band.

From the foregoing, it will be evident that my invention provides a transmission line coupling apparatus suitable for the linear transmission of signals over a wide band of frequencies. By way of illustration only and not by way of limitation, there are listed below values of circuit constants which have been found suitable for the circuits of Figs. 1 and 3. The devices **10** and **60** were type 6SJ7 pentode or triple-grid detector tubes, and the device **11** was a type 6AG7 pentode operated with a plate current of 30 milliamperes. The transmission line had a characteristic impedance of 75 ohms and the lowest frequency transmitted was about 100 cycles per second and the highest frequency was of the order of one-half megacycle. The anode or plate supply voltage was 300 volts. The other values follow:

Resistance **18**	ohms	75
Resistance **43**	do	4,925
Resistances **40** and **68**	do	5,000
Resistances **41**, **50**, and **69**	do	50,000
Condensers **42**, **47**, **49**, **51**, **62** and **70**	μf	1
Resistances **48** and **63**	megohm	1
Resistances **44** and **73**	ohms	750
Resistance **45**	do	80

If the condenser **51** is omitted from the network **21**, a direct current of about 2.8 milliamperes will flow through the resistance **18** when the above values of the circuit components are employed. This direct current is less than 10 per cent of the average plate current of device **11** and is, therefore, less than 10 per cent of the peak to peak signal capability of the device **11**. When the condenser **51** is omitted from the circuit of Fig. 3, the direct current flowing in resistance **18** will cause the control grid **65** of the device **60** to have a slightly positive average voltage. This may be compensated by increasing resistance **73** to a slightly higher value so that the bias voltage effective on the device **60** is correct for proper operation. Because of the regulating properties of the cathode biased amplifier stage employing device **60**, the change of bias caused by omitting the condenser **51** without changing the resistance **73** will be approximately one-tenth of a volt. Except for extremely exacting conditions of operation, this small difference in bias would be of no consequence in a practical application.

The circuit arrangement of Fig. 3 can be employed to transmit input signals extending down to and including zero cycles per second by omitting the condenser **51** and connecting the utilization device **59** directly to the junction of the anode **64** and resistance **68**. The condenser **62** and resistance **63** may then be eliminated. Furthermore, when transmitting very low frequencies and direct current signals, it is necessary that the screen grid potentials be maintained constant; this being accomplished by shunting the condensers **37** and **72** with suitable regulating glow tubes indicated at **75** and **76**, respectively. Similar changes obviously may be made in the circuit of Fig. 1. However, it should be noted that the coupling between device **10** and the control grid **29** of the device **11** must be some suitable form of direct current coupling to prevent destruction of the grid **29** by the impressing of the plate voltage on the control grid **29**.

The circuit of Fig. 1 has the advantage that no correcting or compensating network is required at the terminating end of the transmission line. Furthermore, stray disturbances are less apt to be picked up by the transmission line because the frequency components of the signal are present in the transmission line in their true magnitudes.

The circuit arrangement of Fig. 3 has the advantage that there is no greater danger of overloading either the device **11** or the device **60** at low frequencies than there is at high frequencies. Furthermore, the arrangement of Fig. 3 lends itself more readily to direct current coupling than does the circuit of Fig. 1.

While both circuit arrangements provide linear transmission of signals over a wide band of frequencies including very low frequencies, one circuit or the other may be better for a particular application. It is, therefore, apparent that

I have provided a simple and effective arrangement for securing linear transmission of signals through a transmission line and one which is applicable to a wide range of uses.

While I have shown particular embodiments of my invention it will, of course, be understood that I do not wish to be limited thereto since different modifications may be made both in the circuit arrangement and in the instrumentalities employed, and I intend by the appended claims to cover all modifications which fall within the spirit and scope of my invention.

What I claim as new and desire to secure by Letters Patent of the United States, is:

1. A transmission line coupling apparatus for transferring alternating current wave energy within a wide band of frequencies comprising a low impedance transmission line having a terminating resistance, an electronic amplifier having an input network and an output network, one of said networks comprising a first shunt resistance and a capacity shunting a portion of said shunt resistance; the other of said networks comprising a shunt resistance, said terminating resistance, and a coupling capacity shunted by a second resistance and connected between said line and said shunt resistance, said first shunt resistance, said portion thereof and said shunt capacity comprising said one network being proportioned to accentuate current of low frequency within said band, and said coupling capacity and resistances of said other network being proportioned relative to said shunt capacity and said resistance and said portion comprising said one network to attenuate said low frequency current to produce linear transmission at all frequencies in said band.

2. A transmission line coupling apparatus for transferring alternating wave energy linearly within a wide band of frequencies comprising a low impedance transmission line having a terminating resistance, an electronic amplifier having an input network and an output network, one of said networks comprising a first shunt resistance and a capacity shunting a portion of said shunt resistance, the other of said networks comprising a coupling capacity shunted by a second resistance and connected in series with said transmission line and a third shunt resistance on the input side of said coupling capacity, the ratio of the sum of said third shunt resistance and said terminating resistance to that part of said first shunt resistance not shunted by said capacity being equal to the ratio of said second resistance to said portion of said first resistance and these ratios both being equal to the ratio of said capacity shunting said portion to said coupling capacity.

3. A transmission line coupling apparatus for transferring alternating current wave energy within a wide band of frequencies comprising a low impedance transmission line having a terminating resistance, an electronic amplifier, an input network for said amplifier comprising a shunt resistance and a capacity shunting a portion of said resistance, an output network for coupling said amplifier to said transmission line and comprising a shunt resistance and a coupling capacitor connected between said shunt resistance and said line and shunted by a second resistance, said terminating resistance also constituting a shunt resistance in said network, said input resistance and said portion thereof and said shunt capacity being proportioned to accentuate currents of low frequency within said band, and said coupling capacity, shunt resistance, terminating resistance and second resistance being proportioned relative to said shunt capacity and said input resistance and said portion thereof to attenuate said low frequency currents to produce linear transmission at all frequencies in said band.

4. A transmission line coupling apparatus for transferring alternating current wave energy within a wide band of frequencies comprising a low impedance transmission line and a terminating resistance therefor, an electronic amplifier at the input of said transmission line including a shunt resistance having a coupling capacity shunted by a second resistance, an electronic amplifier connected across said terminating resistance and having an output network comprising a shunt output resistance and a capacity shunting a portion of said output resistance, said coupling capacity, said shunt resistance, said second resistance and said terminating resistance being proportioned relative to said shunt capacity and said output resistance and said portion thereof to attenuate low frequency currents in said band, and said output resistance and said portion thereof and said shunt capacity being proportioned to accentuate said low frequency current to produce linear transmission at all frequencies in said band.

DONALD E. NORGAARD.