June 18, 1940. A. D. BLUMLEIN 2,204,721

IMPEDANCE NETWORK FOR COUPLING ELECTRIC CABLE CIRCUITS

Filed Nov. 13, 1937 2 Sheets-Sheet 1

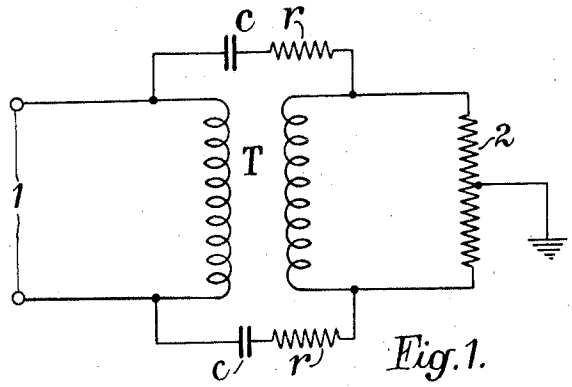


Fig. 1.

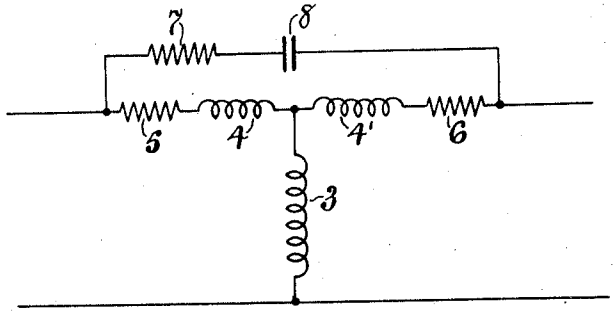


Fig. 2.

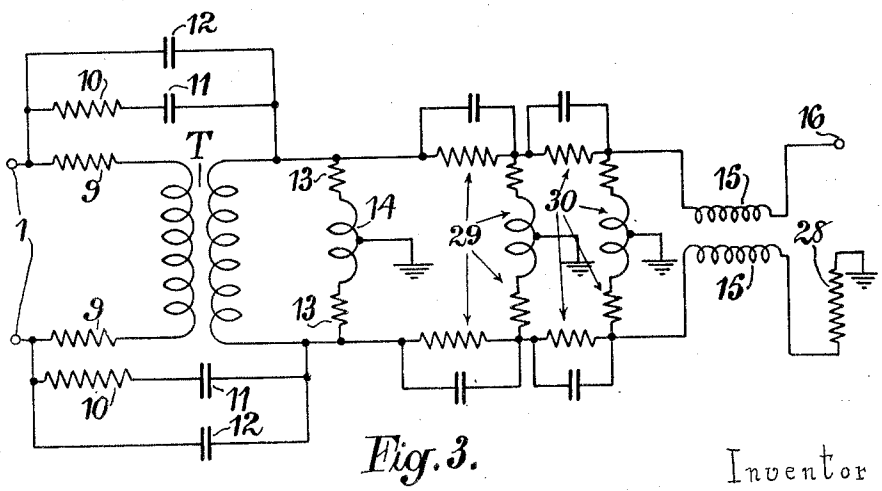


Fig. 3.

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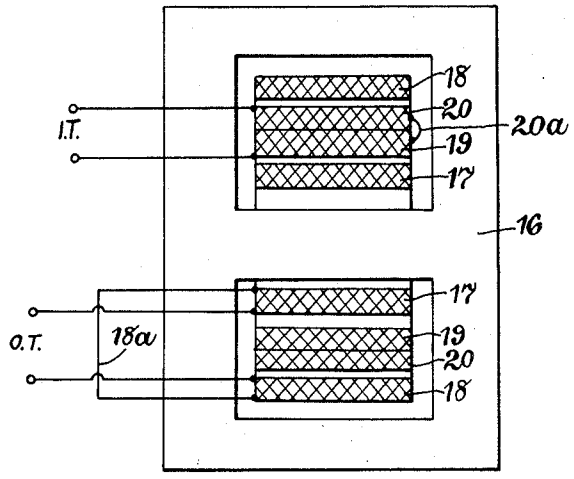


Fig. 4.

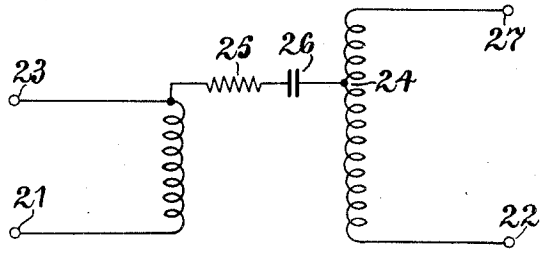


Fig. 5.

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Patented June 18, 1940

2,204,721

UNITED STATES PATENT OFFICE

2,204,721

IMPEDANCE NETWORK FOR COUPLING ELECTRIC CABLE CIRCUITS

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Application November 13, 1937, Serial No. 174,497
In Great Britain December 2, 1936

10 Claims. (Cl. 178—44)

This invention relates to electric coupling circuits and has particular but not exclusive reference to the coupling circuits at the termination of a signal transmission line.

The object of the invention is to provide a coupling network which is capable of transmitting signal currents over a very wide range of frequencies and prevents the transmission of direct current and of undesired low frequencies.

According to the present invention a coupling network for the transmission of signals covering a wide range of frequencies between two circuits and for preventing the passage of undesired direct current and attenuating undesired low frequency signals, comprises a transformer, one winding of which is connected to the output of one of said circuits, and another winding of which is connected to the input of said other circuit. The transformer is such that it will transmit the lower frequency components of desired signals. An auxiliary path is connected between the transformer windings to provide a path for the higher frequency components which are subject to attenuation by the leakage inductance of the transformer. This auxiliary path forms with the leakage inductance and with resistance presented by the transformer windings, a substantially constant impedance, with the result that the transmission efficiency of the coupling system over the range of operating frequencies is substantially uniform.

In a particular coupling network according to the invention the auxiliary path is connected between points in the transformer windings which provide substantially a 1:1 ratio.

A condenser is included in the auxiliary path, and in order to reduce the value of said condenser required to produce said constant impedance, the effective resistance of the transformer windings is increased by connecting a resistance in series with one of said windings. The auxiliary path may include a resistance and a condenser and be connected between the high potential ends of the transformer windings, the resistance being effectively equal to the resistance of the transformer windings and the condenser being equal to said leakage inductance divided by the square of said resistance.

In order to provide the transformer with a turns ratio differing from 1:1 one winding of the transformer may be provided with additional turns beyond the point in that winding at which said auxiliary path is connected.

In a constructional form of transformer according to the invention the direction of the winding is so chosen as to cause the high potential points of similar phase in the windings to lie adjacent each other. Attenuation of phantom currents may be effected by the provision of a choke coil of high inductance for the phantom currents but of low inductance for the currents to be transmitted. In the case of a two winding choke coil used for the above purpose the spacing between the two windings is made such that their characteristic impedance for the currents to be transmitted is similar to that of the circuit in which they operate. An attenuator or equaliser network may be connected between the choke coil and the transformer, the equaliser network serving to attenuate phantom currents and also serving to prevent resonance between the choke coil and a condenser in the auxiliary path connected between the windings of the transformer.

In order that the nature of the invention may be more clearly understood and readily carried into effect, examples of coupling networks embodying the invention will now be described in greater detail by way of example with reference to the accompanying drawings in which:

Figures 1 and 2 serve to illustrate the general principles embodied in the application of the invention.

Figure 3 shows a transformer embodying the invention and forming part of a cable equalising circuit.

Figure 4 shows diagrammatically a constructional form of transformer according to the invention, and

Figure 5 shows a modified application of the invention.

Referring to Fig. 1 of these drawings, terminals 1 represent terminals of a device, in the particular example shown balanced about earth, the voltage between which it is required to pass to a load represented by a resistance 2, also balanced about earth, without passing the low frequency potentials on terminals 1 directly to the resistance 2. If for example, the terminals 1 are connected to the end of a balanced cable subject to power interference, these two terminals may be free of interfering voltages as regards the potential between them, but subject to considerable interfering voltages between the two terminals in parallel and earth. The arrangement shown is capable of isolating the interfering low frequency voltages and preventing them from arriving at the resistance 2. If a transformer coupling the line to the load is required to operate over a very wide range of fre-

quencies, such as for example 50 cycles to 2 megacycles it is found impracticable to obtain a satisfactory low and high frequency response from a simple transformer working between resistive terminations over such a wide range of frequencies. A coupling transformer T is therefore given as small a number of turns in each winding as will not involve undesirable loss of the lowest frequencies of the order of 50 cycles, and the turns are wound to give a 1:1 ratio. The leakage inductance of the transformer will then cause a serious loss at very high frequencies but at high frequencies the terminals 1 will not be subject to appreciable interference so that direct connection to the resistance 2 is permissible at these frequencies. Condensers *c* in series with resistance *r* are therefore inserted between both the upper and lower ends of the primary and secondary windings of the transformer T and serve to by-pass the high frequency currents. The condenser *c* and series resistance *r* constitute an auxiliary transmission path which is of high impedance to undesired low frequencies.

The unbalanced circuit equivalent of Fig. 1 is shown in Fig. 2 in which 3 represents the shunt inductance of the transformer 4, 4' represent the leakage inductance with 5 and 6 the resistance of the transformer windings. The shunt inductance 3 of the transformer is operative only at very low frequencies and at the higher frequencies the leakage inductance 4, 4' prevents satisfactory transmission. A resistance 7 and condenser 8 are therefore shunted between the windings, in effect across the leakage inductance and the resistance of the transformer winding. The resistance 7 is made equal to the resistance of the transformer windings and the condenser 8 is made equal to the leakage inductance divided by the square of the winding resistance. The whole series element then appears as a constant resistance equal to the resistance of the transformer winding. If the winding resistance is variable with the frequency, resistance 7 should be made approximately equal to the winding resistance at the resonant frequency of the leakage inductance 4, 4' and the condenser 8.

It is not essential to employ the exact resistances and capacities described, but a smoother characteristic is obtained by adopting the value specified. Again, the resistance 7 may be omitted altogether so reducing the impedance of the circuit at very high frequencies. By increasing the resistance of the transformer windings as for example by adding additional resistances, the value of condenser required for the constant resistance arrangement preferred, is reduced, so that isolation between the windings is maintained to a higher frequency. In the arrangement shown in Fig. 1, the two added resistances *r* are each equal to half of the resistance 7 and the two condensers *c* are each equal to twice the condenser 8.

In Fig. 3 of the drawings an alternative arrangement is shown embodying a transformer according to the invention and arranged to form an integral part of a cable equalising circuit. As in Fig. 1 the cable is connected to terminals 1 but the transformer T has series resistances 9 added to its primary circuit. Resistances 10 and condensers 11 form bridging circuits between the two windings. If the resistance of the two transformer windings in series together with both resistances 9 is equal to R, then resistances 10 are each made equal to

$$\frac{R}{2}$$

and condensers 11 are made equal to

$$\frac{2L}{R^2}$$

where L is the leakage inductance between the transformer windings.

The combination of the 1:1 ratio transformer with a resistance 9, a resistance 10, and a condenser 11 is at high frequencies equivalent to a plain series resistance equal in value to the resistance 10. Further condensers 12 are connected across the bridging circuits including the resistances 10 and condensers 11 and the secondary winding of the transformer is bridged by resistances 13 connected in series with an inductance 14 the centre point of which is connected to earth. The effective series resistances

$$\frac{R}{2}$$

shunted by condensers 12 and the resistance 13 and inductance 14 form series and shunt arms of a section of cable equalising circuit such as that described in the specification of co-pending application Serial No. 127,929 filed February 26, 1937. In order to provide additional attenuation of phantom currents passing through the condensers 11 and 12, the centre point of the secondary winding of the transformer T may be connected to earth.

Two further sections of similar equalising circuits 29, 30, are shown following the transformer T. Beyond these equalising circuits are connected the two windings of a choke coil 15 the inclusion of which constitutes a subsidiary feature of the present invention. This choke coil is inserted in order to produce high attenuation of phantom currents, while having no attenuating effect upon the currents to be transmitted. Such phantom currents consist of currents flowing in like phase in the two conductors of the cable with the earth or the cable sheath or other conductors as a return. Although large interference voltages are not induced in the phantom circuit, unbalances of the cable may transfer small currents at higher frequencies from the balanced circuit to the phantom or unbalanced circuit or cross-talk arising from other conductors in the cable may similarly produce unwanted phantom currents. These currents at high frequencies are not attenuated by the transformer owing to the condensers shunted across the windings. The provision of the choke coil 15 therefore assists in the attenuation of such currents.

In a constructional form the choke coil 15 preferably consists of a core of thin laminations of high resistance magnetic alloy having two windings, one on top of the other, each winding consisting of a single layer. These windings are designed to be comparatively non-inductive for loop currents but to present a high impedance to phantom currents, thus attenuating the latter. By correct choice of spacing and insulation between the two windings of the choke coil 15 the leakage inductance and the capacity between them form an artificial line the impedance of which is equal to that of the equaliser so that the introduction of this inductance does not modify the impedance seen through it for loop currents. The two windings are wound in the same direction so that the ends adjacent to the

cable are physically adjacent on the two windings. In the example shown in Fig. 3 one side of the balanced circuit is earthed through a resistance 28 equal to half of the characteristic impedance of the cable and the other side forms the output terminal 16 which is terminated by further sections of unbalanced equaliser equal in impedance to half the characteristic impedance of the cable. The sections of equaliser shown to the left of the choke coil 15 including the section formed by the transformer and resistance 13 and inductance 14, are made substantially equal in characteristic impedance to the impedance of the cable. If further attenuation of phantom currents is required, the coil 15 may be followed by further sections of balanced equalisers with centre points earthed and a further similar coil may be inserted. Alternatively, the equaliser system may be maintained balanced up to the input of the amplifier, which amplifier may be a balanced amplifier. By building out the transformer with resistances 9, the correct effective series resistance is obtained for the first equaliser section, and furthermore the values of condenser 11 are reduced, so increasing the frequency up to which isolation is given by the transformer. Above this frequency the unwanted voltages will not be great enough to cause trouble in the resistances 13 and 14 and any phantom currents are heavily attenuated by the coil 15 if such attenuation is required.

In the absence of the equalising circuits preceding the choke coil 15 there would be a series resonance between the condensers 11 and the coil 15 or between the condenser 12 and the coil 15 and such series resonance would remove all the attenuation of phantom currents due to both the transformer T and the choke coil 15. It will be understood that this inclusion of the equalising networks 13, 14 and 29, 30 and also the choke coil 15 is not essential to the carrying out of the present invention and they may be omitted, the line being terminated as shown right of Fig. 3.

Fig. 4 of the drawings shows a suitable constructional form of transformer for use in carrying out the present invention and shows a cross section in the plans of the core laminations through the windings. The core 16 is of conventional design and 17 and 18 are the secondary windings and 19 and 20 are the primary windings. A space is left between the primary and secondary windings for the insertion of substantial insulation if such is required. The direction of winding of the primary is the reverse sense to that of the secondary windings. The inner end of the winding 17 is connected to the outer end of the winding 18 by a conductor 18a. The outer end of the winding 17 and the inner end of the winding 18 are connected to output terminals OT. The outer end of winding 19 is joined to the inner end of winding 20 by a conductor 20a and the inner end of winding 19 and the outer end of winding 20 are connected to input terminals IT. The transformer ratio is 1:1 and since the windings are reverse wound it will be seen that similar potentials occur on the adjacent portions of the primary and secondary windings. The capacity between these windings therefore constitutes in effect an increase of condenser 12, and for cable-like impedance is generally negligible. A more complex interleaving system may if desired be employed, but it is preferable to arrange that the high potential ends of the windings of similar phase lie adjacent.

Fig. 5 shows an application of the invention to a step-up transformer having a small step-up ratio. In this case an unbalanced transformer is shown. Terminals 21 and 22 are both at earth potential for higher frequencies and may for example be connected through condensers to earth. The D. C. or low frequency potential of 21 however, is supposedly different from that of 22, so that an auto-transformer is not practicable. The input terminal 23 of the primary winding is connected through a resistance 25 and a condenser 26 to an intermediate point 24 on the secondary winding, the point 24 being chosen so that the turns between the point 24 on the secondary winding and the terminal 22 are substantially equal to the primary turns between the terminals 21 and 23. Considering 21, 23 and 22, 24 we have a 1:1 transformer. The resistance and condenser render the resistance of the winding and the leakage inductance of this transformer effective as a constant series resistance. The portion of the secondary winding between the high potential terminal 27 and the point 24 constitutes an auto-transformer step-up from the portion between the terminal 23 and the point 24 of the secondary and if the step-up ratio is not large, say 1:2, a reduction of the leakage inductance is obtained, due to the transformer being effectively an auto-transformer at high frequencies.

I claim:

1. A coupling network for the transmission of desired signals covering a wide range of frequencies between two circuits and for preventing the passage of undesired direct current and attenuating undesired low frequency signals, comprising in combination a transformer, comprising two windings and capable of transmitting lower frequency components of said desired signals, means for connecting one of said windings to the output of one of said circuits, means for connecting another of said windings to the input of said other circuit, an auxiliary path connected between said windings for higher frequency components of said desired signals subjected to attenuation by the leakage inductance of said transformer, said auxiliary path forming with at least part of said leakage inductance and with resistance presented by said windings an impedance, which is substantially constant over the wide range of frequencies to be transmitted by the network, thereby rendering the transmission efficiency of the coupling network over said range of frequencies substantially uniform.

2. A coupling network for the transmission of desired signals covering a wide range of frequencies between two circuits and for preventing the passage of undesired direct current and attenuating undesired low frequency signals comprising, in combination, a transformer having two windings and capable of transmitting lower frequency components of said desired signals, means for connecting one of said windings to the output of one of said circuits, means for connecting another of said windings to the input of said other circuit, an auxiliary path connected between said windings for higher frequency components of said desired signals subjected to attenuation by the leakage inductance of said transformer and including a condenser and a resistance, said resistance serially connected with one of said windings to increase their effective resistance, said path forming with at least part of said leakage inductance and with resistance presented by said

windings an impedance which is substantially constant over the wide range of frequencies to be transmitted by the network, thereby rendering the transmission efficiency of the coupling network over said range of frequencies substantially uniform.

3. A coupling network for the transmission of desired signals covering a wide range of frequencies between two circuits and for preventing the passage of undesired direct current and attenuating undesired low frequency signals, comprising, in combination, a transformer having two windings and capable of transmitting lower frequency components of said desired signals, means for connecting one of said windings to the output of one of said circuits, means for connecting another of said windings to the input of said other circuit, an auxiliary path connected between said windings for higher frequency components of said desired signals subjected to attenuation by the leakage inductance of said transformer, said path connected between points in said windings providing substantially a 1:1 ratio and including a condenser and a resistance, said resistance serially connected with one of said windings to increase their effective resistance, said path forming with at least part of said leakage inductance and with resistance presented by said windings an impedance which is substantially constant over the wide range of frequencies to be transmitted by the network, thereby rendering the transmission efficiency of the coupling network over said range of frequencies substantially uniform.

4. A coupling network for the transmission of desired signals covering a wide range of frequencies between two circuits and for preventing the passage of undesired direct current and attenuating undesired low frequency signals, comprising, in combination, a transformer having two windings and capable of transmitting lower frequency components of said desired signals, means for connecting one of said windings to the output of one of said circuits, means for connecting another of said windings to the input of said other circuit, an auxiliary path connected between said windings for higher frequency components of said desired signals subjected to attenuation by the leakage inductance of said transformer, said path including a resistance and a condenser and being connected between points in said windings providing substantially a 1:1 ratio, said resistance being effectively equal to the resistance of said windings, said condenser being equal to said leakage inductance divided by the square of said resistance, said path forming with at least part of said leakage inductance and with resistance presented by said windings an impedance which is substantially constant over the wide range of frequencies to be transmitted by the network, thereby rendering the transmission efficiency of the coupling network over said range of frequencies substantially uniform.

5. A coupling network for the transmission of desired signals covering a wide range of frequencies between two circuits and for preventing the passage of undesired direct current and attenuating undesired low frequency signals, comprising, in combination, a transformer having two windings and capable of transmitting lower frequency components of said desired signals, means for connecting one of said windings to the output of one of said circuits, means for connecting another of said windings to the input of said other circuit, an auxiliary path connected between said windings for higher frequency components of said desired signals subjected to attenuation by the leakage inductance of said transformer, said path connected between points in said windings providing a turns ratio of 1:1, and one of said windings provided with additional turns beyond the point at which said auxiliary path is connected, said path forming with at least part of said leakage inductance and with resistance presented by said windings an impedance which is substantially constant over the wide range of frequencies to be transmitted by the network, thereby rendering the transmission efficiency of the coupling network over said range of frequencies substantially uniform.

6. A coupling network for the transmission of desired signals covering a wide range of frequencies between two circuits and for preventing the passage of undesired direct current and attenuating undesired low frequency signals, comprising, in combination, a transformer having two windings and capable of transmitting lower frequency components of said desired signals, means for connecting one of said windings to the output of one of said circuits, means for connecting another of said windings to the input of said other circuit, an auxiliary path connected between said windings for higher frequency components of said desired signals subjected to attenuation by the leakage inductance of said transformer, a series arm of a section of transmission line equalising circuit comprising a resistance in series with a condenser and another condenser in shunt with them included in said path, said resistance being effectively equal to the resistance of said windings and said series condenser being equal to said leakage inductance divided by the square of said resistance, said path connected between points in said windings providing substantially a 1:1 ratio and forming with at least part of said leakage inductance and with resistance presented by said windings an impedance which is substantially constant over the wide range of frequencies to be transmitted by the network, thereby rendering the transmission efficiency of the coupling network over said range of frequencies substantially uniform.

7. A coupling network for the transmission of desired signals covering a wide range of frequencies between two circuits and for preventing the passage of undesired direct current and attenuating undesired low frequency signals, comprising, in combination, a transformer having two windings and capable of transmitting low frequency components of said desired signals, means for connecting one of said windings to the output of one of said circuits, means for connecting another of said windings to the input of said other circuit, an auxiliary path for higher frequency components of said desired signals subjected to attenuation by the leakage inductance of said transformer connected between points in said windings providing substantially a 1:1 ratio, and the turns of said windings being so wound that the high potential points of similar phase in said windings lie adjacent each other, said path forming with at least part of said leakage inductance and with resistance presented by said windings an impedance which is substantially constant over the wide range of frequencies to be transmitted by the net-work, thereby rendering the transmission efficiency of the coupling network over said range of frequencies substantially uniform.

8. A coupling network for the transmission of

desired signals covering a wide range of frequencies between two circuits and for preventing the passage of undesired direct current and attenuating undesired low frequency signals, comprising, in combination, a transformer having two windings and capable of transmitting lower frequency components of said desired signals, means for connecting one of said windings to the output of one of said circuits, means for connecting another of said windings to the input of said other circuit, an auxiliary path connected between said windings for higher frequency components of said desired signals subjected to attenuation by the leakage inductance of said transformer, said path including a condenser, a choke-coil and an equaliser network connected between said choke-coil and said transformer, said choke-coil having high inductance for attenuating phantom currents but low inductance for said signal currents to be transmitted through the coupling network, said equaliser network serving to attenuate phantom currents and to prevent resonance between said choke-coil and said condenser, said path forming with at least part of said leakage inductance and with resistance presented by said windings an impedance with is substantially constant over the wide range of frequencies to be transmitted by the network, thereby rendering the transmission efficiency of the coupling network over said range of frequencies substantially uniform.

9. A coupling network for the transmission of desired signals covering a wide range of frequencies between two circuits and for preventing the passage of undesired direct current and attenuating undesired low frequency signals, comprising, in combination, a transformer having two windings and capable of transmitting lower frequency components of said desired signals, means for connecting one of said windings to the output of one of said circuits, means for connecting another of said windings to the input of said other circuit, an auxiliary path connected between said windings for higher frequency components of said desired signals subjected to attenuation by the leakage inductance of said transformer, said path including a condenser, a choke coil, and an equaliser network connected between said choke coil and said transformer, said choke coil having high inductance for attenuating phantom currents but low inductance for said signal currents to be transmitted through the coupling network, said choke coil comprising two windings spaced from each other so that their characteristic impedance for said signal currents is similar to that of the characteristic impedance of the circuit in which they are included, said equaliser network serving to attenuate phantom currents and to prevent resonance between said choke coil and said condenser, said path forming with at least part of said leakage inductance and with resistance presented by said windings an impedance which is substantially constant over the wide range of frequencies to be transmitted by the network, thereby rendering the transmission efficiency of the coupling network over said range of frequencies substantially uniform.

10. A signal transmitting system for the transmission of desired signals covering a wide range of frequencies between two circuits and for preventing the passage of undesired direct current and attenuating undesired low frequency signals, comprising a coupling network substantially consisting, in combination, of a transformer having two windings and being capable of transmitting lower frequency components of said desired signals, means for connecting one of said windings to the output of one of said circuits, means for connecting another of said windings to the input of said other circuit, an auxiliary path connected between said windings for higher frequency components of said desired signals subjected to attenuation by the leakage inductance of said transformer, said path forming with at least part of said leakage inductance and with resistance presented by said windings an impedance which is substantially constant over the wide range of frequencies to be transmitted by the network, thereby rendering the transmission efficiency of the coupling network over said range of frequencies substantially uniform.

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