Nov. 2, 1943.

N. BOTSFORD

2,333,148

INDUCTANCE APPARATUS

Filed June 28, 1941

FIG. 1

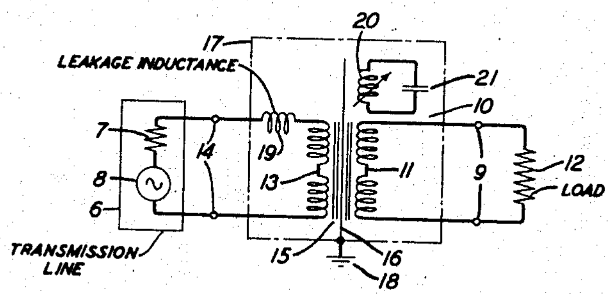


FIG. 2

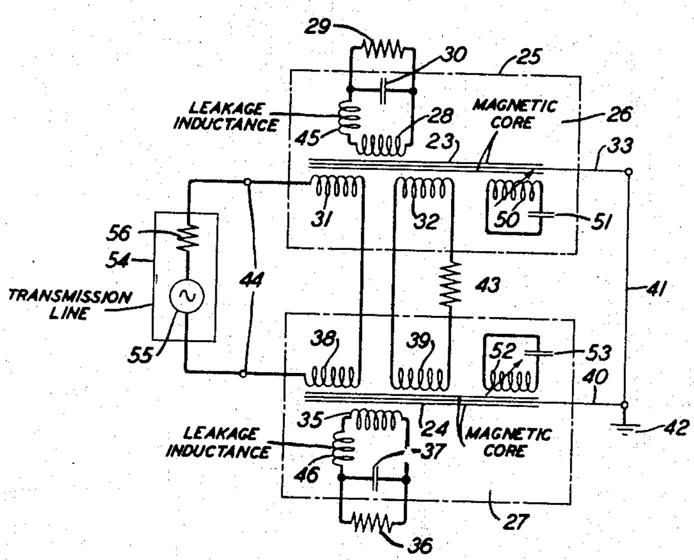
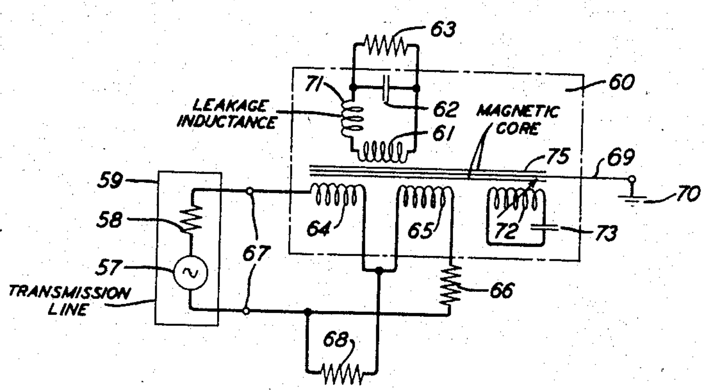


FIG. 3



INVENTOR
N. BOTSFORD
BY H. A. Burgess
ATTORNEY

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INDUCTANCE APPARATUS

Nelson Botsford, Rutherford, N. J., assignor to Bell Telephone Laboratories, Incorporated, New York, N. Y., a corporation of New York

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10 Claims. (Cl. 178—44)

This invention relates to inductance apparatus, and more particularly to inductance apparatus for transmitting signaling waves extending over a relatively broad band of frequencies with substantially uniform attenuation and relatively low reflection.

Carrier current transmission systems are being presently designed with higher frequencies to provide a larger number of discrete carrier channels. This means that certain inductance apparatus, such as repeating coils and transformers, is also being designed to transmit a wider band of frequencies. In the design of such inductance apparatus, one factor involves controlling the reflection characteristic. This characteristic is among others a function of leakage inductance, which inductance is the effective series inductance caused by an imperfect coupling of the windings of the inductance apparatus. Leakage inductance may be partially annulled by the effective shunt capacitance of the inductance apparatus. However, in line repeating coils and transformers where impedance levels are relative low, the amount of leakage inductance may be found to be intolerable. In this connection it has also been found that the amount of leakage inductance is further increased because of design features which tend to minimize modulation effects in the inductance apparatus.

Heretofore, the amount of leakage inductance, not annulled by the effective capacitance of the inductance apparatus, has been partially neutralized by connecting individual fixed capacitors in shunt of the input and output terminals of the inductance apparatus. These capacitors served to function together with the leakage inductance as a low-pass filter having a characteristic impedance of the same order of magnitude as the winding terminations of the inductance apparatus so as to transmit therethrough with tolerable reflection and attenuation signaling waves extending over a certain range of frequencies. In some cases, adjustable capacitors may be required to obtain a finer control of the reflection characteristic of the inductance apparatus. These neutralizing capacitors are expensive as their serviceability involves uniformity with regard to time and temperature, and, in some cases, high voltage operation.

This invention contemplates facile means for controlling the reflection characteristic of inductance apparatus.

The main object of the invention is to provide inexpensive, high quality, inductance apparatus.

A further object is to simplify the manufacture of inductance apparatus.

A further object is to compensate for the leakage inductance of inductance apparatus in so far as such inductance affects reflection and transmission.

Another object is to provide in a system proper terminations for apparatus which functions most effectively, only when terminated in the impedance out of and into which such apparatus is designed to operate.

Another object is to minimize between adjacent transmission lines crosstalk caused by reflected waves thereon.

One type of well-known inductance apparatus, such as a repeating coil, comprises a pair of windings wound on a magnetic core and between which a certain amount of leakage inductance exists, that is, inductance due to magnetic flux which is not mutual to the pair of windings. One winding of this pair may be applied, for example, to central office equipment while the other winding may be connected to a carrier current line transmitting signaling waves extending over a certain range of frequencies. As an uncertain amount of leakage inductance may be introduced in the inductance apparatus due to normal manufacturing variations, it has been found difficult to compensate for the latter amount of leakage inductance without providing for such compensation on the bases of individual inductance apparatus. Unless due care is observed to compensate for the leakage inductance of the inductance apparatus, it may happen that an intolerable impedance mismatch occurs between the inductance apparatus and the carrier current line or between the inductance apparatus and the central office equipment. Such impedance mismatch, depending on the amount, may increase the reflection characteristic of the inductance apparatus to such extent that transmission in the carrier current system is deleteriously affected.

In a specific embodiment of this invention, an impedance network comprising a tertiary winding and a capacitor in shunt thereof is coupled to the pair of windings of the inductance apparatus. The magnitude of the capacity of the capacitor is initially selected at a value suitable with respect to capacitance, physical dimensions and commercial availability, and thereafter the number of turns of the tertiary winding adjusted to neutralize substantially whatever amount of leakage inductance is then present in the inductance apparatus. Thus, the impedance of the inductance apparatus looking into the other winding with the one winding applied to the central office equipment, is substantially matched to the impedance of the carrier current line; and the impedance of the inductance apparatus, looking into the one winding with the other winding connected to the carrier current line, is substantially matched to the impedance of the central office equipment.

A feature of the invention is that it may be expeditiously utilized in various types of inductance apparatus, such as repeating coils, transformers and hybrid coils.

The invention will be readily understood from the following description taken together with the accompanying drawing in which:

Fig. 1 is a schematic circuit showing a specific embodiment of the invention applied to a repeating coil; and

Figs. 2 and 3 are schematic circuits illustrating the specific embodiment of the invention embodied in hybrid coils.

Fig. 1 shows a repeating coil 10 comprising a winding 11 whose terminals 9, 9 are applied to a load 12, which, for example, may comprise central office equipment, and a winding 13 whose terminals 14, 14 are applied to a source 8 of alternating current waves and a resistor 7, both of which, for example, may simulate a suitable carrier current transmission line 6. The windings 11 and 13 are wound on a magnetic core 15, and also may have interposed therebetween a shield 16. The coil 10 may also be enclosed in a casing 17 which together with the shield 16 is connected to a ground 18. An amount of leakage inductance will be present between the windings 11 and 13, and may be represented for the purpose of illustration as inductance 19 in series with one terminal 14.

The coil 10 is theoretically designed to have a substantially flat impedance-frequency characteristic that conforms substantially with substantially flat impedance-frequency characteristics of the central office equipment and the carrier current line to transmit all signaling waves extending over a certain range of frequencies with substantially uniform attenuation. This means that, with the winding 11 terminated in the load 12, the impedance termination of the coil 10, looking into the winding 13 ought to match substantially the impedance termination of the carrier current line 6; and with the winding 13 terminated in the carrier current line 6, the impedance termination of the coil 10 looking into the winding 11 ought to match substantially the impedance termination of the load 12.

However, leakage inductance present in the coil 10, as previously mentioned, will have the effect of upsetting such impedance match, that is, causing a mismatch between the impedance looking into the windings 11 and 13 and the impedance of the respective carrier current line 6 and the load 12. Such impedance mismatch, controlled by the magnitude of the leakage inductance, tends to vary the reflection characteristic of the coil 10, thereby exerting a deleterious effect on transmission in the entire carrier current system of Fig. 1 from the standpoint of both efficiency and fidelity, as will be hereinafter pointed out. Control of the reflection characteristic in inductance apparatus is therefore an important factor in the over-all design of carrier current systems.

Thus, in order to operate filters and hybrid coils embodied in central office equipment substantially in accordance with their design requirements, it is imperative that such equipment be connected to the impedance out of and into which it is designed to operate. Furthermore, in order to minimize the effects of reflection and crosstalk on carrier current transmission lines, it is imperative that individual lines be terminated in their characteristic impedance. Consequently, it is necessary to construct inductance apparatus connecting such central office equipment and the transmission lines so that when the central office winding of the inductance apparatus is terminated in central office equipment, the line winding is terminated in an impedance which is substantially equal to the impedance of the line; and when the line winding of the inductance apparatus is terminated in the line, the central office winding is terminated in an impedance which is substantially equal to the impedance of the central office equipment. Therefore, the impedance looking into either the line or central office winding of the inductance apparatus 10 must, to a tolerable degree, hold the match to the respective line 6 or central office equipment 12 over the entire frequency range of the signaling waves being transmitted in the system.

In accordance with this invention, the impedance looking into winding 13, when the winding 11 is applied to the load 12, is adjusted for signaling waves extending over a certain range of frequencies so as to be substantially equal to the impedance of the carrier current line 6 connected thereto and transmitting said signaling waves extending over said certain range of frequencies with substantially uniform attenuation; and the impedance looking into the winding 11, when the winding 13 is connected to the carrier current line 6, is adjusted so as to be substantially equal to the impedance of the load 12 for the same range of signaling frequencies.

Referring to Fig. 1, the foregoing is accomplished by a tertiary winding 20 coupled to the windings 11 and 13 and across which is connected a capacitor 21. The capacity of the capacitor 21 is initially selected at a value suitable with respect to capacitance, physical proportions and commercial availability, and thereafter the number of turns of the tertiary winding 20 is adjusted to neutralize substantially the leakage inductance present between the windings 11 and 13, that is, the leakage inductance 19, thereby providing substantially flat effective resistive and minimum reactive-frequency characteristics for the coil 10 either looking into the winding 13 from the carrier current line 6, or looking into the winding 11 from the load 12, when the other of these two windings is properly terminated in the manner previously mentioned. Hence, the attenuation-frequency characteristic of the coil 10 tends to conform substantially with the attenuation-frequency characteristics of the respective carrier current line 6 and load 12.

Maintaining the impedance match between the terminated windings 11 and 13 in the manner pointed out above serves (1) to control the effective capacity measured across the terminals of the individual windings 11 and 12, which capacity consists not only of the capacity between turns and layers of the windings 11 and 13 but also the value of the fixed capacitor 21 transformed through from the tertiary winding 20 to the individual winding 11 or 13 being measured; (2) to minimize between adjacent transmission lines crosstalk occasioned by reflected signaling waves; (3) to provide proper terminations for filters or other electrical apparatus which functions most effectively, only when terminated in the impedance out of and into which such filter or apparatus is designed to operate; and (4) to control the reflection characteristic of the coil 10 such that the former is maintained within a tolerable maximum value. Thus, the use of the adjustable winding 20 and capacitor 21 serves to provide an inexpensive, high quality, inductance coil 10 which is relatively simple to manufacture.

Accordingly, neutralization of leakage inductance enables a control of the reflection characteristic of the coil 10 so as to promote both high efficiency and high quality in the operation of the entire carrier current system of Fig. 1.

In connection with Fig. 1, it was found that, for a specific embodiment of the invention, a tertiary winding 20 comprising a number of turns of the order of 32 and a capacitor 21 having a capacity of the order of 0.075 microfarad provided for the coil 10 a substantially flat impedance frequency characteristic over approximately a 0.5–90 kilocycle range of frequencies. The simplicity of this embodiment was found to reside in the fact that an inexpensive and yet stable capacitor meeting relatively lenient minimum and maximum capacity requirements could be initially selected, and thereafter the number of turns of the tertiary winding 20 varied in order to obtain the neutralization of leakage inductance 10 mentioned hereinbefore.

Fig. 2 shows the invention applied to a hybrid coil 25 comprising individual coils 26 and 27. The coil 26 wound on a magnetic core 23 embodies a winding 28 terminated in a suitable load 29 and shunted by a capacitor 30. Coupled to the winding 28 are windings 31 and 32. Interposed between the two latter windings and the winding 28 is a shield 33. The coil 27 wound on a magnetic core 24 comprises a winding 35 terminated in a suitable load 36 and shunted by a capacitor 37. Coupled to the winding 35 are windings 38 and 39. Disposed intermediate the latter two windings and the winding 35 is a shield 40. A link 41 serves to connect both shields 33 and 40 to ground 42. The windings 32 and 39 on the respective coils 26 and 27 are terminated in a load or balancing network 43. The windings 31 and 38 on the respective coils 26 and 27 are applied to terminals 44, 44 which are connected to a source 55 of alternating current waves and resistor 56 both of which simulate a carrier current line 54. This line together with the loads 29, 36 and 43 possess substantially flat effective resistive and minimum reactive-frequency characteristics for transmitting signaling waves extending over a certain range of frequencies with substantially uniform attenuation.

A certain amount of leakage inductance occurs between the winding 28 and the windings 31 and 32, all of which comprise the coil 26, and may be represented for the purpose of this illustration as inductance 45 of Fig. 2. The capacitor 30 shunting the winding 28 serves to neutralize substantially one-half of the total amount of the leakage inductance 45. Also, a certain amount of leakage inductance occurs between the winding 35 and the windings 38 and 39, all of which constitute the coil 27, and may be represented for the purpose of this illustration as inductance 46 in Fig. 2. The capacitor 37 bridging the winding 38 serves to neutralize substantially one-half of the total amount of the leakage inductance 46.

In accordance with the invention as applied to Fig. 2, winding 50 adjustable as to the number of turns and embodied in the coil 26 and shunted by capacitor 51 selected similarly to capacitor 21 of Fig. 1 neutralizes substantially the portion of the leakage inductance 45 occurring in the coil 26 and remaining therein after the above-mentioned neutralizing action of the capacitor 30; and winding 52 adjustable as to the number of turns included in the coil 27 and bridged by capacitor 53 selected similarly to capacitor 21 of Fig. 1 neutralizes substantially the portion of the leakage inductance 46 occurring in the coil 27 and remaining therein after the previously pointed out neutralizing action of the capacitor 37. Consequently, the conjugate branches of the hybrid coil 25 are individually provided with substantially flat effective resistive and minimum reactive-frequency characteristics that are substantially identical with those of the respective line 54 and loads 29, 36 and 43, when the remaining windings are properly terminated, looking (1) into windings 31 and 38 from the carrier current line 54; or (2) into the winding 28 from the load 29; or (3) into the winding 35 from the load 36; and (4) into the windings 32 and 39 from the load 43.

Thus, the attenuation-frequency characteristics of the conjugate branches of the hybrid coil 25 tend to conform substantially with the corresponding attenuation-frequency characteristics of the carrier current line 54, and loads 29, 36 and 43, respectively. In other words, such neutralization of leakage inductance serves to balance the hybrid coil 25 like a bridge by providing similar impedances at the conjugate branches.

Accordingly, the neutralization of leakage inductance controls the reflection characteristic of the hybrid coil 25 so as to promote the operation of the entire carrier current system of Fig. 2 in the manner pointed out above in connection with Fig. 1. It is to be understood that winding 50 and capacitor 51 may also include the action of the capacitor 30 on the coil 26; and that the winding 52 and capacitor 53 may also include the action of the capacitor 37 on the coil 27, if desired. The advantage of splitting the capacity on each side of the leakage inductance is that the range of the hybrid coil is extended upwards in frequency.

Fig. 3 shows the invention applied to a hybrid coil 60 comprising a winding 61 shunted by a capacitor 62 and terminated in a load 63. Coupled to the winding 61 is a pair of windings 64 and 65 and load 66 applied in series across a pair of terminals 67, 67. Across one of the latter terminals and the midpoint of the windings 64 and 65 is connected a load 68. Across the terminals 67, 67 may be connected a source 57 of alternating current waves and a resistor 58 both of which simulate a carrier current line 59. This line together with the loads 63, 66 and 68 possesses substantially flat effective resistive and minimum reactive frequency characteristics for transmitting signaling waves extending over a certain range of frequencies with substantially uniform attenuation. Intermediate the winding 61 and the windings 64 and 65 is a shield 69 one end of which is applied to ground 70. A certain amount of leakage inductance occurs between the winding 61 and the windings 64 and 65, and may be represented for the purpose of this illustration as leakage inductance 71. The capacitor 62 shunting the winding 63 tends to neutralize substantially one-half of the total amount of the leakage inductance 71. The several windings are wound on a magnetic core 75.

In accordance with the invention as applied to Fig. 3, winding 72 adjustable as to the number of turns and shunted by capacitor 73 selected similarly to capacitor 21 neutralizes the portion of the leakage 71 occurring in the hybrid coil 60 and remaining therein after the aforedescribed neutralizing effect of the capacitor 62. Accordingly, the conjugate branches of the hybrid coil 60 are individually provided with substantially flat effective resistive and minimum reactive-frequency characteristics that are substantially identical with those of the respective line 59 and loads 63, 66 and 68, when the remaining windings are properly terminated, looking (1) into the network from the carrier current line 59, or (2) into the network from the load 68, (3) into the network from the load 66, and (4) into the winding 61 from the load 63.

Thus, the attenuation-frequency characteristics of the conjugate branches of the hybrid coil 60 tend to conform substantially with the corresponding attenuation-frequency characteristics of the carrier current line 57 and the loads 63, 66 and 68, respectively. This balances the hybrid coil 60 like a bridge as similar impedances are provided at conjugate branches. Consequently, the neutralization of leakage inductance controls the reflection characteristics of the hybrid coil 60 so as to promote the operation of the entire carrier current system of Fig. 3 in the manner discussed above regarding Fig. 1. It is to be understood that the winding 72 and capacitor 73 may also include the previously mentioned neutralizing action of the capacitor 62, if desired.

Although the illustrations of Figs 1, 2 and 3 show magnetic core coils, it is to be understood that the invention is not necessarily limited to such use as it will achieve equally satisfactory results with coils embodying air cores; and furthermore, the invention may be utilized to accomplish similar results with such coils in the frequency ranges of both voice and radio signaling waves.

In the above description, it has been assumed that the initial inductance is relatively high with respect to the load impedance. This is true of most line repeating coils which must meet severe modulation requirements. However, in other coils in which the mutual inductance has a more finite value, it may be sometimes advantageous to tune such inductance with a capacitor. In the latter connection, it is understood that the invention hereinbefore described may also be expeditiously utilized for this purpose.

What is claimed is:

1. In combination, in broad band inductance apparatus, a plurality of coupled inductance windings between which leakage inductance occurs, and means comprising an impedance network coupled to said plurality of windings to neutralize substantially said leakage inductance to provide said plurality of windings for signaling waves extending over a certain range of frequencies, looking into one pair of winding terminals applied to one load circuit having a preselected attenuation-frequency characteristic for transmitting said signaling waves extending over said frequency range when the other individual pairs of winding terminals are applied to other individual load circuits having attenuation-frequency characteristics substantially identical with that of said one load circuit with an attenuation-frequency characteristic which is substantially identical with the attenuation-frequency characteristic of said one load circuit to which said one pair of winding terminals is connected.

2. In the combination in broad band inductance apparatus according to claim 1, in which said impedance network comprises at least one further inductance winding adjusted as to the number of turns and coupled to said plurality of windings, and a capacitor applied across said further winding.

3. A broad band inductance apparatus, comprising a pair of coupled inductance windings between which leakage inductance occurs, and means comprising a tertiary inductance winding coupled to said pair of windings and a capacitor in shunt of said tertiary winding to control the reflection characteristic of said pair of windings such that said leakage inductance is substantially neutralized to provide said pair of windings for signaling waves extending over a certain range of frequencies, looking into individual windings, with a substantially flat effective attenuation-frequency characteristic that conforms substantially with a corresponding attenuation-frequency characteristic of individual networks to which individual windings of said pair of windings are connected and which transmit said signaling waves of said certain frequency range.

4. A broad band inductance apparatus, comprising two coupled inductance windings between which leakage inductance occurs, a tertiary inductance winding coupled to said two windings and a capacitor in shunt of said tertiary winding, said tertiary winding adjusted as to the number of turns and said capacitor proportioned to neutralize substantially said leakage inductance to provide said two windings for signaling waves extending over a certain range of frequencies, looking into one of said two windings, with substantially flat effective resistive and minimum reactive-frequency characteristics that conform substantially with corresponding resistive and minimum reactive-frequency characteristics of individual networks to which each of said two windings is connected and which transmit said signaling waves of said certain frequency range.

5. A broad band hybrid apparatus, comprising a pair of individual electrical coils, each of said coils embodying a plurality of coupled inductance windings between which leakage inductance occurs, one winding of said plurality of windings on each of said coils being terminated in one impedance having a preselected attenuation-frequency characteristic to transmit signaling waves extending over a certain range of frequencies, circuit means to connect serially a second winding on each of said coils to another impedance having an attenuation-frequency characteristic substantially identical with that of said one impedance and further circuit means to connect serially a third winding on each of said coils to a further impedance having an attenuation-frequency characteristic substantially identical with that of said one impedance, and impedance means on each of said coils to substantially neutralize said leakage inductance, comprising a further inductance winding coupled to said plurality of coupled windings, and a capacitor across said further winding, said impedance means proportioned to provide both said coils for said signaling waves extending over said certain range of frequencies, looking into said windings of both said coils to which windings individual impedances are connected with an attenuation-frequency characteristic that conforms substantially with

the corresponding attenuation-frequency characteristic of the individual impedances to which said windings of both said coils are connected.

6. A broad band hybrid coil, comprising a plurality of inductance windings between which leakage inductance occurs, a first winding having a termination in one impedance which possesses a preselected attenuation-frequency characteristic to transmit signaling waves extending over a certain range of frequencies, a second and a third winding connected to three other discrete impedances, whose attenuation-frequency characteristics are substantially identical with that of said one impedance, such that two of said other impedances are in series with both said second and third windings and a third of said other impedances is disposed in bridge of common points between said second and third windings and said two other impedances, said impedances constituting conjugate branches of said hybrid coil, and an impedance network to neutralize substantially said leakage inductance, comprising a further inductance winding coupled to said plurality of windings, and a capacitor across said further winding, said network proportioned to provide said hybrid coil for said signaling waves extending over said certain range of frequencies, looking into individual conjugate branches, with an attenuation-frequency characteristic that conforms substantially with the corresponding characteristics of the individual impedances to which the individual conjugate branches are connected.

7. In a broad band signaling wave transmission system including a plurality of discrete circuits, each having a substantially flat effective attenuation-frequency characteristic for signaling waves extending over a certain range of frequencies, inductance apparatus comprising at least one plurality of coupled inductance windings connecting operatively discrete circuits of said plurality of circuits with each other to transmit therebetween said signaling waves of said certain frequency range and having an indeterminate amount of leakage inductance between said coupled windings, and means comprising an inductance winding adjustable as to the number of turns and coupled to each said plurality of windings and a capacitor applied across each said adjustable winding to control the reflection characteristic of said plurality of windings by neutralizing substantially said leakage inductance so that said plurality of windings, looking in one winding of said plurality of windings while the other windings thereof are applied to other circuits of said plurality of discrete circuits, possesses a substantially flat effective attenuation-frequency characteristic that conforms substantially with the corresponding characteristic of said one circuit to which said one winding is connected.

8. In a broad band signaling wave transmission system including a pair of discrete circuits, each having a substantially flat effective attenuation-frequency characteristic for signaling waves extending over a certain range of frequencies, inductance apparatus comprising a pair of coupled inductance windings between which leakage inductance occurs and connecting said pair of circuits such that individual windings are connected to individual circuits to transmit therebetween said signaling waves of said certain frequency range, and means comprising a further inductance winding adjustable as to the number of turns and coupled to said pair of windings and a capacitor in shunt of said further winding to control the reflection characteristic of said apparatus by neutralizing said leakage inductance so that said pair of windings, looking into one of said pair of windings while the other winding thereof is terminated in one of said pair of circuits, with a substantially flat effective attenuation-frequency characteristic that conforms substantially with the corresponding characteristic of the circuit to which said one winding is connected.

9. In a broad band signaling wave transmission system comprising a plurality of discrete circuits, each having a substantially flat effective attenuation-frequency characteristic for signaling waves extending over a certain range of frequencies, a hybrid apparatus comprising a pair of individual electrical coils, each coil embodying a plurality of coupled windings between which leakage inductance exists, said hybrid apparatus being connected to said circuits to transmit therebetween said signaling waves of said certain frequency range such that a first winding of each coil is connected to one circuit, a second winding of each coil is connected to another circuit, and a third winding of each coil is connected to a further circuit, and means comprising a further inductance winding adjustable as to the number of turns and coupled to said windings of each of said pair of coils and a capacitor in shunt of said further winding to control the reflection characteristic of said hybrid apparatus by neutralizing substantially said leakage inductance so that said hybrid apparatus, looking into winding terminals connected to one discrete circuit while the remaining winding terminals are applied to other discrete circuits, is provided with a substantially flat effective attenuation-frequency characteristic that conforms substantially with said corresponding characteristic of the one discrete circuit to which said looked-into winding terminals are connected.

10. In a broad band signaling wave transmission system comprising a plurality of discrete circuits, each having a substantially flat effective attenuation-frequency characteristic for signaling waves extending over a certain range of frequencies, a hybrid coil comprising a plurality of coupled windings between which leakage inductance exists and connecting said plurality of circuits to transmit therebetween said signaling waves of said certain frequency such that one circuit is connected to a first winding, two other circuits are serially connected to second and third windings disposed in series, and a further circuit is connected in bridge of common points of said two other circuits and said second and third windings, said circuits constituting conjugate branches of said hybrid coil, and means comprising a further inductance winding adjustable as to the number of turns and coupled to said windings and a capacitor in shunt of said further winding to control the reflection characteristic of said hybrid coil by neutralizing substantially said leakage inductance to provide said hybrid coil, looking into the winding terminals connected to one discrete circuit while the remaining winding terminals are applied to other discrete circuits, with a substantially flat effective attenuation-frequency characteristic that conforms substantially with said corresponding characteristic of the one discrete circuit to which said looked-into winding terminals are connected.

NELSON BOTSFORD.