

Feb. 7, 1933.

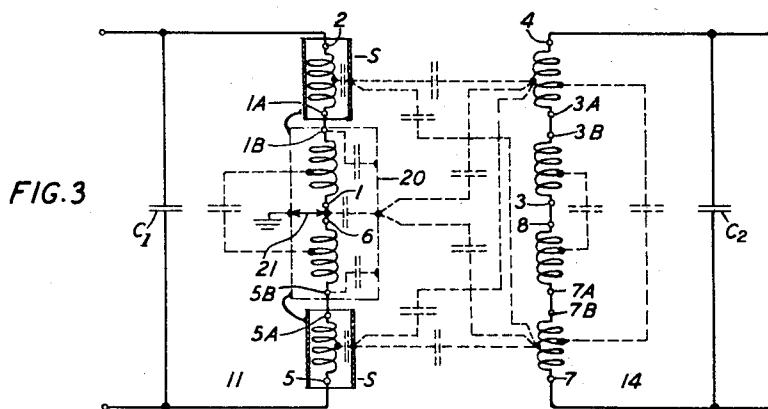
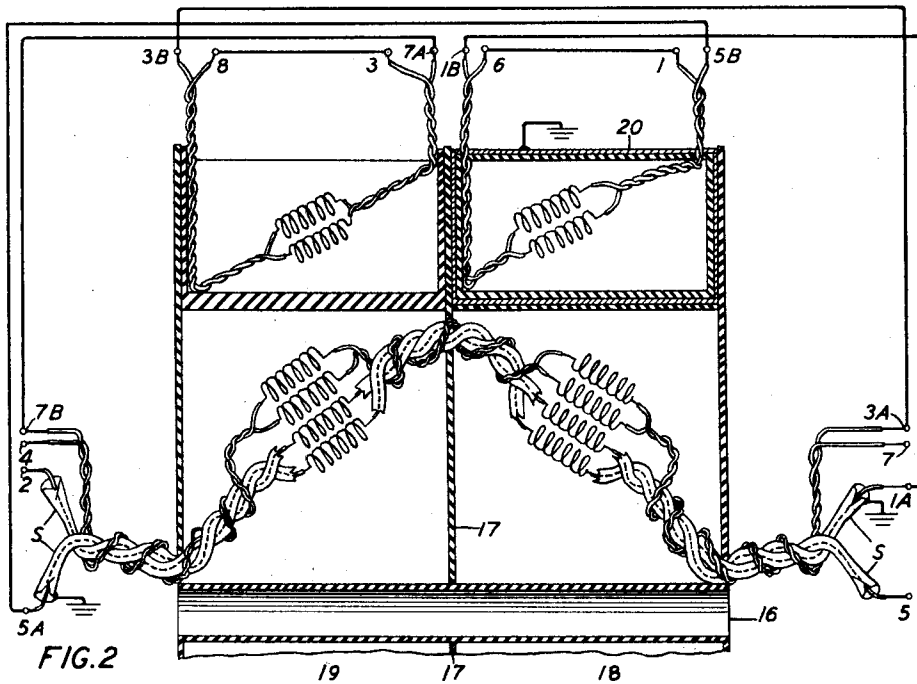
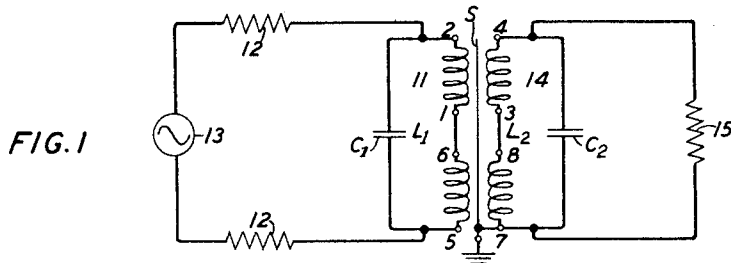
A. J. CHRISTOPHER

1,896,480

BALANCED INDUCTANCE DEVICE

Filed June 29, 1931

3 Sheets-Sheet 1



INVENTOR
A.J. CHRISTOPHER
BY *H.A. Burgess*
ATTORNEY

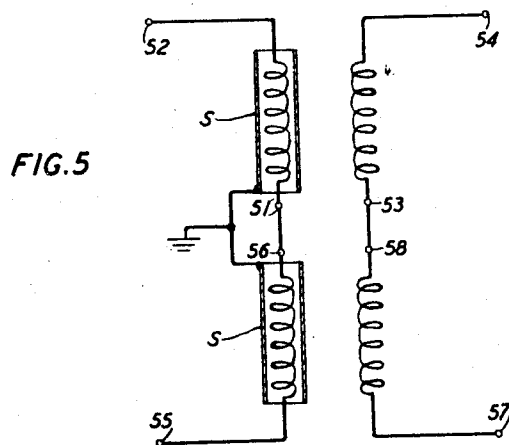
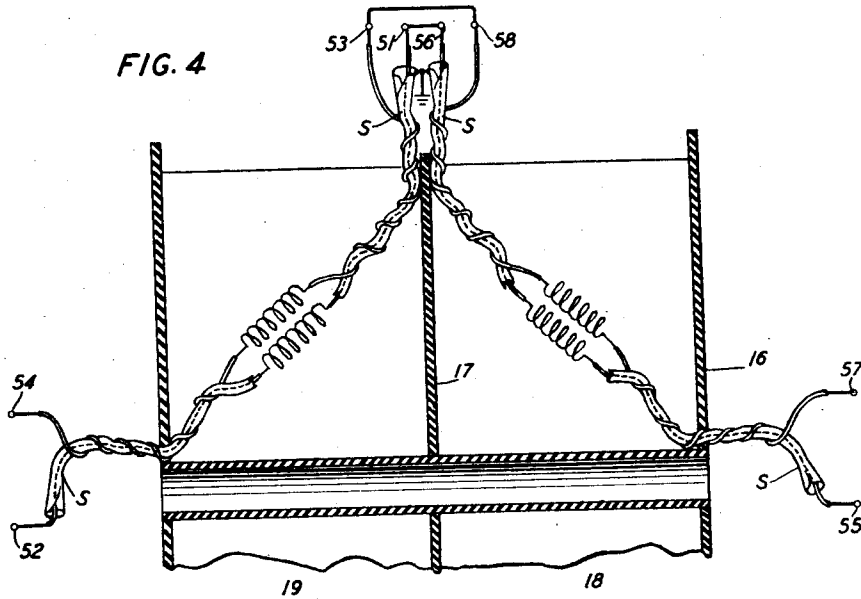
Feb. 7, 1933.

A. J. CHRISTOPHER
BALANCED INDUCTANCE DEVICE

1,896,480

Filed June 29, 1931

3 Sheets-Sheet 2



INVENTOR
A. J. CHRISTOPHER
BY *H. A. Burgess*
ATTORNEY

Feb. 7, 1933.

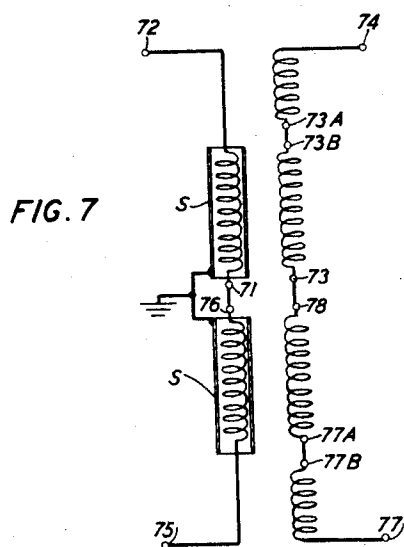
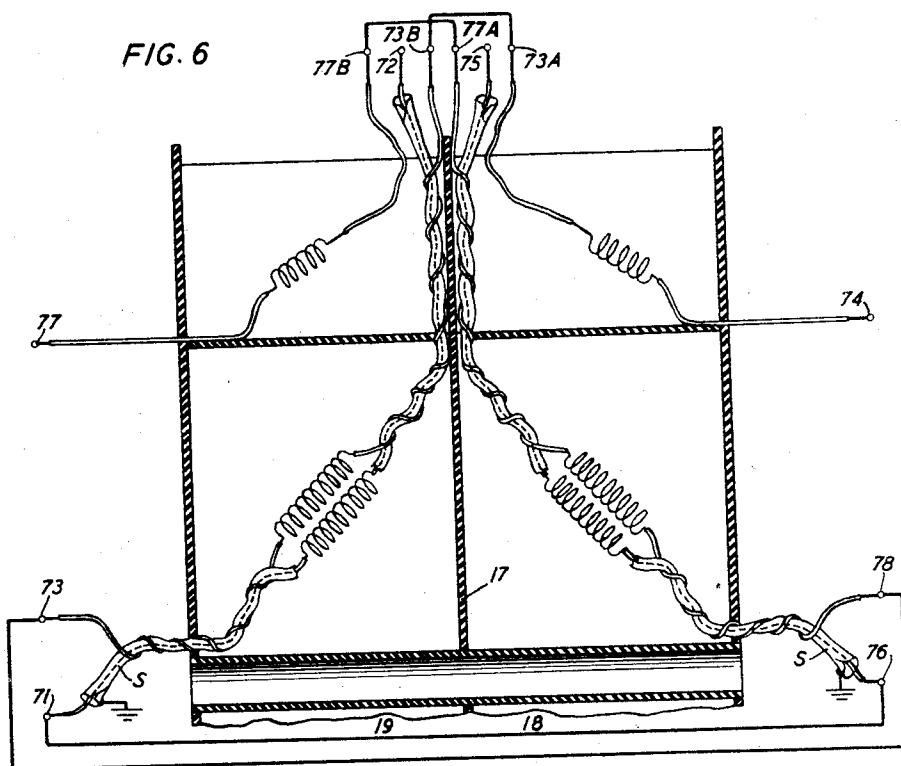
A. J. CHRISTOPHER

1,896,480

BALANCED INDUCTANCE DEVICE

Filed June 29, 1931

3 Sheets-Sheet 3



INVENTOR
A. J. CHRISTOPHER
BY *H. A. Burgess*
ATTORNEY

UNITED STATES PATENT OFFICE

ARTHUR J. CHRISTOPHER, OF TEANECK, NEW JERSEY, ASSIGNOR TO BELL TELEPHONE LABORATORIES, INCORPORATED, OF NEW YORK, N. Y., A CORPORATION OF NEW YORK

BALANCED INDUCTANCE DEVICE

Application filed June 29, 1931. Serial No. 547,618.

This invention relates to inductance devices and more particularly to those comprising a plurality of windings.

An object of the invention is to provide an air core repeating coil or transformer which has a low transmission loss and a low reflection coefficient at frequencies within the so called carrier frequency range.

Another object of the invention is to provide an air core repeating coil or transformer which has a high degree of coupling between the primary and secondary windings thereof, and at the same time an electrostatic shield between the windings to prevent the passage of noise or longitudinal currents from the primary to the secondary winding.

Another object of the invention is to provide an air core repeating coil in which are combined the properties of voltage transformation and of broad band frequency selectivity.

A feature of the invention is a winding arrangement for a repeating coil or transformer in which two primary and two secondary windings are applied partly as a quad and partly as individual twisted pairs.

Another feature comprises a winding arrangement in which the primary winding or windings are placed inside of a hollow or cylindrical conductor or conductors and the secondary winding or windings are twisted with the hollow or cylindrical conductor or conductors.

Another feature of the invention is the proportioning of the number of turns of the primary and secondary windings which are twisted together, and the number of turns of the primary and secondary windings which are separately applied to secure the desired object.

The equivalent performance of a broad band pass filter can be obtained in accordance with the invention by designing the air core repeating coil so that it has windings with proper self-impedance values, proper coupling coefficient between the primary and secondary windings and, when required, adding shunt capacities across the primary and secondary windings. The theory of such an arrangement is the same as that given in

United States Patent No. 1,714,149, dated May 21, 1929, granted to H. Whittle and me, jointly.

The following formulæ, the development of which was explained in the United States Patent No. 1,714,149, referred to above can be applied to the design of repeating coils in accordance with this invention.

(1) Coefficient of coupling

$$k = \frac{f_2^2 - f_1^2}{f_2^2 + f_1^2}$$

(2) Resonance frequency

$$f_0 = \frac{\sqrt{2}f_1f_2}{\sqrt{f_1^2 + f_2^2}}$$

(3) Minimum value of W_a , denoted by $W_{a,m}$

$$W_{a,m} = \sqrt{\frac{L_1}{C_1}} \times \frac{f_0}{f_2 - f_1}$$

(4) Primary inductance

$$L_1 = \frac{W_{a,m}}{2\pi f_0} \times \frac{f_2 - f_1}{f_0} = \frac{1}{4\pi^2 f_0^2 C_1}$$

(5) Primary capacity

$$C_1 = \frac{1}{2\pi(f_2 - f_1)W_{a,m}}$$

$W_{a,m}$, which is the minimum value of the image impedance W_a of the coupling circuit, is chosen as approximately equal to the terminating resistances R which are equal in this case. C_1 is the effective shunt capacity across the primary or secondary winding including the effective distributed capacity of these windings. f_1 and f_2 are respectively the lower and upper limiting frequencies. k is the coefficient of coupling. f_0 is the resonant frequency. L_1 is the primary inductance. W_a is the image impedance of the coupling circuit to which the primary winding of the receiving coil is connected and is equal to the secondary inductance. $W_{a,m}$ is the minimum value of W_a .

From equation (1) it will be found that k is approximately equal to .975 where f_2 is to have a value of 35 kilocycles and f_1 a value of 4 kilocycles. It is impossible to

obtain this value of k with the winding arrangement as employed in the prior art on air core coils. However, by winding the repeating coil in accordance with one of the
 5 embodiments of the invention as described below, this value of k can be obtained. In winding the repeating coil, the first part is applied as a quad (two primary and two
 10 secondary windings twisted together) which is applied with approximately equal turns in each section of a two-section spool. The two primary windings and the two secondary
 15 windings, each consisting of a twisted pair, are then separated, the two primary windings being applied over the quadded section in one section of the spool, while the
 20 two secondary windings are applied over the quadded section in the other section of the spool. This results in an arrangement in which part of the primary winding is closely
 25 coupled with the secondary in the quadded section and loosely coupled in the outer section. By properly proportioning the number of turns in the quadded and outer sections
 30 of the windings, a wide variation in the leakage inductance or coupling factors can be obtained for a predetermined value of self-impedance of the individual windings to satisfy equation (1) above. External
 35 condensers may be added when required across the primary and secondary windings so that their value plus the effective shunt capacity of the windings will satisfy equation (5) above.
 40 With winding arrangements such as described above, it is impossible to electrostatically shield the primary windings from the secondary windings by the usual methods employed in the prior art. However, in accordance
 45 with another embodiment of the invention it is possible to construct a repeating coil having a high coupling coefficient, and at the same time having its primary winding electrostatically shielded from the
 50 secondary winding. This is accomplished by employing a shielded conductor, or a twisted pair of wires enclosed in a shield, and twisting the shielded conductor or conductors with the conductor or conductors
 55 which form the secondary windings, before applying the windings to the spool. Preferably the shield is grounded at the midpoint of the windings. The longitudinal current flowing from the circuit to which the shielded
 60 winding is connected to ground will pass from the shielded winding to the shield and as the flux created by the current flowing in the shield will be opposite in the two halves
 65 of the shield, the resultant impedance to the flow of these currents through the shield can be made very small. However, only longitudinal current will flow through the shield surrounding the conductors as the shield will
 assume practically the same potential as the

winding which it shields all along its length with respect to the transmitted voltage.

The invention will be better understood by reference to the following detailed description and accompanying drawings in which:

Fig. 1 is a conventional schematic representation of a coupling circuit in which the invention may be embodied;

Fig. 2 is a cross-sectional view of a repeating coil showing the method of applying the
 75 windings over the core in accordance with one embodiment of the invention;

Fig. 3 is a conventional schematic representation of the repeating coil shown in
 80 Fig. 2;

Fig. 4 is a cross-sectional view of a repeating coil showing the method of applying the windings over the core in accordance with
 85 another embodiment of the invention;

Fig. 5 is a conventional schematic representation of the repeating coil shown in
 90 Fig. 4;

Fig. 6 is a cross-sectional view of a repeating coil showing the method of applying the winding over the core in accordance with still
 95 another embodiment of the invention; and

Fig. 7 is a conventional schematic representation of the repeating coil shown in
 100 Fig. 6.

Referring to Fig. 1 the coupling circuit
 105 comprises an anti-resonant circuit 11 connected through equal impedances 12 to a source of variable voltage 13 and a second anti-resonant circuit 14 inductively coupled to circuit 11 and connected to an output impedance 15. Circuits 11 and 14 preferably
 110 comprise the primary and secondary windings respectively of an air core repeating coil as shown in Figs. 2 and 3 and are preferably proportioned to resonate at substantially the
 115 same resonant frequency. The primary and secondary windings are preferably electrostatically shielded from each other by a grounded shield S to which shield one end of the secondary winding is preferably
 120 connected. When the electrostatic shield S is not used the midpoint 6, 1 of the primary winding is preferably grounded. The coefficients of capacity elements in the anti-resonant circuits 11 and 14 are C_1 and C_2 , respectively, and the inductances are L_1 and L_2 , respectively. C_1 and C_2 are preferably made
 125 equal to each other and preferably comprise the effective shunt capacity across the primary winding 5, 6, 1, 2 and secondary winding 7, 8, 3, 4 respectively, although individual capacities may be added when required across the primary and secondary windings to obtain the proper value of capacity. The inductances L_1 and L_2 of the primary and secondary windings are preferably made equal
 130 to each other and the sum of the two impedances 12 is equal to impedance 15.

The air core repeating coil shown in Figs. 2 and 3 preferably comprises a spool 16 hav-

ing a central partition 17 forming spool sections 18 and 19. A primary winding 5, 5—A, 5—B, 6, 1, 1—B, 1—A, 2 and a secondary winding 7, 7—B, 7—A, 8, 3, 3—B, 3—A, 4 are applied over the spool. The primary winding is preferably made up of four sections 5, 5—A; 5—B, 6; 1, 1—B; and 1—A, 2, with the terminals 5—A connected to 5—B, 6 connected to 1 and 1—B connected to 1—A so that the sections are connected in series aiding relation. The secondary winding is preferably made up of four sections 7, 7—A; 7—B, 8; 3, 3—B; and 3—A, 4, with the terminals 7—A connected to 7—B, 8 connected to 3 and 3—B connected to 3—A so that the sections are connected in a series aiding relation. The conductors forming the sections 5, 5—A and 1—A, 2 of the primary winding and those forming the sections 7, 7—B and 3—A, 4 of the secondary winding are preferably twisted together to form a quad. One-half of the quadded winding is applied in the spool section 18 and the other half in the spool section 19, the two halves being wound in opposite directions and the outer terminals of the conductors in each spool section connected together. The conductors forming the sections 5—B, 6 and 1, 1—B of the primary winding are preferably twisted together to form a pair and wound in section 18 over the quadded winding. The conductors forming the sections 7—B, 8 and 3, 3—B of the secondary winding are preferably twisted together to form a pair and wound in the section 19 over the quadded winding.

The individual conductors forming the sections 5, 5—A and 1—A, 2 are preferably surrounded by individual electrostatic shields S concentric with the conductors, which shields are applied before the conductors are formed into a quad. The ends of the shields S are connected together adjacent the connections of the terminals of the concentric conductors therein as shown in Fig. 3. The sections 5—B, 6, 1, 1—B of the primary winding are preferably enclosed in an electrostatic shield 20, which shield 20 is connected to the electrostatic shields S as shown in Fig. 3.

If desired the conductors forming the sections 5, 5—A and 1—A, 2 may be formed of a twisted pair enclosed in a shield concentric with the twisted pair.

When it is unnecessary to have the primary and secondary windings electrostatically shielded from each other, concentric shields S and the shield 20 may be omitted.

In a specific embodiment of the invention constructed the conductors forming the winding sections 5, 5—A; 1—A, 2; 7, 7—B; and 3—A, 4 were formed in a quad and 190 turns of the quadded conductors were applied in each spool section, the conductors forming the winding sections 5—B, 6 and 1, 1—B

were formed in a pair and 60 turns of the paired winding were applied over the quadded winding in one spool section and the conductors forming the winding sections 7—A, 8 and 3, 3—B were formed in a pair and 60 turns of the paired winding were applied over the quadded winding in the other spool section. The individual sections of the primary winding and the individual sections of the secondary winding were connected together in a series aiding relation.

Each of the individual conductors comprised No. 24 double cotton covered copper wire. No individual electrostatic shields concentric with the conductors were employed in this particular embodiment. The spool was formed from wood, the core being circular and having a diameter of $2\frac{1}{2}$ inches. Each of the two spool sections was $\frac{7}{8}$ inch wide and $1\frac{3}{4}$ inches deep. The central partition between the two spool sections was $\frac{1}{8}$ inch wide.

Tests made on this coil showed a transmission loss over a range of frequencies from 5KC to 30KC of less than one decibel and a variation in transmission loss of less than one-half decibel. The reflection coefficient over the same frequency range was less than 20%.

In Fig. 3 the inherent capacities existing between the sections of the primary and secondary windings and between the shields S and 20 and the windings are shown. These capacities between the individual sections of the secondary winding are symmetrical with respect to the center and ends of the winding; the capacities between the individual sections of the primary winding are symmetrical with respect to the center and ends of the winding; and the capacities between the shield sections S and 20 and the primary and secondary windings are symmetrical to the shield 20 at the ground connection thereto.

The longitudinal currents flowing from the source 13 through the two balanced impedances 12, to which the shielded primary winding 5, 6, 1, 2 is connected will flow from this winding to the shields S and 20 and to ground and as the fluxes created by the currents flowing in the shields S will be substantially equal and opposite in the two sections 18 and 19 of the spool 16, the resultant impedance through the shields S to this long current is very small. This substantially eliminates stray circulating currents in the secondary winding due to longitudinal current present in the primary side of the circuit. As the shield sections S will have the same potential as the concentric conductors of the primary winding therein, only longitudinal currents will flow through the hollow conductor shields S.

The midpoint 6, 1 of the primary winding may be grounded when the primary winding of the repeating coil is connected to a balanced circuit by the connection 21.

By varying the number of turns in the sections 5, 5—A, and 1—A, 2 of the primary winding the number of turns in the sections 7, 7—B and 3—A, 4 of the secondary winding, which sections are wound as a quad, with respect to the number of turns in the sections 5—B, 6 and 1, 1—B of the primary winding and the number of turns in the sections 7—B, 8 and 3, 3—B of the secondary winding, a large variation in the coupling coefficient may be obtained.

The repeating coil shown in Figs. 4 and 5 comprises a primary winding 55, 56, 51, 52 and a secondary winding 57, 58, 53, 54 wound on a spool 16 having a central partition 17 to form spool sections 18 and 19. Each of the sections 55, 56 and 51, 52 of the primary winding is preferably enclosed in an individual electrostatic shield S which is concentric with the conductor forming the individual section. The section of the secondary winding 57, 58 and the section of the primary winding 55, 56 with its concentric shield are preferably twisted together and wound in the spool section 18 and the section 51, 52 of the primary winding with its concentric shield and the section 53, 54 of the secondary winding are preferably twisted together and wound in the spool section 19 in an opposite direction to that of the winding in the spool section 18. The outer terminals of the winding sections are connected together as shown and the ends of the concentric shields S surrounding the primary winding are connected together and to ground at the outer ends of the windings in the two spool sections 18 and 19.

This construction provides a high degree of coupling, especially in the case of an air core coil and also prevents noise or longitudinal currents from passing from the primary winding to the secondary winding.

The repeating coil shown in Figs. 6 and 7 comprises a spool 16 having a partition 17 forming spool sections 18 and 19, a primary winding 75, 76, 71, 72 and a secondary winding 77, 77—B, 77—A, 78, 73, 73—B, 73—A, 74. Each of the winding sections 75, 76 and 71, 72 of the primary winding is preferably enclosed in an individual electrostatic shield S which is concentric with the conductor forming the individual winding section. Sections 71, 72 of the primary winding and 73, 73—B of the secondary winding are preferably twisted together and wound in the spool section 19. Sections 75, 76 and 77—A, 78 of the secondary winding are preferably twisted together and wound in the spool section 18 in an opposite direction to that of the winding in spool section 19. The inner terminals 71 and 76 of the primary winding sections are connected together and the inner terminals 73 and 78 of the secondary winding sections are connected together as shown. The shield sections S are connected together

and to ground adjacent the terminals 76 and 71. Each of the winding sections 73—A, 74 and 77, 77—B of the secondary winding comprises a relatively few turns which are employed to adjust the coupling coefficient to the desired value to obtain uniform transmission over a range of frequencies and a low reflection coefficient. The winding section 73—A, 74 is preferably wound in spool section 18 over the twisted pair of windings and the winding section 77, 77—B is preferably wound in the spool section 19 over the twisted pair. These winding sections 73—A, 74 and 77, 77—B are connected in a series aiding relation to the secondary winding sections 73, 73—B and 78—77—A as shown.

When it is unnecessary to electrostatically shield the primary and secondary windings from each other the shields S may be omitted.

No attempt has been made to draw the repeating coils shown in Figs. 2, 4 and 6 to scale. When desired, magnetic core material may be used with the repeating coils having their windings applied and shielded as shown in Figs. 2 to 7 inclusive.

While several specific embodiments of the invention have been shown and described in detail it is to be understood that the invention is generic in character and is not to be limited to the particular embodiments since numerous modifications thereof may be made by persons skilled in the art without departing from the spirit of applicant's invention, the scope of which is to be determined by the appended claims.

What is claimed is:

1. An inductive device comprising a spool and two primary and two secondary windings thereon, said windings being applied to said spool partly as a quad comprising turns of both primary and secondary windings and partly as individual twisted pair primary turns and twisted pair secondary turns.
2. An inductance device comprising a plurality of conductors twisted together to form a unitary cord, and means for reducing the direct electrostatic capacity between one of said conductors and at least one other of said conductors, said means comprising a hollow conductor concentric with and insulated from said one conductor to electrostatically shield said one conductor from the other of said conductors.
3. A repeating coil comprising a non-magnetic spool having two winding sections and two primary and two secondary windings thereon, said windings being applied partly as a quad with approximately an equal number of turns in each winding section and partly as individual twisted pair primary and secondary windings with the twisted pair primary winding portion wound in one of said winding sections over the quadded winding portion and the twisted pair secondary winding portion wound in the other of said

winding sections over said quadded winding portion.

4. A repeating coil comprising a spool and at least one primary and one secondary winding thereon, said primary and secondary windings being applied partially as a unitary cord formed of twisted conductors and partially with said primary and secondary windings as individual units separated from each other.

5. An inductance device comprising primary and secondary windings, each of said windings comprising a plurality of sections, the conductor or conductors of at least one of said sections of said primary winding being twisted together with the conductor or conductors of at least one of said sections of said secondary winding, and means to electrostatically shield at least one of said twisted primary and secondary sections from each other, said means comprising an electrostatic shield coaxial to and surrounding one of said conductors.

6. A repeating coil comprising a spool and at least one primary and one secondary winding thereon, said primary and secondary windings being applied partially as a unitary cord formed of twisted conductors and partially with said primary and secondary windings separated from each other, and means to electrostatically shield at least a portion of the conductor forming one of said windings from a portion of the conductor forming the other of said windings, said means including a coaxial shield surrounding the portion of said one conductor which is applied as a unitary cord with said portion of said other conductor.

7. An inductance device having a band frequency characteristic comprising a spool and at least one primary and one secondary winding thereon, part of said primary and secondary windings being applied as a unitary cord in a manner such that a low leakage inductance between the windings is obtained and another part of said windings being applied as individual primary and secondary conductors so that a high leakage inductance between said windings is obtained.

In witness whereof, I hereunto subscribe my name this 26th day of June, 1931.

ARTHUR J. CHRISTOPHER.