

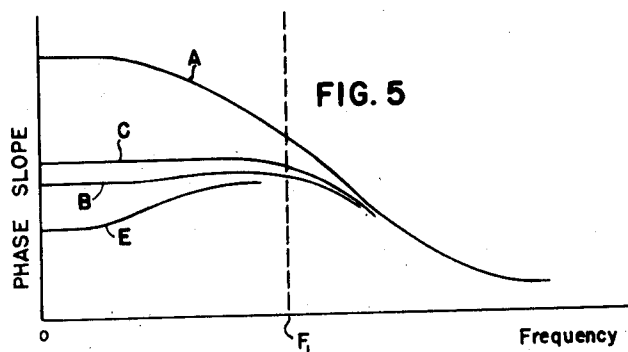
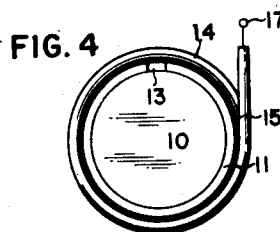
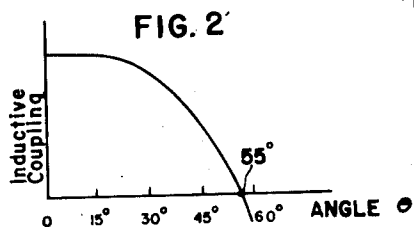
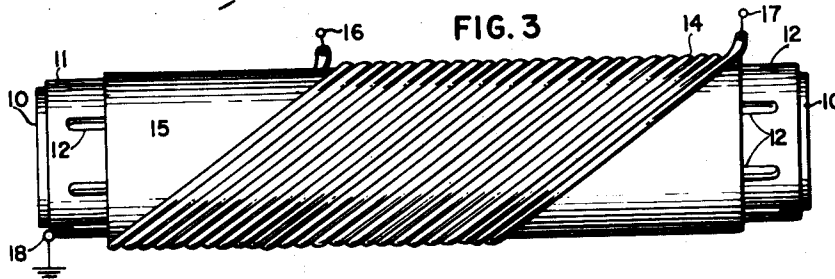
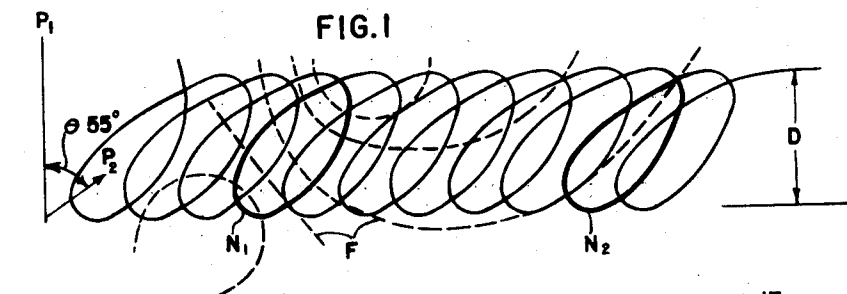
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ELONGATED COIL TIME DELAY NETWORK

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ELONGATED COIL TIME DELAY NETWORK

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This invention is directed to an elongated coil having a plurality of coil turns distributed along its longitudinal axis in a manner to reduce the inductive coupling between turns having an axial spacing at least equal to the coil diameter. As used throughout this specification and in the appended claims, the term "coil diameter" is intended to mean the coil dimension as measured in a plane normal to its longitudinal axis. While the invention is subject to a variety of applications, it is especially suited for use in a time-delay network and will be particularly described in that connection.

One well-known form of time-delay network is the so-called "three-terminal" type. It is essentially an unbalanced circuit, including a single distributed winding or coil insulated from but electrically coupled along its length to a conductive member, such as a conductive core structure, to establish distributed series inductance and distributed shunt capacitance in the network. An input and an output terminal are provided at the opposite ends of the coil, while a third or common terminal is coupled with the core structure and usually takes the form of a ground connection. Such a network simulates a transmission line and has a time delay proportional to the geometric mean of its total effective series inductance and its total effective shunt capacitance. Where long delays are to be realized with structures of practical and useful physical dimensions, the coil has a larger number of turns per unit length.

Prior arrangements of the type referred to are satisfactory for many installations but are subject to a particular type of phase distortion which may be undesirable in certain applications. In the usual construction the coil turns are approximately normal to the coil axis and the magnetic field of each turn cuts most of the remaining turns. As a consequence, a large inter-turn inductive coupling is established and it may be shown that the phase distortion mentioned is primarily caused by this coupling. The distortion is evidenced by the phase slope decreasing at high frequencies. It is especially pronounced when translating pulses have a duration less than the delay of the network. Prior arrangements have been proposed to minimize the inter-turn inductive coupling and improve the phase characteristics of the network. In one known construction, the coil has a very large ratio of length-to-diameter but this is undesirable in that it greatly increases the physical length necessary to obtain a required time delay.

It is an object of the present invention, there-

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fore, to provide an improved elongated coil which substantially avoids one or more of the above-mentioned limitations of prior arrangements.

It is another object of the invention to provide a simplified coil structure including a plurality of coil turns arranged so that a minimum inductive coupling is established between turns having an axial separation at least equal to the coil diameter.

It is a specific object of the invention to provide a time-delay network including an improved coil structure arranged to obtain a substantially uniform phase slope over a selected operating frequency range.

An elongated coil in accordance with the invention exhibits a predominantly reactive impedance and has a longitudinally extending axis, a certain diameter in a plane normal to the axis, and an axial length exceeding its diameter. The coil comprises a plurality of turns distributed along its axis and angularly displaced with reference to the aforesaid normal plane by an angle of at least thirty degrees so that the inductive coupling of each coil turn with any other coil turn, axially spaced therefrom by a distance at least equal to the coil diameter, is substantially less than the coupling between turns having the same axial separation but positioned normal to the axis. The coil turns have a circular shape when viewed in end elevation from a point normal to the axis thereof. The expression "predominantly reactive impedance" as used here and in the appended claims is intended to mean that the coil proposed by this invention is in the art of reactance design in which the reactance device is constructed to have as little resistance as possible.

For a better understanding of the present invention, together with other and further objects thereof, reference is had to the following description taken in connection with the accompanying drawing, and its scope will be pointed out in the appended claims.

In the drawing, Fig. 1 is a schematic representation of an elongated coil in accordance with the invention; Fig. 2 is a curve utilized in explaining the inductance characteristic thereof; Fig. 3 represents a time-delay network including a coil structure of the type illustrated in Fig. 1; Fig. 4 is an end view of the time-delay network; and Fig. 5 comprises graphs utilized in discussing the phase characteristics of the time-delay network.

Referring now more particularly to Fig. 1, there is represented schematically an elongated coil constructed in accordance with the present in-

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vention. This coil has a longitudinally extending or horizontal axis and a uniform maximum diameter, indicated by dimension line D, measured in a plane normal to its longitudinal axis. The coil has an axial length greatly exceeding its diameter D and is comprised of a plurality of identical turns distributed along its longitudinal axis. The turns are angularly displaced with reference to the aforesaid normal plane by such an angle that the inductive coupling of each coil turn with any other turn axially spaced therefrom by a distance at least equal to the diameter D is controlled in a particular manner, presently to be described. The angular relation of each coil turn with the normal plane is designated in Fig. 1 by the angle θ between direction arrows P_1 and P_2 , representing the normal plane and the plane of the coil turns, respectively. The determination of angle θ will be clear from a consideration of the inductive coupling between turns of the coil.

As is well understood, current flow in any coil turn produces a magnetic field. Where the magnetic field links any of the other coil turns, a mutual inductive coupling is established between such turns. In prior coil constructions the angle θ has very small values so that the coil turns are approximately normal to the longitudinal axis. In such constructions a maximum flux linkage of the several coil turns results, establishing a maximum value of inter-turn inductive coupling. This is indicated by the flat portion of the curve of Fig. 2 which illustrates, as a function of the angle θ , the variation in inductive coupling between any coil turn and coil turns axially spaced therefrom by a distance at least equal to the coil diameter D. In accordance with the present invention, the inter-turn inductive coupling of the coil is controlled, as required for any given installation, by appropriately adjusting the angle θ . In one embodiment especially useful as a time-delay network, the inter-turn inductive coupling is reduced by using a critical value of angle θ such that substantially no coupling is present between coil turns having an axial spacing at least equal to the diameter D. The critical value of angle θ is approximately fifty-five degrees and is shown in Fig. 1. It establishes a coupling condition analogous to the zero-coupling relationship of two discrete and spaced coils fully described in the United States Letters Patent 1,577,421 issued March 16, 1926, to Louis A. Hazeltine and assigned to the same assignee as the present invention.

With the critical angle of fifty-five degrees, the flux distribution resulting from current flow in a particular coil turn N_1 may be indicated by the broken lines F of Fig. 1. This flux cuts the coil turns in the immediate vicinity of turn N_1 and establishes a substantial inductive coupling therebetween. However, coil turns, such as that designated N_2 , spaced from the turn N_1 by a distance equal to or greater than the diameter D are not linked therewith to any appreciable extent because the flux lines F which extend as far as this turn, for the most part, pass completely around or completely within it. The total effective inductance of the distributed coil will then be seen to be equal to the self-inductance of its several turns plus the mutual inductance contributed by the mutual coupling which exists only between each coil turn and its immediate neighboring turns.

While the angle θ for the Fig. 1 embodiment has the critical value, a coil constructed in ac-

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cordance with the invention is not limited to this specific angular relationship. In general, the angle θ may have any value such that the inductive coupling of each coil turn with any other turn axially spaced therefrom by a distance equal to the diameter D is substantially less than the coupling which would exist between coil turns having the same axial separation but positioned normal to the axis. From the curve of Fig. 2 it will be apparent that a substantial reduction in inductive coupling between such coil turns is obtained with values of θ at least equal to thirty degrees.

Fig. 3 represents a time-delay network including an elongated coil of the present invention. The network comprises an elongated core structure having a supporting core member 10 of insulating material and uniform cross section throughout its length. A conductive sleeve 11 is supported by the core 10 and is preferably formed of a material having a high conductivity, such as copper. The sleeve has a plurality of longitudinally extending slots 12, 12 extending throughout the major portion of its length. As shown in the end view of Fig. 4, sleeve 11 is discontinuous, having a split or slot 13 extending throughout its length to minimize eddy-current losses within the core structure. The network also includes an elongated coil 14 generally similar to that of Fig. 1. The coil turns are distributed along conductive member 11 and are insulated from but electrically coupled thereto to provide in the network distributed shunt capacitance. For this purpose, an insulating sleeve or tape 15 is interposed between the coil and conductive member 11, although this insulation may be omitted where the insulation of the coil 14 has sufficiently high dielectric properties. Member 11, for the case under consideration, is nonmagnetic so that the magnetic field distribution established by the turns of coil 14 is substantially undisturbed or undistorted by the presence of the core structure.

In assembling the network it may be convenient to apply an adhesive coating to the coil conductor so that after the coil is wound over the core structure it may be dried in place to retain the desired angular relationship of the coil turns. Alternatively, guide slots may be provided to retain the coil turns in this angular relationship. An input terminal 16 is formed at one end of winding 14 and an output terminal 17, for deriving delayed signals from the network, is provided at its opposite end. Conductive member 11 is connected to a third or common terminal 18 which usually is a ground connection, as illustrated. It will be seen from the end view of the time-delay network represented in Fig. 4 of the drawings that the coil turns have a circular shape when viewed in end elevation from a point normal to the axis thereof.

The described arrangement will be seen to constitute an unbalanced or three-terminal network. It is said to be a three-terminal network since it comprises an input terminal 16, an output terminal 17, and a common terminal 18. This network essentially constitutes a simulated transmission line having distributed series inductance provided by the coil 14 and distributed shunt capacitance consisting of the distributed capacitance of coil 14 with conductive member 11. The total time delay of the network is proportional to the geometric means of its total effective series inductance and total effective shunt capacitance. The diameter and length of the core structure,

the size and type conductor utilized in fabricating coil 14, and the number of coil turns are selected to afford such values of series inductance and shunt capacitance that the network produces a desired total time delay. In this connection, it will be appreciated that an increase in the diameter of the core structure and coil results in higher values of inductance and capacitance, while increasing the number of turns increases primarily the inductance.

Such a network, including an elongated coil in accordance with a preferred form of the present invention, has an approximately uniform phase slope over a selected operating frequency range wide enough to preserve the shape of a pulse signal having a duration much less than the network delay. The phase characteristic will be fully explained with reference to the curves of Fig. 5. These curves designate the envelope delay, which is equal to the phase slope or the rate of change of phase angle with angular frequency, of time-delay networks of the type under consideration.

Curve A shows the phase slope for a prior network arrangement wherein the coil turns are positioned approximately normal to the longitudinal axis of the coil. Usually, the self-inductance and mutual inductance of various sections of the coil are regarded as constant because uniform current distribution therealong is ordinarily assumed. However, in time-delay network applications, there is a continual increase in the lagging phase angle along the coil from the input to the output terminals. The phase angle from one end to the other may be several complete cycles at the high frequencies of the network pass band so all phases of current may be present simultaneously in different axially spaced sections of the coil. The effective mutual inductance of the coil is materially decreased under these conditions because sections having currents of opposite phase provide negative mutual inductance which partially cancels the positive mutual inductance contributed by coil sections having currents of the same phase. At low frequencies the coil sections having currents of opposite phase are relatively widely separated, giving only a small reduction in effective mutual inductance. At higher frequencies, sections with currents of opposite phase are closer together, producing a large reduction in effective mutual inductance. As a consequence, the total effective inductance of the coil in the delay network is a maximum at the low frequencies and decreases substantially at the higher frequencies. The change in inductance causes a reduction in the time delay or phase slope at the higher frequencies, as shown by curve A, and introduces one form of phase distortion because the high-frequency components of an applied signal arrive at the output terminals before the lower frequency components.

For distortionless signal translation a uniform phase slope over the desired operating frequency range is necessary. For the case under consideration where it is contemplated that the network is to operate over a frequency range O-F₁, curve B represents the desired phase slope. In contrast with this curve, curve A shows the phase distortion inherent in a conventional network having a large value of inter-turn inductive coupling. In order to avoid this form of distortion, the network embodying the invention has a coil with minimized mutual inductance between axially spaced sections in which currents of opposite phase are likely to occur within the operating frequency range. Some reduction in ef-

fective mutual inductance and consequent phase distortion is unavoidable at extremely high frequencies in any coil construction of the type under discussion, as indicated by the curves of Fig. 5. However, with this invention it is possible to minimize the distortion over a selected operating frequency range.

Where the coil-turn angle θ has the aforementioned critical value of approximately fifty-five degrees the phase slope may be represented by curve C, which is approximately uniform over the operating frequency range. This improvement in phase slope over that of curve A obtained with prior delay networks is attributable to the fact that, where angle θ has its critical value, there is substantially no inductive coupling between turns of the coil having an axial separation equal to or greater than the coil diameter D. The condition of curve B may be realized by using a slightly greater value of angle θ , adjusted in accordance with the operating frequency range.

Where the angle θ has an excessive value much larger than fifty-five degrees, the phase slope may vary in the manner of curve E. This curve clearly indicates that the angular relation of the coil turns has its most pronounced effect in the lower portions of the operating frequency range. It also shows that the phase slope for angles greater than fifty-five degrees varies in an opposite sense from that of curve A and may thus provide a phase correction, to realize the desired condition, indicated by curve B.

A time-delay network of the type illustrated in Fig. 3 having the phase slope characteristics of curves B or C may translate an applied pulse substantially free of phase distortion even though the pulse duration is less than the time delay of the network. Such a network may be coupled through its terminals to any desired signal-translating system. It may be used for example to obtain desired time delays of applied transient signals. Also, through appropriate termination of the output terminals echoes or reflections of an applied signal may be obtained as with conventional reflecting transmission-line arrangements.

While there have been described what are at present considered to be the preferred embodiments of this invention, it will be obvious to those skilled in the art that various changes and modifications may be made therein without departing from the invention, and it is, therefore, aimed in the appended claims to cover all such changes and modifications as fall within the true spirit and scope of the invention.

What is claimed is:

1. An elongated coil exhibiting a predominantly reactive impedance, having a longitudinally extending axis, a certain maximum diameter in a plane normal to the axis, and an axial length exceeding said diameter comprising, a plurality of coil turns distributed along said axis and angularly displaced with reference to said normal plane by an angle of at least thirty degrees so that the inductive coupling of each coil turn with any other coil turn axially spaced therefrom by a distance at least equal to said diameter is substantially less than the coupling between coil turns having the same axial separation but positioned normal to said axis, said coil turns having a circular shape when viewed in end elevation from a point normal to said axis.

2. An elongated coil exhibiting a predominantly reactive impedance, having a longitudinally extending axis, a certain maximum diameter in a plane normal to the axis, and an axial length

exceeding said diameter comprising, a plurality of coil turns distributed along said axis and angularly displaced with reference to said normal plane by an angle of approximately fifty-five degrees so that the inductive coupling of each coil turn with any other coil turn axially spaced therefrom by a distance at least equal to said diameter is substantially zero, said coil turns having a circular shape when viewed in end elevation from a point normal to said axis.

3. An elongated coil exhibiting a predominantly reactive impedance, having a longitudinally extending axis, a uniform diameter along its length measured in a plane normal to the axis, and an axial length exceeding said diameter comprising, a plurality of similar coil turns uniformly distributed along said axis and angularly displaced with reference to said normal plane by an angle of at least thirty degrees so that the inductive coupling of each coil turn with any other coil turn axially spaced therefrom by a distance at least equal to said diameter is substantially less than the coupling between coil turns having the same axial separation but positioned normal to said axis, said coil turns having a circular shape when viewed in end elevation from a point normal to said axis.

4. In a time-delay network including an elongated conductive member having a longitudinally extending axis, an elongated coil, which in space exhibits a predominantly reactive impedance, coaxially aligned with said conductive member, having a certain maximum diameter in a plane normal to said axis, and an axial length exceeding said diameter comprising, a plurality of coil turns distributed along said conductive member and insulated from but electrically coupled thereto to provide in said network distributed shunt capacitance, said coil turns being angularly displaced with reference to said normal plane by an angle of at least thirty degrees so that the inductive coupling of each coil turn with any other coil turn axially spaced therefrom by a distance at least equal to said diameter is such that said network has approximately uniform phase slope over a selected operating frequency range.

5. In a time-delay network including an elongated conductive member having a longitudinally

extending axis, an elongated coil, which in space exhibits a predominantly reactive impedance, coaxially aligned with said conductive member, having a certain maximum diameter in a plane normal to said axis, and an axial length exceeding said diameter comprising, a plurality of coil turns distributed along said conductive member and insulated from but electrically coupled thereto to provide in said network a distributed shunt capacitance and to establish within the said coil a magnetic field distribution substantially undisturbed by the presence of said conductive member, said coil turns being angularly displaced with reference to said normal plane by an angle of approximately fifty-five degrees so that each coil turn has substantially zero inductive coupling with any other coil turn axially spaced therefrom by a distance at least equal to said diameter and said network has substantially uniform phase slope over a selected operating frequency range.

6. In a time-delay network including an elongated conductive core structure having a longitudinally extending axis, an elongated coil, which in space exhibits a predominantly reactive impedance, wound over said core structure, having a certain maximum diameter in a plane normal to said axis, and an axial length exceeding said diameter comprising, a plurality of coil turns distributed along said conductive member and insulated from but electrically coupled thereto to provide in said network a distributed shunt capacitance, said coil turns being angularly displaced with reference to said normal plane by an angle of at least thirty degrees so that the inductive coupling of each coil turn with any other coil turn axially spaced therefrom by a distance at least equal to said diameter in such that said network has approximately uniform phase slope over a selected operating frequency range.

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