

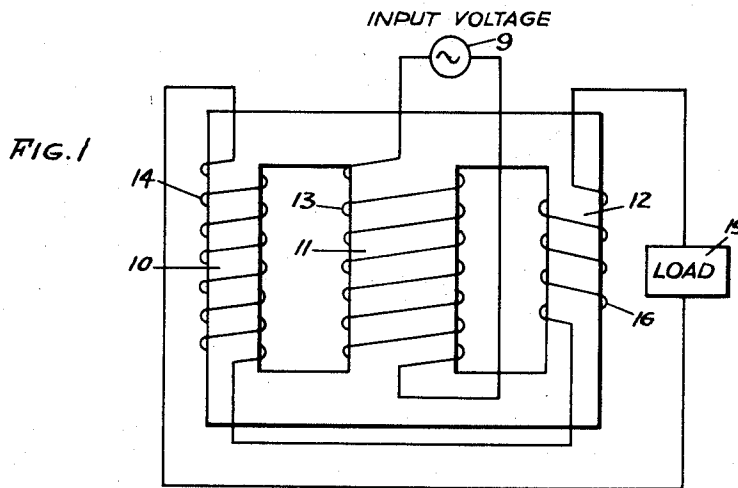
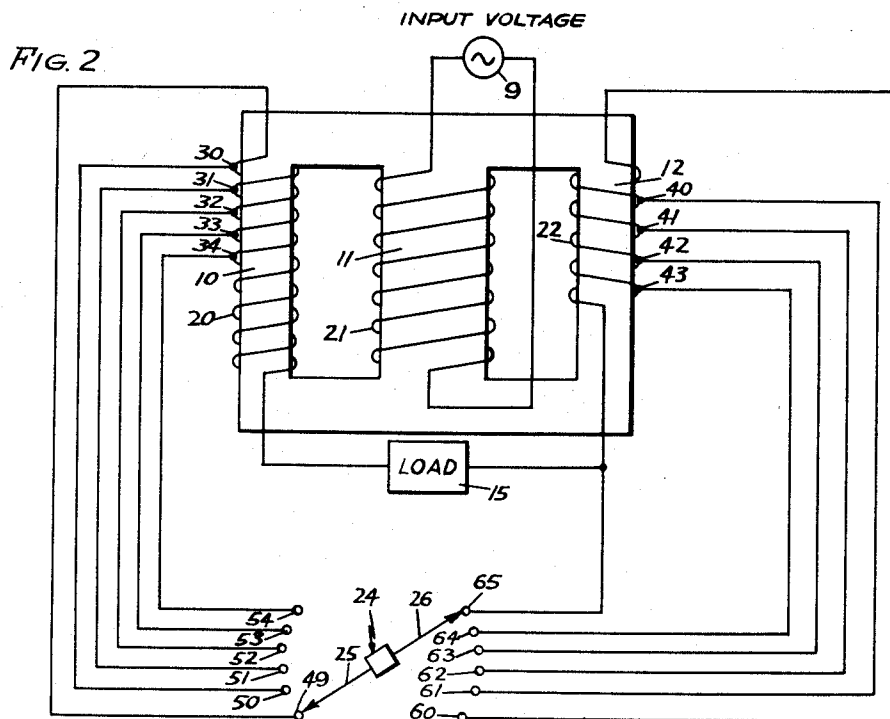
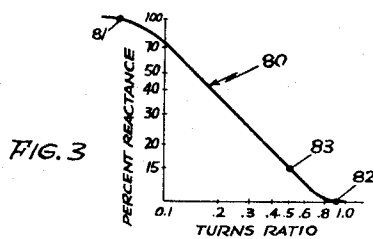
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HIGH REACTANCE TRANSFORMERS

Filed Oct. 28, 1955



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HIGH REACTANCE TRANSFORMERS

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This invention relates to transformers, and, more particularly, to a high reactance transformer having a control winding for obtaining a wide range of values of leakage reactance.

Transformers of the high reactance or leakage reactance type generally consist of a rectangular main core structure having one or more core members on which primary and secondary windings, or coils, are wound and one or more ferromagnetic shunts positioned adjacent the core members to provide a shunt path for magnetic flux traversing one of the coils. As is generally known, a transformer of this type is capable of greatly limiting the current under short circuit conditions, the value of the current so limited depending upon the length of an air gap or gaps between the shunt and the adjacent portion or portions of the main core. Control of the leakage reactance and, in like manner, control of the short circuit flux path is obtained by an adjustment of the length of the air gap which provides a sensitive shunt for flux linking the coils, which, with the usual manufacturing techniques, generally requires careful adjustment to provide a leakage reactance of proper value to meet predetermined transformer operating requirements. In addition, it becomes increasingly difficult, with conventional production line techniques, to maintain close tolerances during punching and assembly of the laminations making up the main core and shunt iron assembly for a plurality of transformers and, consequently, it becomes difficult to maintain substantially constant the desired length of the air gap. In a majority of cases, therefore, individual adjustment of the air gap between the shunt iron and the main core becomes necessary, resulting in the expenditure of additional time and effort as well as in extra labor and testing costs. It is, therefore, an object of the invention to provide a novel leakage reactance-type transformer, in which it is possible to affect precisely predetermined values of leakage reactance without the use of a variable air gap, and in a manner which can readily be established by design. An advantage of apparatus embodying this invention is that it may be used as a current-limiting transformer in which accurate control of leakage reactance is achieved in a simple and convenient manner. This current-limiting effect may be used, for example, in connection with limiting the initial heating of the filament of certain types of hot cathode tubes where the filament, due to its initial low resistance when cold, might suffer shock damage from the application of heavy filament current from a standard-type transformer.

In accordance with this invention, accurate control of transformer leakage over a wide range of values is obtained without the use of an air gap shunt through the use of a three-coil transformer comprising a magnetic core arranged to be operated at a relatively moderate flux density below the knee of the B—H curve of the core material, the core comprising three core members on which are wound a primary winding, a secondary or load wind-

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ing, and a novel control winding connected in series with the load winding. The primary winding is wound on the center core member in order to provide separate flux paths linking the two outer legs. When the control winding on one outer leg is connected in series with the load winding, the distribution of the amount of flux supplied by the primary winding linking the two outer windings, and, consequently, the leakage reactance, can be controlled by changing the reluctance of the leakage flux path. It has been found that this is easily achieved by changing the ratio of turns on the control winding with respect to the turns on the load winding, the total number of turns on both windings, and the open circuit transformer output voltage, remaining the same. In this manner, the ratio of turns on the control leg with respect to the number of turns on the load leg controls the short circuit current flowing through each leg. In another embodiment of the invention, the number of turns on the load and control windings, and, in turn, the degree of leakage flux traversing the control flux path is varied by providing each winding with a series of taps, so that as the number of turns on the control winding is increased, the number of turns on the load winding is decreased in order to maintain the total number of turns on the two windings, and thus the transformer output voltage, at all times constant. In like manner, the control of degree of leakage and the value of the short circuit current which can be obtained thereby, is simplified to an unexpected degree.

Other objects and a better understanding of the invention may be had by referring to the following specification and claims in connection with the accompanying drawings in which:

Fig. 1 is a diagrammatic view of a leakage reactance transformer shown with a winding on the leakage flux path;

Fig. 2 is a diagrammatic view of a modification of Fig. 1 showing taps on the windings on the leakage flux path and on the load flux path; and

Fig. 3 illustrates the changes accomplished in the reactance of the transformer by application of the invention thereto.

Referring now to Fig. 1, there is shown a magnetic core having two outer flux paths, the one including the core member 10, the other including the core member 12, with the member 11 being common to both flux paths. The flux paths including the members 10 and 12 is a closed path which has a cross-sectional area large enough to permit the magnetic core to be operated at a relatively moderate flux density below the knee of the B—H curve of the core material in a manner that will be described in detail below. The two flux paths are magnetized by a primary winding 13 on the center member 11, winding 13 receiving its energy from a single-phase alternating current source 9. As is well known, the sum of the fluxes through outer core members 10 and 12 is substantially equal to the flux in center member 11. Located on outer core members 10 and 12 are windings or coils 14 and 16 which, in this embodiment, are connected in series with one another to form a secondary or output circuit connected in series with load 15. Thus, flux caused by current flow in the primary winding 13 passes through the center member 11, and then divides and flows through the outer members, thereby to produce a reactive effect or output voltage in the secondary circuit. It should be noted, however, that coil 14 is designated as the load winding and coil 16 as the control winding, respectively, and that, because these windings are connected in series to form the secondary circuit, they can be interchanged as long as the turns ratio of the secondary circuit is preserved. Furthermore,

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if load winding 14 and control winding 16 were open-circuited, or disconnected from load 15, as shown in Fig. 2, the flux produced by the primary winding divides equally between the two outer legs, and the voltage per turn of each outer winding becomes one-half the voltage per turn produced by primary winding 13. It will also be apparent that the manner in which the flux in center member 11 divides between the main or load core member 10 and the shunt or leakage path 12 depends upon the relative reluctances of these two paths, and that by increasing or decreasing the reluctance of the leakage path, the proportion of flux traversing the load magnetic flux path may be increased or decreased. In like manner, the leakage reactance of the transformer and, in turn, its current-limiting effect may be controlled, in a simple and reliable manner, without the use of a magnetic shunt and attendant air gap by controlling the reluctance of the leakage or control magnetic flux path which, in accordance with the invention, has been found to be substantially proportional to the ratio of turns between the control winding 16 and the load winding 14. It should be noted, however, load winding 14 and control winding 16 may be connected either into series opposition to produce different reactive effects or, as here, in series addition, providing the circuit is fed from a common flux source, such as center member 11. However, an important advantage of this invention is due to the fact that the control winding 16 is connected in series addition with the load winding 14, so that each turn contributes to the total output voltage, making unnecessary the additional expenditure of copper for biasing or control windings not directly contributing to the output voltage of the secondary circuit.

Referring now to Fig. 2, there is shown a modification of the arrangement of Fig. 1, with windings having additional turns on outer core members 10 and 12 and on center member 11. Thus, a load winding 20 is connected in series with load 15 and control winding 22 to form the usual secondary and load circuit for primary winding 21, which is connected to the single-phase alternating current source 9. However, to obtain different values of transformer leakage, load winding 20 is provided with taps 30 to 34 inclusive, and control winding 22 with taps 40 to 43 inclusive, which, in turn, are connected to appropriate contacts 50 to 54 inclusive and 60 to 64 inclusive on rotary switch 24, in the manner shown. In addition, taps 49 and 65 provide a means for disconnecting control winding 22 from load winding 20, when it is desirable to use the transformer in a conventional manner. Switch 24 is provided with rotatable contacts 25 and 26 and, as shown, is positioned to shunt out control winding 22 from the load circuit. In this manner, the turns ratio between the load and control windings, and hence the reactance, is adjusted as rotatable switch 24 is progressively advanced to link each set of the remaining contacts connected to the taps on the load and control windings. As noted, if all turns on the leakage flux path 12 are disconnected by means of switch 24 remaining in its initial position, as shown, maximum transformer leakage is obtained, and the leakage flux traverses control member 12 unimpeded by reluctance which is set up when coil 22 is energized. Thus, when all the secondary turns are on core member 10, core member 12 acts as a conventional magnetic shunt, and when current is drawn from secondary winding 20 by load 15, flux is forced from core member 10 to core member 12, and the voltage across the secondary winding 20 drops to a lower value in accordance with well-known transformer theory. Also, transformer operation is equivalent to that of a conventional transformer having a shunt provided with a very small air gap. Because the amount of flux which can be shifted from core member 10 to core member 12 is related to the ratio of turns on the respective members, the use of one winding only, representing a turns ratio

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of zero, should theoretically produce a zero flux in load member 10 when the winding is short-circuited, but, due to the iron losses in the core material, some flux remains in load member 10 and, thus, the use of this single winding provides a high but finite impedance. As noted, if equal turns on each outer core member are connected into the secondary circuit, minimum transformer leakage is obtained. By proportioning the turns between the two outer legs, the degree of leakage and, consequently, the short-circuit current can be controlled, and, since it has been found that the leakage is proportional to the turns ratio, transformer reactance can be accurately controlled without the use of an air gap.

Referring again to Fig. 2, when switch 24 is rotated in a clockwise direction to engage contact 50, connected to tap 30 on load winding 20, it also engages contact 64, connected to tap 43 on control winding 22. In this position a single turn is subtracted from the load winding and added to the control winding in the manner shown. The control winding is now placed in series with the load circuit 15, and leakage flux, which traverses control member 12, is now impeded by the reluctance set up by the first turn of the control winding. As switch 24 is progressively advanced through contacts 51 to 54 connected to corresponding taps 31 to 34 on load winding 20, the number of turns on the load winding decreases, as shown, while the number of turns on the control winding increases by the action of contact 26 advancing through contacts 64 to 60 connected to corresponding taps 43 through 40 inclusive. Thus, as each successive turn is added to the control winding, the reactance of the transformer decreases until an equal number of turns on each winding is reached, corresponding to switch positions 54 and 60. In this position, the use of an equal number of turns on each leg, representing a turns ratio of one, results in a low but finite transformer impedance due to iron losses, rather than a theoretically zero impedance. Thus, in practical applications, a transformer having a single control winding can be designated as having a 100 percent reactance, while the lowest transformer reactance obtained with equal coils on both legs will be substantially 10 percent of this value. However, the desired transformer reactance will usually be obtained from turns ratios from between 0.1 and 0.8, as will be described with reference to Fig. 3, where it has been found that a substantially linear relationship exists and transformer reactance may be accurately calculated in a manner that will be described in detail below.

Of course, it is to be understood that while switch 24 may be rotated to position 54 and 60 to provide an equal number of turns on each winding, it is possible that additional turns could be added to the control winding which would have the effect of making the control winding operate as a load winding, and the present load winding then, in effect, become a control winding, the reactance of the transformer remaining proportional to the turns ratio of the aforementioned windings. For this reason, this embodiment shows the control winding having no more than the same number of turns as the load winding.

By utilizing the principles of the invention, as described above, a typical leakage reactance transformer, as shown in Fig. 1, can be constructed using standard E- and I-shaped laminations interleaved by alternately reversing the position thereof to provide a minimum air gap as is customary in conventional transformer designs. Thus, as shown in Fig. 1, this typical leakage reactance transformer consists of a closed core having a transverse over-all dimension of three inches, the length of the three core members contained therein being 2.5 inches over-all, and alternately interleaved with E and I laminations in a conventional manner. The width of the two windows is approximately one-half of an inch, as is the width of the material making up the main and control magnetic flux paths. In order that the transformer will

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operate at all times below saturation of the core material, the primary or center member is at least as wide as the outer members. Furthermore, the core material consists of 26-gauge, 4 percent silicon steel, grade 72, in the form of sheets which have been punched into E and I laminations. It is to be understood, however, that other methods of interleaving may be employed or other methods of core construction, such as wound cores, may be used. In addition, the primary coil in the present embodiment consists of approximately 2500 turns of No. 29 wire, which is wound around the center leg in the direction shown in Fig. 1. The load coil comprises a thousand turns of No. 29 wire, the control winding having 500 turns of the same size wire wound in the direction indicated. The number of control turns may be calculated in the manner described in detail below.

For purposes of explanation, Fig. 3 shows curve 80 representing percentages of total transformer reactance or impedance recorded for typical turns ratios generally having values between 0.1 and 0.8. The limits of the percentages of transformer impedance shown at 81 and 82 may be obtained by measuring the open circuit voltage and the short circuit current and, as is well known, dividing the former by the latter to obtain the maximum transformer reactance for this particular design. Thus, using the curve shown in Fig. 3, when the desired values of the open circuit voltage and short circuit current are given, these two factors can be used to establish the number of turns on the load winding and thus the design of the novel transformer, shown in Fig. 1, in accordance with the invention. For example, assuming the present transformer requirements are for an open circuit voltage of 35 volts, and a short-circuit current of 0.230 amperes, the transformer impedance is equal to 35 divided by 0.230, or 152 ohms required impedance. It is determined from well-known calculation that one thousand turns of the correct size wire, No. 29, will fill the available space in the window of the load coil 14 and that this number of turns will produce a load coil impedance of 1000 ohms. Referring now to the curve shown in Fig. 3, the impedance of 1000 ohms is related to the curve as 100 percent impedance at a turns ratio of zero. This is shown on the curve 80 at 81 representing substantially no control turns. As noted, 82 corresponds to a turns ratio of one, or substantially equal control turns and load turns. Now, the required impedance is approximately 150 ohms, which is 15 percent of the maximum impedance and 83 on the curve 80 shows that 15 percent impedance is equal to a turns ratio of 0.5. Since this ratio is the ratio of control turns to load turns on the secondary winding, the number of control turns is equal to 1000 multiplied by 0.5, which is equal to 500. Thus, the secondary winding of the transformer shown in Fig. 1 has 1000 turns on the load coil and 500 turns on the control coil. Since the sum of the voltages for the two coils must equal 35 volts, the volts per turn in each coil must equal 35 divided by 1500 turns, which is equal to 0.0233. Then, according to well-known transformer theory, since the volts per turn on the center winding must be twice this value, the primary coil will have a volts-per-turn value of 0.0466. Now in order to operate from the usual 115-volt alternating current line, the number of turns required will, therefore, be 115 divided by 0.0466 which is equal to 2460 turns of wire, which is substantially equal to 2500 turns, as mentioned previously. Of course, the number 29 wire size may be established in the well-known manner from the total secondary volt amperes. In this manner, therefore, it is possible to transfer the burden of accurate control of transformer reactance from the assembly line to engineering design by the elimination of the air gap shunt with its attendant difficulties.

Although the invention has been described with a certain degree of particularity, it is understood that it is not to be limited to the particular embodiment described

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herein. For example, the output power of the load winding can be controlled by varying the value of a resistor across the control winding, or similar control may be obtained by supplying current from a separate source to the control winding, thereby permitting control of very high voltages or high currents generally beyond the limits of conventional controls, such as rheostats connected in series with such load circuits. Furthermore, while the load in the above-described embodiment, shown in Fig. 2, is connected between the load and control windings in the manner shown, it also may be placed at any other point within the series secondary circuit. Also, the load winding may consist of separate symmetrical windings connected together to provide a center tap which may be grounded to meet external circuit requirements.

In addition, it will be appreciated that many variations of the features shown and described herein in connection with the single embodiment of the invention illustrated will occur to those skilled in the art to which the invention relates. It is, therefore, intended that the claims which follow shall not be limited by the particular details of the illustrated embodiment but rather by the prior art.

What is claimed is:

1. A reactance transformer comprising in combination a closed magnetic core having three core members, a primary winding only on one core member adapted to be connected to a source of alternating current and to provide a source of flux equally traversing said other core members, a secondary circuit adapted to be connected to a load comprising a winding on the first of said other core members connected in series addition with a winding on the second of said other core members, said latter core winding co-acting with said first core winding to determine the percentage of leakage flux applied to said latter core winding from said first core winding in response to said load connected to said secondary circuit.

2. A reactance transformer comprising in combination a closed magnetic core having three core members, a primary winding on only one of said core members adapted to be connected to a source of alternating current and to provide a source of flux traversing said other core members, and a secondary circuit comprising a winding on the first of said other core members connected in series addition with a winding on a second of said other core members, said second core winding co-acting with said first core winding to provide a flux leakage path for flux normally traversing said first core member, said leakage flux being responsive to the ratio of turns of said first and second core members.

3. A variable reactance transformer comprising in combination a closed magnetic core having a load magnetic flux path and a control magnetic flux path, a primary winding of a pre-determined number of turns providing therein a source of magnetic flux in each path, means for supplying said primary winding with alternating current, a secondary circuit comprising a load winding linking said load magnetic flux path and a control winding linking said control magnetic flux path, said windings connected in series addition and in such a manner that the percentage of leakage flux in said control magnetic flux path changes in response to a change in the number of turns of said control and load windings linking said control and load paths, said total number of turns of said secondary circuit remaining constant.

4. A leakage reactance-type transformer comprising in combination, first, second and third nonsaturable magnetic flux paths, a primary circuit comprising a winding of a predetermined number of turns linking only said second flux path and adapted to be energized by a source of alternating current to produce oppositely flowing flux in said first and third flux paths, a secondary circuit comprising windings linking said first and third flux paths

connected in series with a load, the amount of flux linked by said third winding with respect to said first winding being proportional to the ratio of turns on said first and third windings.

5. In a leakage reactance-type transformer comprising a closed magnetic core of a predetermined value of leakage reactance having three core members and a nonsaturating winding of a predetermined number of turns on each member, means for supplying only one of said windings linking only one member with a source of alternating current, means connecting said windings on the two other core members in series addition with respect to an output load circuit, and switching means for changing the number of turns on one member with respect to the number of turns on the other member while maintaining constant the total number of turns of said two members, thereby changing the leakage reactance of said transformer from said predetermined value in response to a change in load in said output circuit.

6. A leakage reactance-type transformer comprising a closed magnetic core having first, second and third core members, and a nonsaturating winding of a predetermined number of turns on each member, said winding on said second core member in a circuit separate from said other windings and adapted to be connected to a source of alternating current, said third core member providing a leakage flux path adapted to shunt part of the flux of said first core member around said third core member, said third winding connected in series addition to said first winding and cooperating with said first winding to control the percentage of said flux from shifting said first core member through said third core member, thereby changing the leakage reactance of said transformer in proportion to the ratio of turns of said first and third windings.

7. A leakage reactance transformer comprising a magnetic core having first, second, and third nonsaturable core members and windings of a predetermined number of turns on each core member, said first and third windings on said first and third core members being connected in series addition relationship with respect to an output load circuit, said second winding connected in a circuit separate from said other windings and adapted to be energized by a source of alternating current, said third core member having a predetermined number of turns to produce a change in leakage reactance in said transformer in response to a change in load in said output circuit, said leakage reactance being proportional to the ratio of turns of said first and third windings.

8. A reactance transformer comprising a closed magnetic core having three core members providing three nonsaturable flux paths, means acting in connection with only one core member to provide a source of magnetic flux equally traversing said other core members in the absence of a load, means on said third member co-acting with means on said first member to control the proportion of flux distributed from said source through said first and third core members in response to a load, there-

by to control the reactance of said transformer, said means on said third core member coupled in series with said means on said first core member to provide an output current varying in response to a change in load applied to said transformer.

9. A nonsaturable high reactance transformer system adapted to operate without an air gap magnetic shunt for leakage flux, a plurality of magnetic core members having continuous magnetic core flux paths interconnected at a common junction, an input power source connected to a primary winding linking only one of said members, first and second windings on at least two of said core members, said first and second windings connected in series aiding with a load circuit and coacting with said load circuit to control the percentage of leakage flux flowing through one of said core members other than the member to which said primary winding is connected.

10. A leakage reactance transformer comprising a closed magnetic core having three core members adapted to provide three nonsaturable flux paths, means coacting with one of said core members to provide a source of magnetic flux traversing and other core members, first winding means for setting up a counter flux in response to a load connected to said first winding on a first of said other core members to oppose said flux traversing said first core member, said other core member providing a leakage flux path, thereby to attain a relatively high leakage reactance, and, second winding means on said other core members adapted to control the percentage of leakage flux applied to said other member from said first core member, said second winding means connected in circuit with said first winding means and said load.

11. A leakage reactance transformer comprising a closed magnetic core having first, second, and third nonsaturable core members providing three nonsaturable flux paths, a first winding on only the first of said core members adapted to be energized by a source of alternating current to provide a source of flux at all times equally traversing said second and third core members, said third core member arranged to act as a leakage flux path for a portion of said flux traversing said second core member, and a secondary circuit comprising windings on said second and third core members adapted to be connected to a load circuit, said load circuit cooperating with said leakage flux path to control the distribution of flux in said second and third core members, said third winding connected to said second winding in a manner to oppose said flow of leakage flux through said third core member when said secondary circuit is connected to said load circuit.

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UNITED STATES PATENT OFFICE
CERTIFICATION OF CORRECTION

Patent No. 2,944,208

July 5, 1960

Robert S. Quimby

It is hereby certified that error appears in the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 1, line 36, for "deactance" read -- reactance --; column 4, line 55, before "then" insert -- would --; column 7, line 31, strike out "from" and insert the same after "shifting" in line 32, same column 7; column 8, line 23, for "and" read -- said --.

Signed and sealed this 1st day of August 1961.

(SEAL)

Attest:

ERNEST W. SWIDER

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Commissioner of Patents

UNITED STATES PATENT OFFICE
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