June 16, 1931. F. E. FIELD 1,809,839

TRANSFORMER AND TRANSFORMER SYSTEM

Filed June 19, 1925

Fig. 1

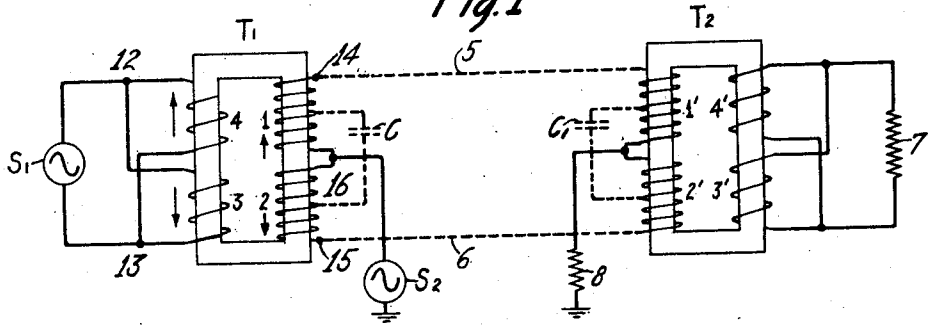


Fig. 2

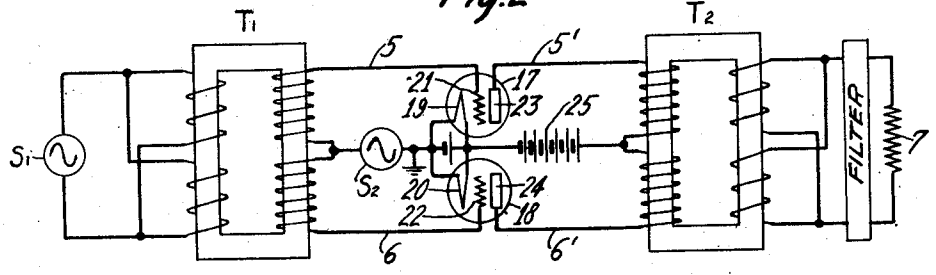


Fig. 3

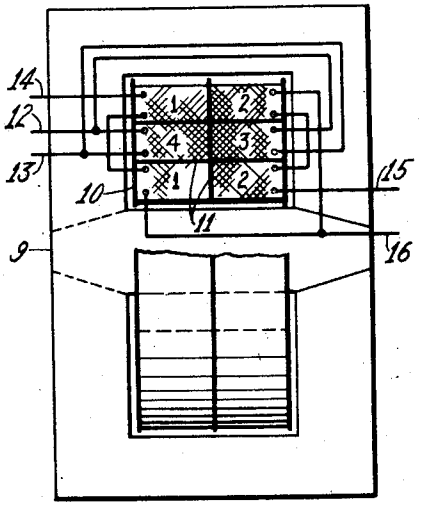
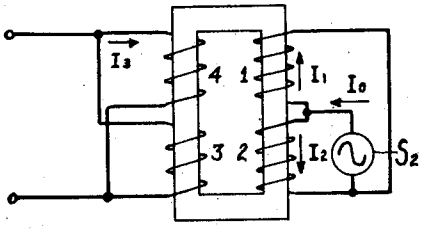


Fig. 4



Inventor:
Frank E. Field
by E. W. Adams. Atty.

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UNITED STATES PATENT OFFICE

FRANK E. FIELD, OF SOMERVILLE, NEW JERSEY, ASSIGNOR TO WESTERN ELECTRIC COMPANY, INCORPORATED, OF NEW YORK, N. Y., A CORPORATION OF NEW YORK

TRANSFORMER AND TRANSFORMER SYSTEM

Application filed June 19, 1925. Serial No. 38,124.

This invention relates to transformers and more particularly to differential, or bridge, transformers for use in connection with simplexed transmission systems.

An object of the invention is to improve the transmission efficiency of differential transformers.

Another object is to reduce the effective leakage inductance of the differential windings of such transformers while at the same time maintaining a low electrostatic capacity between the windings.

The invention is applicable to simplexed transmission systems, such as phantomed telephone circuits, and to the so-called duplex modulating systems of the type described in U. S. Patent No. 1,343,308 to J. R. Carson issued June 15, 1920.

In this connection further objects of the invention are to facilitate the superposition of currents in simplexed systems, and to improve the transmission efficiency of systems of this type.

A feature of the invention lies in the coupling of the leakage magnetic fields of the transformer windings with a short-circuited winding, the reactions of which due to induced circulating currents cause the leakage inductance to be substantially neutralized.

A further object is therefore to utilize the effect of induced circulating currents to neutralize the leakage inductance of transformer windings.

The nature of the invention will be more fully understood from the following detailed description taken in conjunction with the accompanying drawings, of which:

Fig. 1 shows in simplified schematic form a simplexed transmission system embodying the invention;

Fig. 2 shows the application of the invention to a modulating system;

Fig. 3 shows in detail the winding arrangement of the transformers employed in the circuits of Figs. 1 and 2; and

Fig. 4 is a simplified diagram for purposes of analysis.

Referring to Figs. 1, 5 and 6 are a pair of line wires adapted for simplex operation by means of differential transformers T_1 and T_2, through which two separate sources of currents S_1 and S_2 are connected over the line wires to receiving impedances 7 and 8 respectively.

Transformer T_1 is provided with balanced secondary windings 1 and 2 which are connected in series, inductively aiding, and with two equal primary windings 3 and 4 which are connected in parallel, inductively aiding. Transformer T_2 is of similar type and is provided with corresponding windings designated 1′, 2′, 3′ and 4′, respectively.

Source S_1 is connected to the terminals of the primary windings of transformer T_1, and receiving impedance 7 is similarly connected to transformer T_2, thereby establishing a simple series transmission circuit over the wires 5 and 6.

Source S_2 is connected between the midpoint of windings 1 and 2 and ground, and receiving impedance 8 is connected in like manner between windings 1′, 2′ and ground. Currents from S_2 are thereby superimposed upon the lines in parallel, returning from impedance 8 to the source by way of the ground. If the lines are of equal impedance, as is generally the case, the superimposed current divides equally between them, the two parts flowing through the transformer windings in opposite directions, and producing a differential magnetic effect which is practically zero except for the effect of magnetic leakage.

For the efficient transmission of the superimposed current, the two series-connected windings of each transformer should be very closely coupled together so that the leakage impedance of the parallel connection is reduced to a minimum.

A common method of securing this result is to wind the two windings bifilarly thereby securing the most intimate coupling of the windings possible. This method however produces a large capacity between the windings, indicated in the figure by C and C′, which is effectively in shunt to the series circuit and which may be a series source of transmission loss in that circuit.

Winding arrangements by which the shunt capacity of the secondary windings is reduced

generally result in the introduction of larger leakage inductances, so that the transmission of the superimposed current is impaired.

According to the invention the leakage inductance of the differential windings is reduced without causing the introduction of a large shunt capacity by means of a special arrangement of the transformer windings. This winding arrangement is illustrated in Fig. 3 which shows in detail the physical construction of one of the transformers, such as T_1.

The transformer comprises a shell type magnetic circuit 9 built up of laminated magnetic material such as iron or silicon steel, around the central core of which is placed a spool 10 of insulating material containing the windings. The windings are applied in six sections which are arranged in two groups of 3 concentric coils each, the individual sections being designated in the figure by numbers corresponding to the designations of the windings in Figure 1. The primary windings 3 and 4 occupy the two middle sections of each concentric group, secondary winding 1 is divided equally between the outer and inner sections of the one group, and secondary winding 2 is divided between the outer and inner sections of the other group. All sections are wound in the same direction. The interconnection of the sections and the method of connecting the transformer in the transmission circuit are indicated by the numbers 12, 13, 14, 15 and 16 which designate corresponding terminals in both Figs. 1 and 3.

It will be seen that winding 1 is unequally coupled to windings 3 and 4, being more closely coupled to winding 4 than to 3. Similarly winding 2 is more closely coupled to winding 3 than to 4. With respect to the main flux threading the magnetic circuit the windings are of course equally coupled and the differences in the degrees of coupling between the individual windings are due to the leakage fluxes which surround them without traversing the magnetic circuit.

Further, although windings 1 and 2 are unsymmetrically coupled to windings 3 and 4 individually, the arrangement is of such symmetry that they are equally coupled to the parallel combination of windings 3 and 4.

When equal currents from source S_2 traverse windings 1 and 2 in opposite directions the current in winding 1, by virtue of the unbalanced coupling, induces an unbalanced E. M. F. in windings 3 and 4 tending to produce a current in winding 4 in the direction, for example, from terminal 13 to terminal 12. Similarly, the current in winding 2 produces an unbalanced E. M. F. tending to send a current through winding 3 in the opposite direction. The directions of these induced currents and of the inducing currents in windings 1 and 2 are indicated in the figure by the arrows associated with the respective windings.

The induced currents circulate in the same direction in a closed path constituted by windings 3 and 4 connected in series, and since these windings are magnetically aiding when connected in parallel, their series connection is practically non-inductive. To the unbalanced induced E. M. F. the windings therefore act in the same manner as a short-circuited secondary winding in a transformer and hence tend to neutralize the mutual inductance by which the induced E. M. F.'s are created, that is, a substantial portion of the leakage inductance of windings 1 and 2 in their parallel connection.

The neutralizing action may be quantitatively analyzed by a consideration of the simplified circuit shown in Fig. 4. This figure corresponds to part of Fig. 1, comprising transformer T_1, and source S_1, line wires 5 and 6 being disconnected and terminals 14 and 15 being connected together and to the ground tap. Under these conditions current from the source S_2 encounters only the open circuit impedance of the transformer due to the effective leakage impedances.

The currents in windings 1 and 2 are designated I_1 and I_2 respectively and the circulating current in windings 3 and 4 by I_3. The total current from the source S_2 is designated by I_0 which is equal to the sum of I_1 and I_2.

The following equations, based on Kirchoff's laws serve to determinate the value of the four currents:

$$\left.\begin{aligned} &I_1Z_1 - I_2Z_{12} + I_3(Z_{14} - Z_{13}) = E \\ &I_1Z_{12} + I_2Z_2 + I_3(Z_{23} - Z_{24}) = E \\ &I_1(Z_{14} - Z_{13}) + I_2(Z_{23} - Z_{24}) + \\ &\quad I_3(Z_3 + Z_4 - 2Z_{34}) = 0 \\ &I_0 = I_1 + I_2 \end{aligned}\right\} \quad (1)$$

in which E is the E. M. F. of source S_2; Z_1, Z_2, Z_3, Z_4, are the impedances of windings, 1, 2, 3, and 4, respectively; and in which the mutual impedances between the various pairs of windings are denoted by the two-digit subscripts corresponding to the numbers designating the windings. The signs of the various terms take account of the differential effects of the winding connections.

Solving these equations, for the case in which the windings are balanced and symmetrically disposed, gives for the current I_0 the value

$$I_0 = \frac{2E(Z_3 - Z_{24})}{(Z_3 - Z_{34})(Z_1 - Z_{12}) - (Z_{14} - Z_{13})^2} \quad (2)$$

The mathematical conditions corresponding to the specified symmetry being expressed by the equation

$$\left.\begin{aligned} Z_1 &= Z_2 \\ Z_3 &= Z_4 \\ Z_{13} &= Z_{24} \\ Z_{14} &= Z_{23} \end{aligned}\right\} \quad (3)$$

Equation 2 shows that the circuit is equivalent to a pair of coupled circuits having total impedances Z_p and Z_s respectively and a mutual impedance Z_m, the values of these impedances being given by the equations:

$$\left.\begin{aligned} Z_p &= (Z_1 - Z_{12}) \div 2 \\ Z_s &= (Z_3 - Z_{34}) \div 2 \\ Z_m &= (Z_{14} - Z_{13}) \div 2 \end{aligned}\right\} \quad (4)$$

The impedances constituting the equivalent coupled circuits are evidently the leakage impedances of the transformer windings, and the mutual impedance is that due to the coupling of the leakage fields.

Equation 2 may be converted to the form

$$I_0 = \frac{2E}{(Z_1 - Z_{12})(1 - k^2)}, \quad (5)$$

in which k is the coefficient of coupling, defined by

$$k = \frac{Z_m}{\sqrt{Z_p Z_s}}. \quad (6)$$

In this form the effect of the coupling of the leakage fields in reducing the effective leakage inductance is made evident.

To secure a large value of the coupling coefficient k it is necessary that the differential mutual inductance, $Z_{14} - Z_{13}$ be as large as possible in comparison with the leakage inductances $(Z_1 - Z_{12})$ and $(Z_3 - Z_{34})$. Complete neutralization cannot be obtained, but by the method of interleaving the windings shown in Fig. 3, the greater part of the leakage inductance is effectively destroyed.

The invention is of particular utility when the system upon which the currents are superimposed is of high impedance, for in that case highly inductive secondary windings using a large amount of wire must be employed, and if recourse is had to the bifilar method of winding the two secondaries, the capacity between them becomes excessively large. In fact, the loss in the series circuit due to the shunt capacity increases very rapidly as the impedance of the system is increased, due to the fact that shunt admittance, causing the loss, increases more or less proportionately to the impedance.

Fig. 2 shows the invention applied to a differential modulating system of the type described in U. S. Patent 1,343,308 to J. R. Carson issued June 15, 1920. Systems of this type are in general of much higher impedance than the ordinary simplexed transmission systems such as telephone systems.

The system is of the same general type as that shown in Fig. 1 with the addition of an asymmetric coupling device, in the form of two three element space discharge tubes 17 and 18, which divides the line into two parts. These parts are denoted by 5, 6, and 5′, 6′ to correspond with Fig. 1.

The space discharge tubes are of the customary type in which an electron stream between a cathode and an anode is controlled by the potential of a third, or control, electrode. Cathodes 19 and 20 are connected together and to ground, control electrodes 21 and 22 are connected respectively to lines 5 and 6, and anodes 23 and 24 are connected respectively to line wires 5′ and 6′. Space current is provided by a common battery 25 which is connected in a circuit between the mid-point of the secondary windings of transformer T_2 and ground.

The system is arranged for modulation. Waves of one frequency from source S_1 are impressed upon lines 5 and 6 in series, thereby energizing the control electrodes in opposite phases. These waves are repeated in the space paths of the tubes and the repeated waves are impressed upon lines 5′ and 6′ in series and thence through transformer T_2 to load 7.

Waves of a different frequency from source S_2 are impressed upon the control electrodes in parallel, thereby energizing the control electrodes in the same phase. The repeated waves are also in the same phase, and are impressed upon lines 5′ and 6′ in parallel and thence in opposition through the secondary windings of transformer T_2 to ground.

When the two sets of waves traverse the space paths of the discharge tubes simultaneously, modulation E. M. F.'s are generated therein, the principal modulation products being those of frequencies corresponding to the sum and to the difference of the impressed wave frequencies.

These products, known as second order modulation products, are of opposite phase in the two tubes and hence are impressed upon the lines 5′ and 6′ in series whereby they are transmitted by transformer T_2 to load 7.

The system may be used for modulating or for demodulating, the two processes being identical in principle. Thus, S_1 may be a source of speech frequencies and S_2 a carrier wave source giving a wave of 30 kilocycle frequency, in this case both the speech frequency waves and the modulation products being transmitted to impedance 7 while the carrier wave is suppressed in the output by the differential action of the output transformer. The modulation products comprise two bands of side frequencies, one comprising waves of the difference frequencies between the carrier and speech frequencies, and the other comprising the corresponding summation frequencies.

Again, the source S_1 may be a line from which is received one of these bands of side frequencies and S_2 a local source of carrier waves of appropriate frequency to cooperate in the reproduction of speech or signal currents from the side bands. In this case the modulation products include detected speech

currents which along with the repeated side band waves are transmitted to the impedance 7.

In each case, if it is desired, the repeated waves from source S_1 may be prevented from reaching the load impedance by inserting in front of the load impedance a wave filter or other selective network such as shown in U. S. Patent 1,227,113 to G. A. Campbell, May 22, 1917.

In order that the modulation E. M. F.'s generated in the space paths may have their maximum value it is necessary that the repeated currents due to the impressed waves should be as large as possible, and to secure this it is desirable that the repeated waves should encounter substantially zero impedance in the output circuit external to the tubes.

The principles leading to this conclusion are developed in U. S. Patent 1,448,702 to J. R. Carson issued March 13, 1923 and in U. S. Patent 1,624,498 to F. Mohr, issued April 12, 1927. This condition is secured with respect to the waves repeated from source S_2 as a result of the winding arrangement of transformer T_2 in accordance with the invention.

When the system is adapted to modulate a carrier wave from source S_2 by a speech wave from source S_1 the windings of transformer T_2, being proportioned for the efficient transmission of the relatively high frequency side bands, would generally have low impedances at speech frequencies and would have little effect in limiting the repeated speech currents.

When the system is adapted to reproduce speech signals by demodulation it might appear that it would be desirable to have a large capacity between the transformer secondary windings in order that the high frequency waves repeated from source S_1 may have a low impedance path in the output circuit, but it is also necessary that such capacity be very carefully proportioned to avoid excessive loss to the transmission of the detected speech currents, and the proper capacity value can be provided with much greater certainty by means of a separate condenser. In practical systems, it would commonly be the case that such capacity would form part of a filter or other selective network and in consequence its value would be determined by a number of design requirements. For this reason, it is desirable to eliminate the capacity of the windings, completely if possible.

The nature and the mode of employing the invention in specific cases having been disclosed, the scope of the invention is defined by the following claims.

What is claimed is:

1. In combination, in a simplexed transmission system, a pair of line wires, a third line constituting a return path for waves superimposed upon said line wires in parallel, a transformer, a pair of windings on said transformer connected in series inductively aiding between said pair of line wires and having their common point connected to said third line, and a second pair of windings on said transformer connected in parallel, inductively aiding, said windings being applied in a plurality of sections on a common magnetic core and said sections being symmetrically interleaved whereby the impedance of said series connected windings to superimposed waves is neutralized at least in part by virtue of their resultant coupling with the closed circuit constituted by said parallel connected windings.

2. In combination, in a simplexed transmission system, a pair of line wires, a third line constituting a return path for waves superimposed upon said line wires in parallel, a transformer, a pair of windings on said transformer connected in series inductively aiding between said pair of line wires and having their common point connected to said third line, and a second pair of windings on said transformer connected in parallel, inductively aiding, said windings being so interleaved upon a common core that the leakage inductances of said series connected windings with respect to simplex currents are substantially neutralized by the action of circulating currents in said parallel windings.

3. In a simplexed transmission system, a pair of line wires, a transformer having a pair of balanced windings connected in series, inductively aiding between said line wires, a tap at the common connection of said windings, a third path connected to said tap and constituting a return circuit for waves superimposed upon said line wires in parallel, and means for reducing the impedance of said transformer to superimposed currents, said means comprising a short-circuited path inductively coupled to said balanced windings.

4. In a simplexed transmission system, a transformer comprising a pair of windings connected in series, magnetically aiding, the terminals of said series pair being connected to a pair of line wires and their common point to the third line of the simplexed system, a second pair of windings on said transformer, connected in parallel, magnetically aiding, each of said latter windings being individually interleaved with one of said first windings and more completely linked by the leakage flux thereof than by the leakage flux of the other of said first windings.

5. In combination, in a simplexed transmission system, a pair of line wires, a third line constituting a return path for waves superimposed upon said line wires in parallel, a transformer comprising a pair of windings connected in series inductively aiding between said pair of line wires and having their common point connected to said third line, and comprising also a second pair of windings

connected in parallel, inductively aiding, said first windings being each closely magnetically associated with an individual one of said latter windings and less closely magnetically associated with the other of said latter windings.

6. In a simplexed transmission system a pair of line wires, an inductance element having a pair of balanced windings connected in series, inductively aiding between said line wires, a tap at the common connection of said windings, a third path connected to said tap and constituting a return circuit for waves superimposed upon said line wires in parallel, and means for reducing the impedance of said inductance element to simplexed currents comprising a short-circuited path linked with the leakage flux of said balanced windings.

7. In a simplexed transmission system comprising a pair of line wires and a third return wire, a differential transformer having a pair of windings connected across said line wires in series, inductively aiding, with their common point connected to said return wire, and a second pair of windings connected in parallel, inductively aiding, each of said latter windings being interleaved with an associated first winding to link the leakage flux thereof and connected in a closed path for dissipating the energy represented by said leakage flux.

In witness whereof, I hereunto subscribe my name this 9th day of June A. D., 1925.

FRANK E. FIELD.