A coaxial cable transformer which includes a shielded conductor for reducing primary to secondary winding capacitive coupling which results from the mutual capacitance therebetween. Included between and concentric with inner and outer coaxial conductors, operating as primary and secondary windings, is a selectively grounded shield conductor. This shield conductor is grounded such that there is no instantaneous potential difference between corresponding points on the shield and secondary winding. To reduce indirect primary to secondary capacitive coupling which results from capacitive current between the primary and shield conductors, additional capacitance is included in the transformer circuit.

5 Claims, 10 Drawing Figures
SHIELDED COAXIAL CABLE TRANSFORMER

BACKGROUND OF THE INVENTION

An important requirement of a high-frequency transformer is the generation of an output signal which corresponds as precisely as possible to the input signal, save for amplitude distinctions resulting from the primary to secondary turns ratio. As a result of stray capacitance and inductance in transformer circuits, output signals often appear distorted. In pulse transformers, this distortion appears primarily as a distorted transient response. Transient distortion is seen as a slow rise time along with a ringing or oscillatory transient portion of the output pulse.

In prior transformers with non-concentric windings, the primary cause of transient distortion was stray inductance, stray capacitance being negligible. Development of coaxial cable transformers such as those described in U.S. Pat. No. 3,005,965 and U.S. Pat. No. 3,197,723 resulting from the realization that stray inductance could be appreciably reduced by forming the primary and secondary windings from concentric conductors wound on a suitable core.

Although coaxial cable transformers did indeed reduce stray inductance, the close proximity between the primary and secondary windings gave rise to an appreciable stray capacitance caused by the mutual capacitance between these windings. It is the object of this invention to reduce this capacitive coupling between the primary and secondary windings.

SUMMARY OF THE INVENTION

In accordance with the teaching of this invention transient distortion in coaxial cable transformers is substantially eliminated by reducing the capacitive current which results from the mutual capacitance. Reduction of capacitive current reduces the transient distortion. To reduce capacitive current in the secondary circuit a third conductor is located between first and second concentric conductors, functioning as primary and secondary windings. This third or shield conductor is selectively connected to a reference potential so that corresponding points on the shield and secondary conductors have the same instantaneous high-frequency potential with respect to the reference potential. As a result, no capacitive current, which results from an instantaneous potential difference between adjacent windings, flows through the mutual capacitance between the shield conductor and the secondary.

The shield conductor may give rise to an indirect capacitive coupling between the primary and secondary windings. This coupling results from the instantaneous potential difference between the primary and the shield conductor which causes capacitive current to flow in the shield conductor. This capacitive current can give rise to an induced capacitive current in the secondary. To eliminate this indirect capacitive coupling, the invention provides for the addition of a capacitor between the primary and the shield conductors, when needed, to assure that the resultant potential induced in the secondary in response to the shield conductor's capacitive current is substantially zero.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 represents an equivalent circuit for a high-frequency transformer,

FIG. 2 represents the transient portions of input and output pulses from a coaxial cable transformer without the improvements of the present invention.

FIG. 3a and 3b illustrate a transformer constructed according to the teaching of this invention.

FIG. 4 illustrates a prior art current transformer coupled to a circuit in which it operates.

FIG. 5 illustrates the circuit of FIG. 4 modified to include the teachings of this invention.

FIG. 6 illustrates the circuit of FIG. 5 further modified to include a capacitor between the primary and shield conductor.

FIGS. 7a and 7b illustrate a transformer constructed according to the teachings of this invention and including a shielded box surrounding substantially all of the transformer, and

FIG. 8 illustrates a transformer embodiment built according to this invention and providing a 1:2 turns ratio.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS OF THE INVENTION

FIG. 1 represents an equivalent circuit for a high-frequency transformer valid for concentric and non-concentric winding transformers. This equivalent circuit will be used to explain the operation of the invention.

The primary of the transformer of FIG. 1 is coupled at points a, b to source $E_o$ containing an internal resistance $R_o$. Source $E_o$ drives the primary winding to induce a potential across the secondary to drive the load $R_s$. The primary inductance of the circuit given by $L_p$. The stray inductance on the primary side is given by $L_y$ and is represented by two inductors in series with the inductance $L_y$. The stray inductance produced on the secondary side of the transformer is given by $L_s$ and is represented in the equivalent circuit by two inductors in series with the winding capacitance $C_s$. Capacitance $C_p$ represents the capacitance between adjacent turns of the secondary winding, while capacitance $C_o$ represents the capacitance between adjacent turns of the primary. Since each secondary turn in a coaxial cable transformer is shielded by the outer braid, the value of $C_o$ is negligible. The mutual stray capacitance, hereinafter referred to simply as the mutual capacitance, between the primary and secondary windings is distributed along the length of the windings. This distributed capacitance is represented in FIG. 1 by a pair of lumped capacitive elements $C_p$. In practice $C_p<<C_o$.

For ease in discussing the theory behind the invention a capacitance $C''_s$ is defined as the equivalent stray capacitance as viewed from the primary side of the transformer where $C''_s = kC_s + C_d$. $C_d$ representing all the stray capacitance excluding the mutual capacitance. Since the value of $C_p$ for coaxial cable transformers is negligible compared to the value of $kC_s$ the equivalent stray capacitance is essentially equal to the equivalent mutual capacitance and therefore $C''_s = kC_s$. The value of the constant of proportionality, $k$, depends on the circuit in which the transformer is used and is primarily dependent upon the transformer turns ratio and the transformer-load interconnection. For example, if points b and d in FIG. 1 were grounded or more generally connected to the same high frequency reference potential, the equivalent mutual capacitance
3,717,808

would be considerably lower than if points b and c were coupled to the same high frequency reference potential. Such variations are reflected in the value of k. At this point it is noted that the term ground will be used herein to denote any suitable common high frequency reference potential.

It has been determined that as C’ increases so does the transient distortion.

A better appreciation of the transient distortion may be had by referring to FIG. 2. Waveform α represents the transient portion of an essentially ideal pulse. It is not ideal since it shows a finite rise time. The transient portion of the corresponding output pulse is illustrated by waveform β. The transformer producing this pulse does not contain the elements of this invention. The 10%/90% rise time for the ideal pulse is represented by time tα. The rise time for the output pulse is given by tβ. The difference between tα and tβ is the rise time distortion caused by the stray capacitance and inductance. Ringing distortion, shown as the oscillatory portion of waveform β also results from the stray inductance and capacitance.

In transformers with primary and secondary windings not formed from concentric conductors, the relatively large distance between the windings results in a negligible stray capacitance. Therefore, the transient distortion is primarily a function of the stray inductance. This can be seen from the following equation. With stray capacitance neglected the 10%/90% rise time t is expressed as:

\[ t_r = 2.2 \left( L_s R_0 + R'_L \right) \]

where: \( L_s = L + n^2 L_p \), \( n^2 L_p \) representing the secondary stray inductance viewed from the primary side of the transformer and \( R'_L = n^2 R_L \) the equivalent load resistance.

Thus, when stray capacitance can be neglected, transient distortion can be reduced by decreasing the value of \( L_s \). A popular method of reducing \( L_s \) has been to form the primary and secondary windings from a pair of concentric conductors. However, such a transformer configuration causes an appreciable increase in the equivalent capacitance \( C'_s \) which counters the advantages realized with lowering \( L_s \). Therefore, it becomes necessary to reduce the effect of this equivalent capacitance \( C'_s \) without effecting the value of \( L_s \). This is done by controlling the capacitive current flowing in the secondary which results from \( C'_s \).

Capacitive current in the secondary is controlled by providing a third or shield conductor grounded so that each point on the shield conductor has the same instantaneous high-frequency potential with respect to ground as the corresponding point on the secondary conductor. Under this condition, there is no instantaneous voltage difference between corresponding points on the shield conductor and the secondary winding, thereby preventing a capacitive current between the primary and secondary windings.

FIG. 3a illustrates the basic configuration of a transformer designed in accordance with the teachings of this invention, while FIG. 3b illustrates the FIG. 3a configuration in schematic form. The three conductor coaxial cable is wound around a core 1. The outer conductor 2 which may be used as the primary winding cylindrically encloses and is isolated from the shield conductor 6 by suitable insulating material 8. Similarly, inner conductor 4 is isolated from the shield conductor 6 by insulating material 10. When outer conductor 2 acts as a primary winding, conductor 4 acts as the secondary. The shield conductor is provided with a terminal 0 for coupling the shield to ground at one point only. The position of terminal g on conductor 6 is dependent upon the circuitry coupled across terminals c, d. In every case, however, terminal g is positioned so that corresponding points on the shield and secondary conductors have the same instantaneous high-frequency potential with respect to ground. Therefore, there is no instantaneous potential difference between the shield and the secondary winding and thus no capacitive current flow.

The rules for selectively grounding the shield conductor may better be explained with reference to a circuit which includes a coaxial transformer. FIG. 4 shows a coaxial cable transformer connected as a current transformer. The primary of this transformer is connected to source 12 at terminal a and to load 14 at terminal b. Terminal c of the secondary is connected to ground through a load resistor R, while terminal d is connected to ground through load resistor R. This transformer is not constructed in accordance with the teaching of this invention.

Capacitance \( C_{ab} \) and \( C_{ad} \) represent mutual capacitance between primary winding 2 and secondary winding 4. At this point it is noted that common numerical designates equivalent elements in the different figures. If resistance \( R_a \) and \( R_b \) are equal, then in the absence of capacitive current, the voltages across resistances \( R_a \) and \( R_b \) are equal in magnitude, but of opposite instantaneous polarity with respect to ground. If capacitive current, \( i_C \), flows through the mutual capacitances \( C_{ab} \) and \( C_{ad} \), the voltages across the resistances have additional components, \( i_C R_a \) and \( i_C R_b \) which have the same instantaneous polarity with reference to ground causing \( v_{R_a} = -v_{R_b} \).

The generation of this capacitive current flow between the primary and secondary windings can be explained as follows. In operation, source 12 produces a high-frequency, high potential signal to feed load 14 which may for example be an antenna. As connected in FIG. 4 only a small potential is seen across terminals b, c. For example, with source 12 generating a 1,000 volt peak voltage it is conceivable to have only a 1 volt drop across the primary winding. With \( R_c \) and \( R_d \) of equal magnitude the 1 volt difference between terminals c, d (assuming a 1:1 turns ratio) appears as a 0.5 volt drop across each of the resistors. Thus, by way of explanation only and with no intent to so limit the invention, terminal c may be at +0.5 volts with respect to ground in which case terminal d would be at -0.5 volts with respect to ground. However, terminals a and b are both at approximately 1,000 volts with respect to ground giving rise to a potential difference between terminals a and c and b and d. Of course corresponding potential differences appear between other corresponding points on the primary and secondary windings. This potential difference causes the flow of capacitive current through the mutual capacitance, illustrated as \( C_{ab} \) and \( C_{ad} \), causing transient distortion. Thus in our illustrative example, as can be seen from FIG. 4, the voltage drop across resistor \( R_d \) due to the capacitive current \( i_C \) is in a
direction that causes it to increase the absolute potential of $V_{se}$ such that $|V_{se}| = |0.5 - i_2 R_4|$ while
b. a third conductor located concentric with and between said first and second conductors, and
c. coupling means coupling said third conductor to a
reference potential whereby the instantaneous potential at corresponding points on the second and third conductors are equal so that capacitive
current flow in said second conductor resulting from the mutual stray capacitance between said
first and second conductors is substantially reduced.

FIG. 5 illustrates the circuit of FIG. 4 modified to
include a transformer constructed in accordance with the
teachings of this invention. This transformer includes a
selectively grounded shield conductor 6 surrounding
inner conductor 4 which is functioning as a secondary
winding. Mutual capacitance exists between the prima-
ry winding 2 and the shield conductor 6 as well as
between the shield conductor 6 and conductor 4, as il-
lustrated by capacitances $C_{se}$, $C_{sf}$, and $C_{se}$, $C_{sf}$ respec-
tively.

To eliminate direct capacitive coupling between the
shield conductor 6 and winding 4 there must be no in-
stantaneous voltage difference between the windings.
This is accomplished in accordance with the teachings
of this invention by selectively locating terminal g on
winding 6 and coupling that terminal to ground. With
resistors $R_1$ and $R_2$ assumed equal and with the winding
resistance of conductor 4 distributed uniformly over its
length, the midpoint between terminals c and d is at
ground potential. Therefore, the terminal g is located at
the mid-point of conductor 6 and then connected to
ground. Since points $e$ and $f$ are at the same instantaneous
potential with respect to ground as points c and d
respectively, corresponding points on the shield and
secondary conductors have the same instantaneous
potential. If resistors $R_1$ and $R_2$ are unequal then a point
other then the midpoint of conductor 4 is at ground
potential. In general, the ground point on conductor 4
for the configuration shown is determined by the ratio
of $R_1/R_2$. Therefore the location of terminal g is such
that $n_{pg} = n_{pg} - n_{pg}$, where $n_{pg}$ and $n_{pg}$ represent the
number of turns between points $e$, $g$ and $g$, $f$ respecti-

Introduction of the shield conductor 4 results in a
possible indirect capacitive coupling between the pri-
mary and secondary windings. This indirect coupling
occurs because of the potential difference between the
primary and shield conductors. As a result, capacitive
current flows through the mutual capacitance represen-
ted in FIG. 5 by capacitances $C_{se}$ and $C_{sf}$. This
capacitive current in winding 6 induces a voltage which
by transformer action appears in secondary winding 4
giving rise to capacitive current in the secondary cir-
cuit.

A technique for eliminating this indirect capacitive
coupling will now be explained. For the circuit of FIG.
5, terminal g was positioned at the midpoint of conduc-
tor 6. Therefore, the voltage across capacitors $C_{se}$ and
$C_{sf}$ is $V_{se}$, the source voltage, causing the capacitive
currents $i_{c1}$ and $i_{c2}$ to be of the same magnitude but of
opposite direction and thus their effect is suppressed.
That is, the potential induced in conductor 4 as a result
of $i_{c1}$ and $i_{c2}$ are equal in magnitude but opposite in

polarity. When $R_1$ does not equal $R_2$, the positioning of
the terminal g on conductor 6 is changed to assure that
the instantaneous potential difference at corresponding
points on the shield and secondary conductors is zero.
As previously explained, this requirement is met by
positioning terminal g such that the ratio $n_{pg}/n_{pg} =
R_1/R_2$. In such a case, the capacitive current induced
potential in winding 4 does not cancel and a capacitive
current caused current flows in the secondary cir-
cuit.

FIG. 6 represents an embodiment of the invention incor-
porating means for compensating for this capacitive
current. The potential across conductor 4 due to
 capacitive currents $i_{c2}$ and $i_{c3}$ is given by the expression

$$V_{vc} = n_{pg} V_{cf} - n_{pg} i_{c3}$$

where $n_{pg}$ and $n_{pg}$ represent the number of turns between points $e$ and $f$ on conductor 6 respectively. Therefore, if $V_{vc} > V_{vc}$, $V_{vc}$ can be
reduced by increasing $i_{c3}$. Since $i_{c3} = C_{sf} dV_{vc}/dt$, $i_{c3}$ can be
increased by increasing $C_{sf}$. In practice this is
achieved by increasing the capacitance in the vicinity of
the turns $n_{pg}$.

The added capacitance is illustrated in FIG. 6 by

 capacitor $C_{sf}$. Since conductor 6 protects against
direct coupling between the primary and secondary
windings, an increase in the capacitance between the
primary and shield conductors has no effect upon the
secondary circuit.

FIG. 7a illustrates another transformer arrangement
which incorporates the teachings of this invention. This
embodiment further protects against the introduction
of capacitive induced current in the secondary circuit by
enclosing the transformer in a shielding box.

FIG. 7b is a schematic drawing of the FIG. 7a trans-
fomer configuration. The split primary configuration
illustrated in FIG. 7b is conventional. In such trans-
fomer configurations equal and opposite pulse trains
are applied to the primary side of the transformer to
produce output pulses having twice the amplitude as
the input pulses. However, in accordance with the
teachings of this invention the transformer which in-
cludes shield conductor 6 is surrounded by a shielding
box 20. Terminals a and b, which receive input signals
are connected to primary conductor 2 through
the shielding box 20 by means of coaxial connectors shown
diagrammatically at 7. Terminals h and i are connected
directly to the shielding box 20 by any suitable means.
For example, these terminals may be soldered to the
box 20. Openings are made in the box to permit pass-
geage of conductors 4 and 6. With this configuration
terminals a and b are capacitively shielded from ter-
minals c and d, thus further reducing secondary circuit
capacitance induced current.

FIG. 8 illustrates the applicability of this invention to
a coaxial transformer built with a primary to secondary
turns ratio other than 1:1. Again, shield conductor 6 is
selectively grounded at one point only so that there is
no instantaneous potential difference between cor-
responding points on conductors 6 and 4. In other
respects the configuration of this coaxial cable trans-
fomer is conventional.

Although the invention has been described with re-
spect to the preferred embodiment thereof, it is to be
understood by those skilled in the art that various
modifications can be made in construction and ar-
angement within the scope of the invention as defined
in the appended claims.
What is claimed:

1. In a transformer circuit including a source and load impedance, a coaxial cable transformer comprising:
   a. first and second concentric conductors, said first conductor cylindrically enclosing said second conductor, said first and second conductors functioning as primary and secondary windings, the voltage drop across resistor $R_2$ due to the capacitive current $i_c$ is in a direction that causes it to decrease the absolute potential of $V_{dc}$ such that $|V_{dc}| = |0.5 + i_cR_2|$. Thus, $|V_{ca}| = |V_{dc}|$. This voltage imbalance gives rise to transient distortion of the output.

2. The transformer circuit of claim 1 further including applied capacitance between said first and third conductors to substantially eliminate the resultant capacitive current in said third conductor caused by the mutual stray capacitance between said first and third conductors.

3. The transformer circuit of claim 1 further comprising shielding means surrounding said transformer circuit and electrically connected to one end of said first conductor and said reference source, and connector means for permitting electrical connections through said shielding means to said circuit.

4. The transformer circuit of claim 3 further comprising a fourth conductor surrounding said third conductor, one end of said fourth conductor being electrically connected to said shielding means and means for connecting the other ends of said first and fourth conductor to said connector means.

5. In a transformer circuit including a source and load impedance, a coaxial cable transformer comprising:
   a. first and second concentric conductors said first conductor surrounding said second conductor, said first and second conductors functioning as primary and secondary windings,
   b. a third conductor located concentric with and between said first and second conductors,
   c. coupling means coupling said third conductor to a reference potential to cause the instantaneous potential at corresponding points on the second and third conductors to be equal so that capacitive current flow in said second conductor resulting from the mutual stray capacitance between said first and second conductors is substantially reduced, and
   d. wherein the primary winding of said coaxial cable transformer is serially connected between said source and load, further including a second load impedance coupled between one end of the secondary winding of the transformer and said reference potential and a third load impedance coupled between the other end of said secondary winding and said reference potential, said coupling means being connected to said third conductor at a point along the length of said conductor such that the ratio of the number of turns of said third conductor between said one end and said coupling means to the number of turns of said third conductor between said other end and said coupling means equals the ratio of the values of said second load impedance to the said third load impedance.

* * * * *