

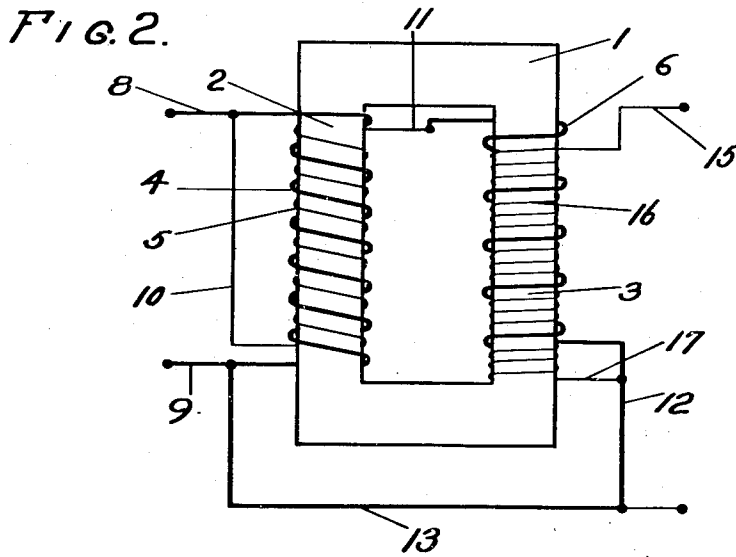
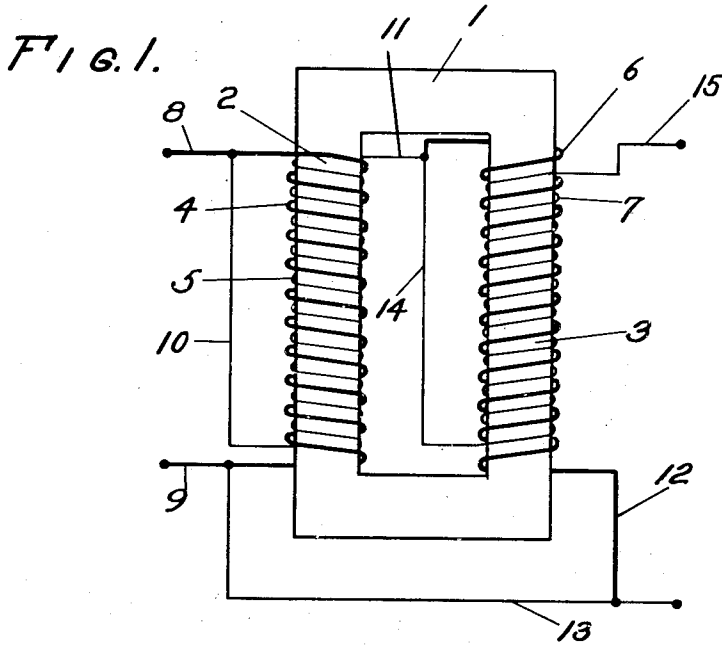
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ELECTRICAL SYSTEM

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ELECTRICAL SYSTEM

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This invention relates to electrical transform-
er systems and more particularly to such systems
as are responsive to a relatively wide band of fre-
quencies.

In order for a transformer system to be useful
over an extended band of frequencies, it is de-
sirable that the product of the distributed cap-
acities and the leakage inductances of the trans-
former system as a whole be reduced to a mini-
mum. Heretofore, attempts substantially to re-
duce such capacity-inductance product, in a
transformer system in which a substantial ratio
exists between the output and the input voltages,
have been unsuccessful.

An object of this invention is to devise a trans-
former system in which the product of the dis-
tributed capacity and the leakage inductance
thereof is substantially reduced below the maxi-
mum values heretofore obtainable.

Another object is to utilize a cascaded trans-
former arrangement utilizing one or more auto-
transformers to accomplish the diminishing of
said capacity-inductance product.

A further object is to utilize an auto-trans-
former in the low impedance section of the trans-
former system to secure the maximum benefits
of my invention.

The foregoing and other objects of my inven-
tion will be best understood from the following
description of exemplifications thereof, reference
being had to the accompanying drawing wherein:

Fig. 1 is a diagram of one embodiment of my
invention; and

Fig. 2 is a diagram of another embodiment of
my invention.

Extended band width or frequency response in
a transformer, as pointed out above, can be ob-
tained by reducing the product of the distributed
capacity and the leakage inductance of the trans-
former windings. The leakage inductance in any
single transformer can be reduced to a minimum
by using a single layer winding each for the pri-
mary and the secondary and winding these lay-
ers with equal lengths directly one over the other.
The effective distributed capacity can also be
minimized by polarizing the windings so that the
voltage difference between the two layers at each
point along them is maintained at a minimum.
For unity ratio between the number of turns of
the primary and secondary windings, the distrib-
uted capacity between these windings can be
made substantially zero for various types of
transformers. As the turns ratio is increased,
however, the distributed capacity becomes sub-
stantial. For purposes of analysis I have divided

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transformers into two types, the iso-transformer
and the auto-transformer. The iso-transformer
is one in which separate windings are utilized for
the primary and secondary windings. The auto-
transformer is one in which the secondary wind-
ing includes at least a portion of the primary
windings, said windings being called respectively
the shunt winding and the series winding.

In an iso-transformer of the above described
two-layer type, the distributed capacity between
the primary and secondary windings is propor-
tional to

$$\left(\frac{N_2}{N_1} - 1\right)^2$$

where N_1 is the number of primary turns and N_2
is the number of secondary turns. In an auto-
transformer of the same type, the distributed ca-
pacity between the series and shunt windings
is proportional to

$$\frac{(K-2)^2}{3} + (K-2) + 1$$

where

$$K = \frac{N_1 + N_2}{N_1}$$

From the foregoing it will be seen that with in-
creasing turns ratios the distributed capacity in-
creases rapidly. The auto-transformer inher-
ently has a higher distributed capacity than the iso-
transformer.

In an iso-transformer of the above type the
leakage inductance is proportional to $(N_2)^2$. In
an auto-transformer of the above type the leak-
age inductance is proportional to the square of
the number of secondary turns which are not
common to the primary. In the usual case in
which all of the primary is common to the sec-
ondary, this leakage inductance becomes

$$(N_2 - N_1)^2$$

Thus it will be seen that increasing the turns ra-
tios also increases the leakage inductance, said
increase being proportionately greater in the
auto-transformer. However, the auto-trans-
former inherently has a lower leakage inductance
than the iso-transformer.

The above analysis shows that where a rela-
tively high step-up ratio between the input and
output voltages of a transformer system is de-
sired, the problem of securing a system having a
wide band of frequency response is aggravated.
If an attempt is made to use a plurality of iso-
transformer sections in cascade for the purpose
of maintaining a relatively low ratio of transfor-
mation for each section, the distributed capacity

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can be reduced substantially. Under optimum conditions in a two-section cascade, the distributed capacity theoretically can be reduced one half. However, the leakage inductance of such a cascade arrangement as a whole increases to such an extent that no significant reduction in the product of capacity and inductance is secured.

Despite the higher inherent distributed capacity of the auto-transformer, I have found that it can be used in a cascade system with a remarkably great reduction in the capacity-inductance product of the system. This effect is particularly marked where an auto-transformer is used in a low impedance section and an iso-transformer is used in a high impedance section of such a cascade despite the higher inherent leakage inductance of the iso-transformer.

An arrangement utilizing a pair of auto-transformers in cascade and embodying the principles of my invention is shown diagrammatically in Fig. 1. In this arrangement the transformer system consists of a core member 1 preferably having a pair of leg sections 2 and 3. The leg section 2 carries a series winding 4 and a shunt winding 5. The leg section 3 carries a series winding 6 and a shunt winding 7. Each of the windings is preferably of the single layer type wound directly one over the other. The series and shunt windings on each leg are likewise preferably of the same length.

The series winding 4 is provided with a pair of end conductors 8 and 9 which are adapted to be connected to a suitable source of alternating current. It is intended that this source shall have a relatively wide band of frequencies to which it is desired that the transformer system be responsive. The shunt winding 5 is wound in the same direction as the series winding 4 and the lower end of said shunt winding is connected by conductor 10 to the upper end of conductor 8 of the series winding 4. The upper end of shunt winding 5 is connected by a conductor 11 to the upper end of the series winding 6. The lower end of series winding 6 is connected by conductors 12 and 13 to the lower end of conductor 9 of the series winding 4. Due to the foregoing connections the windings 4 and 5 constitute a step-up auto-transformer. The ratio of transformation may be any suitable value which, however, should be as low as practicable.

In order that the windings 6 and 7 may be incorporated on the same core structure as the windings 4 and 5, the series winding 6 is wound in such a direction as to set up a flux which passes through the core member 1 in the same direction as the flux set up by the series winding 4. The shunt winding 7 is also wound in the same direction as the series winding 6. The lower end of the shunt winding 7 is connected by a conductor 14 to the upper end of the winding 6. The upper end of the shunt winding 7 is connected by a conductor 15 to one of the output terminals of the transformer system. The lower conductor 13 is connected to the other output terminal of the transformer system. Due to the foregoing connections the windings 6 and 7 likewise constitute a step-up auto-transformer. Here likewise the ratio of transformation may be any suitable value which, however, should be as low as practicable.

The arrangement as described above constitutes two step-up transformers in cascade. As pointed out above these two transformers may be incorporated in a single core structure. Of course

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it is to be understood that a separate core structure could be used for each of these transformers.

Transformers built in accordance with the arrangement as shown in Fig. 1 have had their capacity-inductance product substantially reduced below the minimum which has heretofore been possible with prior arrangements. Furthermore transformers of the type as described in Fig. 1 have been able to respond to a greatly increased band of frequencies.

In order to utilize to a maximum degree the benefits of a cascade containing an auto-transformer section, it is desirable that the auto-transformer be utilized in that portion of the cascade which is connected to the lowest impedance. As higher impedance sections are encountered, it becomes less desirable to use an auto-transformer connection and more desirable to use an iso-transformer connection. Since the lowest impedance section is usually the first step-up section of the cascade, the auto-transformer is preferably used at that point while at one or more succeeding stages the iso-transformer is used, the last or high impedance stage preferably involving an iso-transformer.

A two-stage cascade utilizing the foregoing principles is illustrated in Fig. 2 wherein the same reference numerals are applied where the arrangements are identical with those of Fig. 1. In Fig. 2 it will be seen that the initial transformer, consisting of the windings 4 and 5, is an auto-transformer. Associated with the primary winding 6 is a secondary winding 16. This secondary winding is related to its primary in an iso-transformer step-up relationship. Therefore, a larger number of turns is utilized in the secondary winding 16 than in its primary winding 6. Preferably this step-up ratio is substantially higher than for the auto-transformer windings 4-5. The lower end of the secondary winding 16 may be connected by a conductor 17 to the lower end of the primary winding 6. Since the two transformer sections represent successive step-up transformations, it will be seen that the transformer section 4, 5 is a low impedance section and the transformer section 16 is a higher impedance section. The arrangement as described in connection with Fig. 2 likewise gives a lower capacity-inductance product and a greatly increased frequency response.

The reasons for the beneficial effects derived from the cascade arrangement as the type shown in Fig. 2, I believe, are due at least in part to the following. The capacity C effectively connected across the secondary of a transformer is reflected as an equivalent capacitance C_e across the primary circuit of the transformer, said equivalent capacitance having a value

$$C_e = \left(\frac{N_2}{N_1} \right)^2 C$$

The inductance L effectively in series with the secondary of a transformer is reflected as an equivalent inductance L_e in series with the primary circuit of the transformer, said equivalent inductance having a value

$$L_e = \left(\frac{N_1}{N_2} \right)^2 L$$

Thus the higher the ratio of transformer, the greater will be the effect of the distributed capacity and the smaller will be the effect of the leakage inductance on the system as a whole. The higher transformation ratios are usually associated with the high impedance portions of a

system while the lower transformation ratios are associated with the lower impedance portions of a system. Thus it will be seen that the higher distributed capacity of the auto-transformer will have a minimum effect when used in a low impedance or low transformation ratio section and the higher leakage inductance of the iso-transformer will have a minimum effect when used in a high impedance or high transformation ratio section. I have found that by using an auto-transformer in a low impedance section of a cascade, the effects of its distributed capacity can be made negligible, and by using an iso-transformer in a high impedance section of the cascade, the effect of its leakage inductance can be made negligible.

By utilizing the principles as enunciated above I have been able to construct a transformer system having a substantially flat response to frequencies from about 80 cycles per second to several megacycles per second, which response had heretofore been practically impossible.

Of course it is to be understood that this invention is not limited to the particular details as described above as many equivalents will suggest themselves to those skilled in the art. It is accordingly desired that the appended claims be given a broad interpretation commensurate with the scope of the invention within the art.

What is claimed is:

1. A transformer system comprising a plurality of voltage changing transformer sections connected in cascade, the section having the lowest ratio of transformation comprising an auto-transformer, the section having the highest ratio of transformation comprising an iso-transformer, each of said sections including windings of equal length wound in the same direction, whereby said system has a substantially uniform response over an appreciable frequency band.

2. A transformer system comprising a plurality of voltage changing transformer sections connected in cascade, one transformer section comprising a core member carrying a primary and a secondary winding, another transformer section being an auto-transformer comprising a core member carrying a series and a shunt winding, each of said windings comprising a single layer of turns, the length of the primary winding along its core being substantially equal to the length of the secondary winding along said core, the length of the series winding along its core being substantially equal to the length of the shunt winding along said core, the section having the lowest ratio of transformation comprising the auto-transformer, and the windings of each of said sections being of equal length and wound in the same direction, whereby said system has a substantially uniform response over an appreciable frequency band.

3. A transformer system comprising a plurality of voltage changing transformer sections connected in cascade, each transformer section being an auto-transformer comprising a core member carrying a series and a shunt winding, said windings being superimposed and each comprising a single layer of turns, the length of the series winding of each section along its core being substantially equal to the length of the winding of its associated shunt winding along said core, and said series and shunt windings being wound in the same direction, whereby said system has a substantially uniform response over an appreciable frequency band.

4. A transformer system comprising a plural-

ity of voltage changing transformer sections connected in cascade, one transformer section being an iso-transformer comprising a core member carrying a primary and a secondary winding, another transformer section being an auto-transformer comprising a core member carrying a series and a shunt winding, each of said windings comprising a single layer of turns, the length of the primary winding along its core being substantially equal to the length of the secondary winding along said core, the length of the series winding along its core being substantially equal to the length of the shunt winding along said core, the section having the lowest ratio of transformation comprising the auto-transformer, the section having the highest ratio of transformation comprising the iso-transformer, each of said sections having its windings wound in the same direction, whereby said system has a substantially uniform response over an appreciable frequency band.

5. A transformer system comprising a plurality of voltage changing transformer sections connected in cascade, each transformer section being an auto-transformer comprising a core member carrying a series and a shunt winding, the series and shunt windings of each section being superimposed, of equal length and wound in the same direction on the associated core.

6. A transformer system comprising a magnetic core, a pair of voltage changing transformer sections connected in cascade, one transformer section comprising a primary and a secondary winding wound on said core, another transformer section being an auto-transformer comprising a series and a shunt winding wound on said core, the primary and series windings being wound in a direction to send a magnetic flux through said core in the same direction, the section having the lowest ratio of transformation comprising the auto-transformer, and the windings of each of said sections being of equal length and wound in the same direction, whereby said system has a substantially uniform response over an appreciable frequency band.

7. A transformer system comprising a magnetic core, a pair of voltage changing transformer sections connected in cascade, one transformer section being an iso-transformer comprising a primary and a secondary winding wound on said core, another transformer section being an auto-transformer comprising a series and a shunt winding wound on said core, the primary and series windings being wound in a direction to send a magnetic flux through said core in the same direction, the section having the lowest ratio of transformation comprising the auto-transformer, the section having the highest ratio of transformation comprising the iso-transformer, and the windings of each of said sections being of equal length and wound in the same direction, whereby said system has a substantially uniform response over an appreciable frequency band.

8. A transformer system comprising a plurality of voltage-changing transformer sections connected in cascade, each of said sections including superimposed equal-length windings wound in the same direction, whereby said system has a substantially uniform response over an appreciable frequency band.

9. A transformer system comprising a magnetic core, a pair of voltage changing transformer sections connected in cascade, each transformer section being an auto-transformer comprising a series and a shunt winding wound on said core,

the series windings of both of said sections being wound in a direction to send a magnetic flux through said core in the same direction, and the series and shunt windings of each of said sections being superimposed, of equal length and wound in the same direction.

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