July 30, 1940. R. C. CURTIS 2,209,390

TRANSFORMER SYSTEM

Filed July 27, 1939

FIG. 1

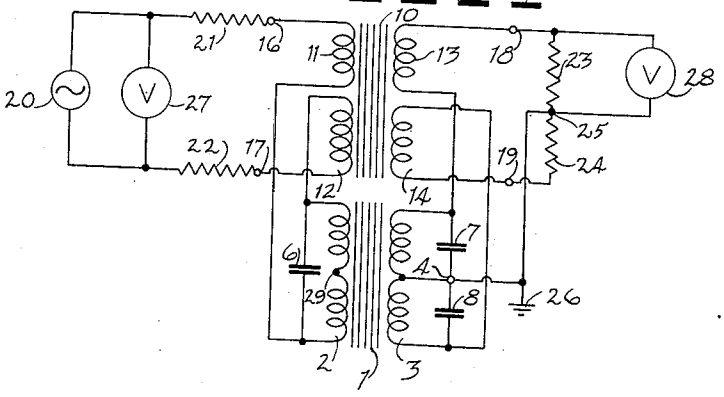


FIG. 2

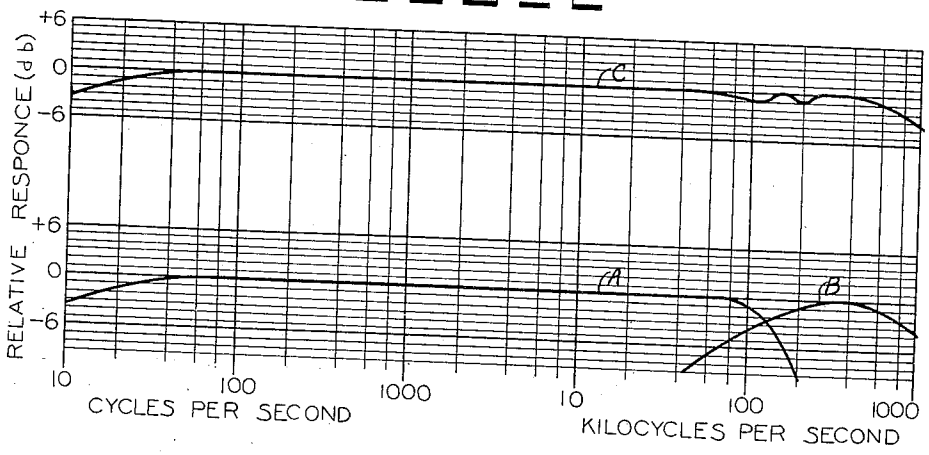
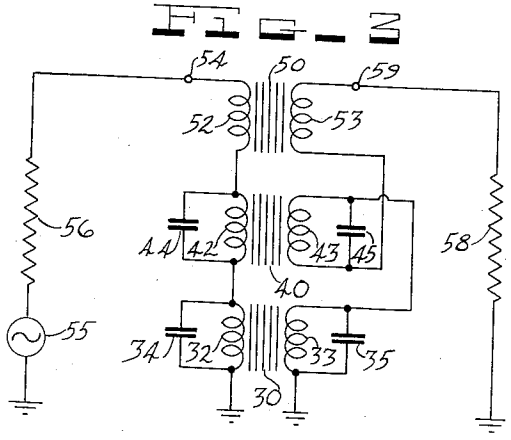


FIG. 3



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TRANSFORMER SYSTEM

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7 Claims. (Cl. 178—44)

This invention relates to electrical transformers and especially to transformers having a useful frequency range extending beyond the audio frequency spectrum.

The principal object of the invention is to extend the frequency range of transformation well into the radio frequency spectrum.

A further object is to provide a transformer covering a continuous band of frequencies from the low end of the audio range up to any desired radio frequency, or between two selected frequencies even though widely separated.

Other objects will become apparent as the description proceeds.

The invention makes use of design features which have enabled transformers to function substantially uniformly throughout the audio frequency range and into the supersonic or very low radio frequencies. Such features are, for instance, low-loss cores of laminated or powdered types, special alloy core metals, and sectionalized windings arranged to give low leakage reactance and low distributed capacity. However, even with the most careful design, the upper frequency limit for such transformers has been in the neighborhood of 140 to 200 kilocycles.

According to the present invention, a plurality of transformer sections, each section designed to cover uniformly a different frequency band, are so connected and so related in their frequency characteristics that in combination they function as a transformer having a continuous range which includes all the frequencies of said bands.

The invention is set forth with greater particularity in the following description and is illustrated in the accompanying drawing, in which:

Fig. 1 represents diagrammatically a two-section transformer according to the invention, with input and output impedances connected thereto;

Fig. 2 shows characteristic curves of the arrangement of Fig. 1; and

Fig. 3 is a diagrammatic representation of a modified three-section transformer.

In Fig. 1, a low frequency transformer section is indicated by its core 1 having thereon a primary winding 2 and a secondary winding 3 provided with a center tap 4. A condenser 6 is connected across the primary 2 and condensers 7 and 8 are connected between the respective ends and center of the secondary 3. A high frequency transformer section is indicated by its core 10 having thereon a divided primary winding 11—12 and a divided secondary winding 13—14.

The primary 2 of the low frequency section is connected in series between the halves 11 and 12 of the high frequency primary. Similarly, secondary 3 is connected in series between the halves 13 and 14 of the high frequency secondary. It should be noted, however, that the connections to primary 2 are reversed in polarity relative to the connections to secondary 3.

The transformer comprising sections 1 and 10 as described, is provided with input terminals 16 and 17 connected respectively to the extreme ends of primary winding 11—12. Similar output terminals 18 and 19 are connected to the extreme ends of secondary winding 13—14, respectively.

In order to simulate conditions of use, the input terminals 16 and 17 may be connected to a source of voltage 20 of adjustable frequency through an input impedance which in Fig. 1 is the sum of resistances 21 and 22. The output terminals 18 and 19 may be connected to an output or load resistance 23—24 having a common point 25 connected to center tap 4 which may be grounded as shown at 26.

For the purpose of measuring the relative response of the transformer, suitable voltmeters 27 and 28 are connected across the voltage source 20 and across the output resistance 23, respectively.

The curves in Fig. 2 are characteristics obtained with the arrangement shown in Fig. 1 when the input impedance is 500 ohms and the output impedance is 10,000 ohms; that is, resistances 21 and 22 are 250 ohms each and resistances 23 and 24 are 5,000 ohms each. The condenser 6 has a capacity of .002 microfarad and each condenser 7, 8 has a capacity of .0002 microfarad. A suitable voltage supplied by source 20 is maintained constant at voltmeter 27 and the resulting secondary voltage at various frequencies is measured by the voltmeter 28. The relative response of the transformer is calculated in the usual way from the voltmeter readings and is plotted against frequency, as in Fig. 2. The normal response is taken at zero decibels (db.) and variations therefrom are plotted in db. above or below normal.

Curve A in Fig. 2 is the characteristic curve of transformer section 1 when section 10 is disconnected, but including the shunt condensers 6, 7, 8. It will be noted that the characteristic is substantially flat from 30 cycles to 100 kilocycles; also, that it is down only about three db. at 10 cycles and at 140 kilocycles. The structure of a transformer having a similar frequency range is described in Patent No. 1,983,657, issued December 11, 1934, to Butler and Weston.

Curve B in Fig. 2 is the characteristic curve of

transformer section 10 when section 1 is disconnected. It will be noted that this curve is substantially flat from 200 to 600 kilocycles and is down only about four db. at 100 kilocycles and at 1000 kilocycles.

Curve C is the characteristic curve of the complete transformer comprising the two sections 1 and 10 connected in series and including shunt condensers, as shown in Fig. 1. It will be noted that curve C is substantially flat throughout the entire range from 30 cycles to 600 kilocycles; also that curve C is down only about four db. at 1000 kilocycles, which is well within the radio frequency spectrum.

It is important that either the primary or the secondary of one transformer section be reversed in polarity relative to the other windings. Ordinarily, such reversal of connections would cause the transformer sections to oppose each other and reduce their output to a low value. However, inasmuch as the opposed sections 1 and 10 cover different frequency ranges, they have substantially no effect on each other except in the band of frequencies where their characteristic curves overlap. In Fig. 2, such band may be taken as approximately from 70 to 170 kilocycles. This is the upper end of curve A for transformer section 1, where its impedance is determined by the shunt condensers 6, 7 and 8 and is therefore capacitative, the inductive reactance of windings 2 and 3 being practically infinite at such frequencies. The reversal of polarity of one winding in accordance with this invention prevents the mutual inductance of section 10 from resonating with capacities 6, 7 and 8 to form a short circuit across the load. Such short circuit would occur if the mutual inductance were positive, but cannot occur when the mutual inductance is made negative by such reversal. The result is that the relative response of the transformer remains substantially constant in the overlapping band, as shown by curve C.

At the frequency where the response curve of section 1 alone, without the shunting condensers, would be down about three db., which may be called the transfer frequency, the reactance of condensers 6, 7 and 8 should be approximately equal to the impedance with which each condenser is associated. For instance, the reactance of primary shunting condenser 6 should equal approximately the input impedance 21—22, and the reactance of each of the condensers 7 and 8 should equal approximately the resistances 23 and 24, respectively, at the transfer frequency of section 1 which is about 160 kilocycles. The above mentioned capacities for condensers 6, 7 and 8 follow this rule, but preferably they should be smaller to allow for the distributed capacities of windings 2 and 3. With such allowance the curve C would be even more uniform in the overlapping range. It is understood, of course, that if the windings have sufficient distributed capacity, the shunt condensers may be omitted. The inductive reactance of windings 11, 12 in series at the transfer frequency should equal one-half of the generator impedance 21, 22. Since the turns ratio of section 10 is the same as section 1, the inductive reactance of windings 13, 14 in series will be equal to one-half of the total load resistance 23, 24 at the transfer frequency.

In practical operation of the two-section transformer of Fig. 1, its primary terminals 16 and 17 are connected to a 500 ohm telephone circuit or the like, whereas its secondary terminals 18 and 19 and tap 4 may be connected to a pair of vacuum tubes in push-pull arrangement or to other translating devices or loads. If a balanced or push-pull input is desired, a neutral grounded connection may be made to the center 29 of primary 2 and the condenser 6 divided into two equal condensers each of double capacity.

Fig. 3 shows a simple transformer without center taps and having its primary and secondary grounded at one end. The transformer of Fig. 3 has three sections covering, respectively, low, intermediate and high frequency bands. The low frequency section has a core 30, primary winding 32 and secondary winding 33. It may be designed for the frequency range from 30 to 15,000 cycles. Its primary is shunted by a condenser 34 and its secondary is shunted by a condenser 35. The intermediate section has a core 40 and primary and secondary windings 42 and 43, respectively, which may be designed for the range from 10 kilocycles to 200 kilocycles. Primary 42 is shunted by condenser 44 and secondary 43 is shunted by condenser 45. The high frequency section has a core 50, primary winding 52 and secondary winding 53, which may be designed for the range from 100 to 1000 kilocycles. No condensers are used across the high frequency windings 52 and 53.

All of the primary windings 32, 42 and 52, are connected in series and thence through terminal 54 to an input source 55 having impedance 56. All of the secondary windings are connected in series and to an output impedance 58 through terminal 59. The connections to the secondary winding 43 of the intermediate section are reversed for the reason explained above. If desired, the primary may be reversed instead of the secondary. The reactance of each condenser 34 and 44 and winding 52 should be about equal to the input impedance 56 and the reactance of each condenser 35 and 45 and winding 53 should be about equal to the output impedance 58 at their respective transfer frequencies. For the ranges stated above the transfer frequency for condensers 34 and 35 may be taken as 13 kilocycles and the transfer frequency for condensers 44 and 45 and also windings 52 and 53 may be taken as 160 kilocycles.

It will be noted that the three-section transformer of Fig. 3 covers substantially the same total range of frequencies as the two-section transformer of Fig. 1. The principal advantage of the three-section arrangement is that its low frequency section covers only the audio frequency band, whereas the low frequency section in Fig. 1 must cover both the audio frequency band and the band from the upper range of audibility to about 140 kilocycles. The narrower bands covered by each section of the three-section arrangement permit greater freedom of design of the individual sections.

The transformer sections are shown as having separate cores which may be mounted in one frame or container. It may be desirable in some cases, to put all of the windings on one core, in which event sufficient magnetic leakage should exist between adjacent sections to prevent deleterious action between their windings. Separate cores are preferable, however, because cores and windings for high frequency sections are much smaller and usually of different construction and core material than cores and windings for low frequency sections.

The invention is not limited to two-section or three-section transformers, but any number of sections may be provided and the continuous

range of frequencies covered may extend as high as any single section can conveniently be made. In transformers having more than three sections, one winding of each alternate section should be reversed in polarity as above mentioned and proper shunting condensers should be provided across all windings except in the highest frequency section.

Although certain preferred embodiments have been described and illustrated, it is not intended that the invention be limited thereto and it is obvious that many modifications can be made within the true spirit and scope of the invention.

What is claimed as new and original to be secured by Letters Patent of the United States is:

1. A wide frequency range transformer comprising, a plurality of transformer sections, each section covering substantially uniformly a different wide range of frequencies and having a primary winding and a secondary winding, the primary windings of said sections being connected in series and the secondary windings thereof also being connected in series, the connections to one winding of each alternate section being reversed in polarity relative to the other windings so that the mutual inductance of said reversed section is negative, and condensers shunting the windings of all said sections except the primary and secondary windings of the section which covers the highest frequency range.

2. A wide frequency range transformer comprising, a plurality of transformer sections having their primary and secondary windings respectively connected in series but with the polarity of at least one winding reversed relative to the other windings so that the section containing said reversed winding has a negative mutual inductance, each said section covering substantially uniformly a different portion of the total frequency range of said transformer with the portion covered by each section overlapping the portion covered by the next higher frequency section for only a small percentage of said total frequency range.

3. A wide frequency range transformer comprising a plurality of transformer sections having their primary and secondary windings respectively connected in series but with the polarity of at least one winding reversed relative to the other windings, each said section covering substantially uniformly a different portion of the total frequency range of said transformer with the portion covered by each section overlapping the portion covered by the next higher frequency section for only a small percentage of said total frequency range, and wherein each primary and secondary, except those of the lowest frequency section, has an inductive reactance at its lower frequency limit approximately equal to one-half of the input and load impedances, respectively, and each winding except those of the highest frequency section has a capacitative reactance effectively in shunt therewith approximately equal to the associated impedance at the upper frequency limit of said winding.

4. A transformer having a continuous and substantially uniform response from low audio frequencies to frequencies well within the radio frequency spectrum, said transformer comprising a plurality of sections each having primary and secondary windings arranged to give substantially uniform response over a different portion of said frequency range, said portions overlapping for a relatively narrow band of frequencies, connections between adjacent sections whereby the primary and secondary windings are respectively in series, one winding of each two adjacent sections being connected with reverse polarity, and a shunt capacity for each said winding except in the highest frequency section such that the reactance of said capacity at the upper frequency limit of its corresponding winding is approximately equal to the impedance associated with said winding, the inductive reactance of each primary and secondary at its lower frequency limit being approximately equal to one-half the input and output impedances, respectively associated therewith, except in the lowest frequency section.

5. A wide frequency range transformer comprising, a relatively low frequency section and a higher frequency section, primary windings for said sections connected in series and secondary windings for said sections connected in series, one of said windings being connected with reverse polarity, and condensers shunting the primary and secondary of said low frequency section so that the capacitative reactance across said primary is approximately equal to the input impedance associated with the transformer at a frequency common to both said sections and so that the capacitative reactance across said secondary is approximately equal to the load impedance associated with the transformer at said common frequency.

6. A transformer comprising an audio frequency section, a supersonic frequency section and a radio frequency section, each section having a primary winding connected in series with the other primaries, each section also having a secondary winding connected in series with the other secondaries, one winding of the supersonic section being connected with reverse polarity, and condensers shunting the respective windings of only the audio and supersonic frequency sections.

7. A transformer as defined in claim 6 wherein each primary and secondary of the audio and supersonic frequency sections has a capacitive reactance at its upper frequency limit, including the reactance of its shunt condenser, which is approximately equal to the input and load impedances respectively of said transformer; and wherein each primary and secondary of the supersonic and radio frequency sections has an inductive reactance at its lower frequency limit which is approximately equal to one-half of said impedances respectively.

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