Feb. 7, 1961 HITOSHI H. KAJIHARA 2,971,173

WIDE BAND RADIO FREQUENCY TRANSFORMERS

Filed Nov. 25, 1957

FIG. 1

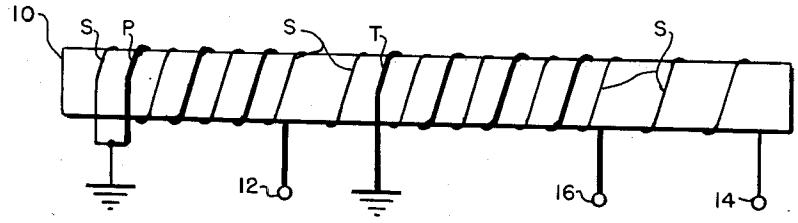


FIG. 3

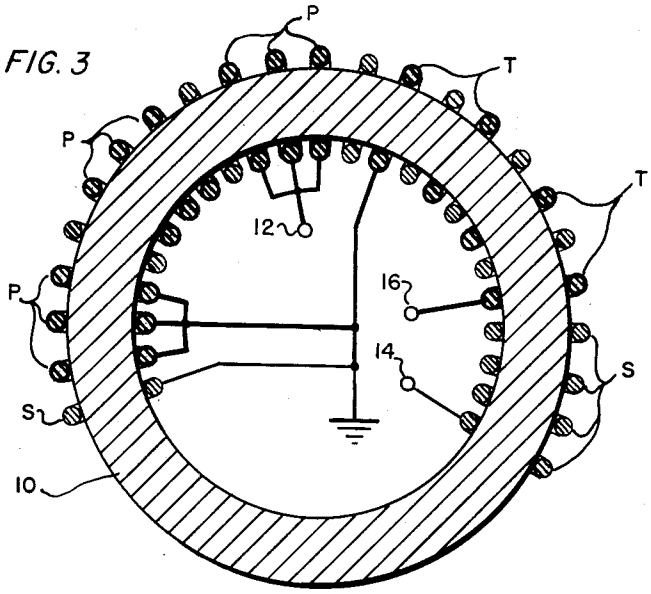
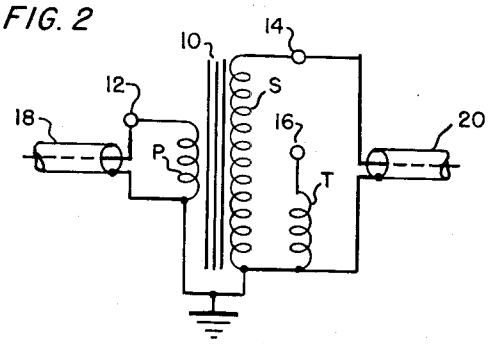


FIG. 2



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WIDE BAND RADIO FREQUENCY TRANSFORMERS

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2 Claims. (Cl. 336—170)

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The invention described herein may be manufactured and used by or for the Government for governmental purposes without the payment to me of any royalty thereon.

The present invention relates to wide band radio frequency transformers and more particularly to such transformers operating in the region between 1 mc. and 200 mc.

In designing an efficient transformer, it is necessary to select a magnetic core material having a low core loss and a high permeability. In the present state of core material development, ferrites are the most suitable materials for use in wide band transformers operating above 1 mc., since they most favorably satisfy the low core loss and high permeability requirements. However, their permeability values are still not high enough, since at those frequencies they provide a coefficient of coupling of which is less than unity. Therefore, the input impedance, which is a function of the coefficient of coupling, will exhibit a reactive component as well as a resistive component, the magnitude of each of these components being a function of the frequency.

It is desirable to reduce the reactive component of the input impedance to as low as value as possible when the transformer is being matched to a resistive source. It is further desirable that the input impedance be relatively constant over the entire frequency band in which the transformer operates.

It is an object of the present invention to provide a simple and efficient radio frequency transformer to operate over a wide band of frequencies.

It is a further object of the invention to provide a wide band radio frequency transformer having a minimum leakage inductance.

It is a further object of the present invention to provide a wide band radio frequency impedance matching transformer having a substantially resistive input impedance characteristic.

An analysis of the input impedance characteristic of the complete basic equivalent network of a wide band radio frequency transformer indicates that the most critical parameters which determine the bandwidth are the leakage inductance and the secondary distributed capacitance.

In accordance with the present invention the effect of leakage inductance is minimized by providing a tertiary winding having its turns interspersed between the secondary turns.

The exact nature of this invention, as well as other objects and advantages thereof, will be readily apparent from consideration of the following specification taken in connection with the annexed drawing, wherein like reference characters designate similar elements, and wherein:

Fig. 1 is a schematic diagram of a transformer built in accordance with the invention;

Fig. 2 is a schematic circuit diagram of a circuit incorporating the transformer in Fig. 1; and

Fig. 3 is a cross section of a practical embodiment of the transformer in Fig. 1.

In Fig. 1 there is shown a transformer comprising a core **10** of magnetic material about which are wound a primary winding P, a secondary winding S, and a tertiary winding T.

Core **10** is of a material which has a high permeability and low core losses. Suitable core materials are ferromagnetic ferrites of the general formula $XOFe_2O_3$, where X stands, in general, for a bivalent metallic ion such as nickel, zinc, magnesium, and others, or mixtures thereof. In some cases a monovalent ion such as lithium is used. One type of commercially available ferrite suitable for the purposes of this invention is sold under the trade name "Ferramic." Although a linear core is shown, it is preferable to make it toroidal in shape in order to minimize leakage inductance.

Primary winding P is bifilarly wound around the core with a portion of the secondary winding S, i.e., the turns of the primary alternate with a portion of the secondary. In the example illustrated, the secondary S consists of eleven turns and the three turns of the primary alternate with the first three turns of the secondary. Similarly wound, are the four turns of the tertiary winding, which alternate with the next four turns of the secondary. The number of turns given are merely illustrative.

The end turns of both the primary and secondary are connected to a common terminal which may be grounded. The other ends of the primary and secondary are connected to terminals **12** and **14**, respectively, which constitute the high potential terminals of the coils. The end of the tertiary coil nearest the high potential end of the primary is also connected to the common terminal, while the other end of the coil, represented by terminal **16**, is adapted to be used as an open terminal, i.e., no portion of a circuit is connected thereto.

In Fig. 1, the primary and tertiary turns are drawn more heavily than the secondary turns merely to make it easier to distinguish them. It does not necessarily represent any difference in the structure thereof.

The manner in which the transformer is connected to a circuit is illustrated in Fig. 2. Input signals are applied to primary coil P through a transmission line **18**. The secondary coil S is connected to a load through a transmission line **20**. The tertiary T is connected to ground at one end and the other terminal **16** thereof is left unconnected.

Fig. 3 shows a preferred practical embodiment of a 25 watt transformer built in accordance with the invention. It is designed to operate over a bandwidth of 20 megacycles to 70 megacycles and match a 92 ohm input cable to a 1200 ohm load.

The core **10** is cylindrical in shape, having an outer diameter of $1\frac{15}{16}$ inches, an inner diameter of $1\frac{7}{16}$ inches, and a $\frac{3}{4}$ inch. Actually it is made of two superposed elements each $\frac{3}{8}$ inch in height. The core material is a commercial ferrite available under the trade name Ferramic Q2 and comprises a mixture of 18.2% nickel oxide, 8.6% zinc oxide, and 73% iron oxide. The secondary coil S consists of elevent turns of No. 14 wire.

The primary coil P consists of three turns of No. 14 wire, each turn of the primary consisting of three separate strands of wire wound side by side. The three primary turns respectively alternate with the first three turns of the secondary. The tertiary coil T consists of four turns of No. 24 wire, said turns respectively alternating with the fourth to seventh turns of the secondary coil.

In Fig. 3 the primary and tertiary coils are shown in heavier lines merely for clarity in illustration. For the same reason, the turns of the coils are shown somewhat

separated from the core and from each other, but in practice they may be wound close together.

The effect of the tertiary coil, as shown in actual measurements, is to increase the secondary distributed capacitance. It can be shown that the highest operating frequency of the transformer will be limited by the resonance between the leakage inductance and direct capacitance between primary and secondary. It is evident, therefore, that minimizing leakage inductance becomes of utmost importance for high frequency operation. Also to be considered is the effect of the reflected load resistance, as seen at the input terminals. It is affected by the immediate shunting capacitance, leakage inductance and direct capacitance. Depending on the frequency of operation, it is possible, by the use of the tertiary coil, to reproportion the secondary distributed capacitance to make the apparent primary inductance larger than its actual value. This permits reduction of the number of turns with resultant reduction in the leakage inductance and adjusts the reflected load resistance to a more favorable value. In this manner operation over a wider frequency band at higher frequencies is achieved. Actual measurements have shown, that for a given transformer, when used in accordance with this invention, the useful frequency range is several times greater than without the tertiary coil.

While there has been described what is at present considered a preferred embodiment of the invention, it will be obvious to those skilled in the art that various changes and modifications may be made therein without departing from the invention, and it is aimed in the appended claims to cover all such changes and modifications as fall within the true spirit and scope of the invention.

What is claimed is:

1. A wide band radio-frequency transformer for operation in the region between one megacycle and two hundred megacycles comprising a toroidal core, a secondary coil wound on said core, a primary coil bifilarly wound with a portion of said secondary coil, a means to increase the distributed capacity of said secondary coil, said means comprising a tertiary coil bifilarly wound with another portion of said secondary coil, the first turn of each of said coils being connected in common, the last turn of said primary and secondary coils being connected to separate terminals which respectively form with said common terminal the input and output circuits of said transformer, the last turn of said tertiary coil being an open circuit.

2. A transformer as set forth in claim 1, wherein the first turn of said tertiary coil is substantially adjacent to the last turn of said primary coil and wherein said toroidal core is a ferrimagnetic ferrite of the general formula $XOFe_2O_3$, where X stands for a bivalent metallic ion composition.

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