

Feb. 11, 1958

C. WENTWORTH

2,823,359

MINIATURE INTERMEDIATE-FREQUENCY TRANSFORMER

Filed June 1, 1954

Fig. 1.

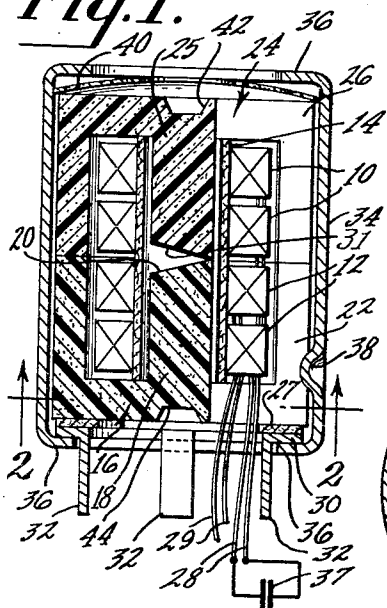


Fig. 4.

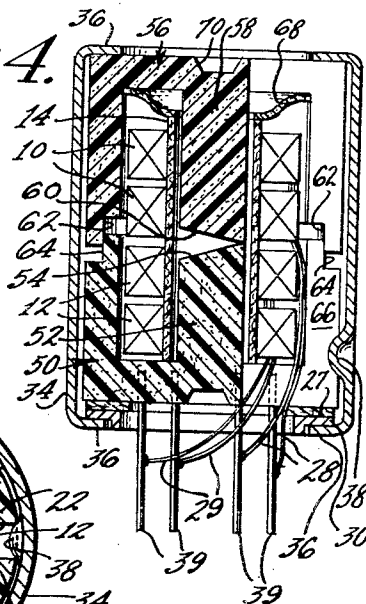


Fig. 2.

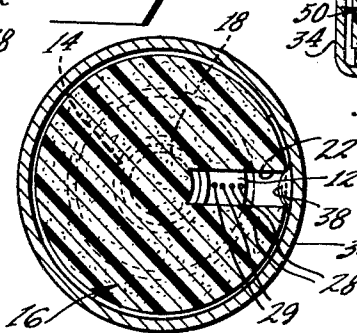


Fig. 5.

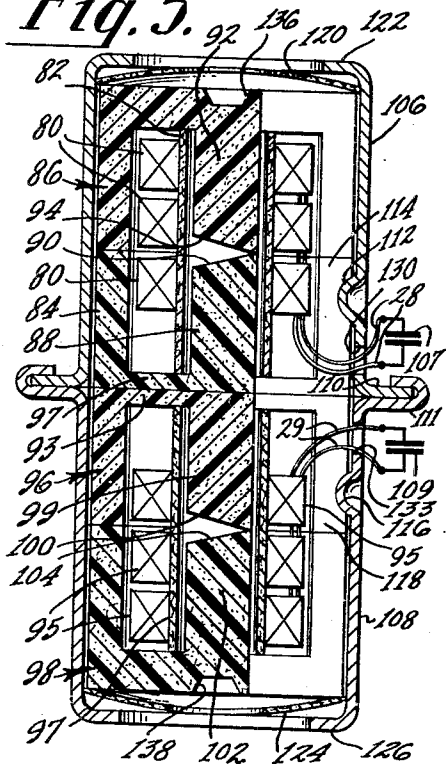
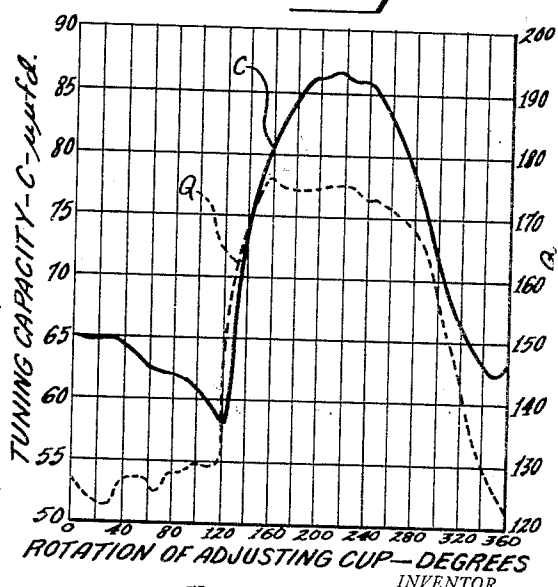


Fig. 3.



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1

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MINIATURE INTERMEDIATE-FREQUENCY
TRANSFORMERChandler Wentworth, Princeton, N. J., assignor to Radio
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Application June 1, 1954, Serial No. 433,362

2 Claims. (Cl. 336—30)

This invention relates to intermediate-frequency transformers and more particularly to coupling transformers of that type which are adapted for use in modern miniaturized radio receivers and the like.

In the past, the size of the various components of radio receivers and the like, was not an important factor since such equipment was ordinarily not designed to be readily portable and space was not a consideration. Today, portable and easily transportable radio and like equipment is becoming increasingly important, and the size and weight of the components therein are becoming a determining factor in the reduction of the size of the equipment. Also radio communications equipment is more complex and the physical space requirements of such equipments may be relatively large. Consequently, miniaturization of tubes and components has been of prime importance to the radio industry.

Until recently in the manufacture of intermediate-frequency transformers for use in superheterodyne radio receiver circuits, it has been the custom to use air cores or "slug" cores. Transformers having a ferromagnetic core or "slug" can be made smaller in size than an air core transformer. An example of such a transformer is found in the U. S. patent to Harvey 2,364,291, issued December 5, 1944, for an Intermediate-Frequency Transformer.

With the advent of the use of transistors and miniature and sub-miniature tubes it became desirable to have still smaller transformers to accompany these much smaller tubes and transistors.

Miniaturization of intermediate-frequency transformers leads to many problems. It is necessary, of course, to maintain the overall efficiency needed in such transformers by keeping the "Q" of the transformer windings at a high value. At small sizes stability of operation becomes difficult to achieve, and the tuning adjustment becomes critical if the conventional type of construction is attempted.

Accordingly, it is an object of this invention to provide an intermediate-frequency transformer for radio receivers and the like that is physically much smaller than presently available intermediate-frequency transformers, while at the same time providing a high degree of operating efficiency.

It is another object of this invention to provide a miniature intermediate-frequency transformer that retains the "Q," tuning range, and stability of a conventional intermediate-frequency transformer, and which may be manufactured and assembled at low cost and with a minimum number of parts.

It is another object of this invention to provide a miniature intermediate-frequency transformer that is tunable over a relatively broad frequency band.

It is yet another object of this invention to provide a temperature-compensated miniature intermediate-frequency transformer.

These and further objects and advantages of the pres-

2

ent invention are achieved, in general, by providing a split ferrite outer core element surrounding and enclosing highly miniaturized and formed primary and secondary windings or coils of the transformer and a central core element integral with the outer core element surrounded by the transformer windings. This construction provides an enclosed path of high permeability for the flux of the transformer except for a small air gap in the flux path provided by bevelling the adjacent faces of the central core elements at the point where they would otherwise abut. Adjustment of certain operating characteristics of the transformer, such as the frequency response, is provided by varying the space between the central core faces and the air gap, by rotating or turning the ferrite cores one with respect to the other. In order that the degree of miniaturization may be comprehended, it may be pointed out that a 455 kc. intermediate-frequency transformer in accordance with the invention can be made in the shape of a cylinder having a diameter of the order of $1\frac{1}{32}$ inch and a length of the order of $\frac{7}{16}$ inch overall.

However, the invention itself, both as to its organization and operation will be best understood from the following description when read in connection with the accompanying drawings, in which:

Figure 1 is a vertical sectional view of an intermediate-frequency transformer constructed in accordance with the present invention;

Figure 2 is a horizontal sectional view of the embodiment shown in Figure 1 taken through line 2—2;

Figure 3 is a graph showing curves illustrating certain performance characteristics of a transformer constructed in accordance with the invention, as shown in Figure 1;

Figure 4 is a vertical sectional view of a transformer illustrating a modification of the invention with temperature compensation;

Figure 5 is a vertical sectional view of a double tuned transformer as a further embodiment of the present invention.

Referring now to the drawings wherein like elements are designated by like reference numerals throughout the figures, and referring particularly to Figures 1 and 2, an intermediate-frequency (I. F.) transformer in accordance with the present invention includes primary windings constituted by spaced coils 10 and secondary windings constituted by spaced coils 12, wound or mounted in any suitable manner on a coil form 14 of insulating material. The coil form carrying the primary and secondary coils 10 and 12 rests in a fixed ferrite cup 16 or cup-like member. The fixed cup 16 is cylindrical in form and has a solid cylindrical central core 18 extending from the closed end or bottom of the cup, coaxial and coextensive with the walls thereof. The upper or free end of the core 18 has a bevelled end face 20 extending from the plane of the open end of the cup toward the closed end or bottom. The cup 16 in which the coil form 14 and coils 10 and 12 rest also has a radial slot 22 therein extending through the side walls and through the closed end or bottom radially inwardly to the core base, as shown more clearly in Figure 2. One purpose of this slot is to provide means for connecting primary and secondary leads 28 and 29 to the coils.

An adjusting ferrite cup 24, identical with the first cup member rests with its open end on the open end of the first cup 16, and has a central core 25 also with a correspondingly bevelled end face 31. When fitted together in this manner the walls of the cups 16 and 24 form the outer core element, the central cores 18 and 25 of the cups 16 and 24 form the central core element, and the bevelled end faces 20 and 31 of the central cores 18 and 25 provide the desired air gap in the flux

path of the transformer. The radial slot 26 is not required in the adjusting cup 24, but in production it is easier and more efficient to make all the cups the same, since the slot 26 in the adjusting cup 24 does not affect the performance of the transformer.

The fixed cup 16 rests on an insulating fiber washer 27 that prevents the leads 28 and 29 to the coils 10 and 12, from coming into contact with the metal or conducting parts of the transformer. The insulating washer 27 in turn rests on a mounting ring 30, preferably of sheet metal, which has downwardly projecting lugs 32 that are used for mounting the transformer.

Surrounding the internal parts of the transformer is an outer tubular casing 34, preferably of conducting material such as metal, having inwardly projecting annular end flanges 36 which are formed to hold the parts in place. The case 34 has an indentation 38 projecting into the slot 22 in the wall of the fixed cup 16 to hold this cup in place and to keep it from turning as the adjusting cup 24 is turned for tuning, as will be more fully explained hereinafter. A spring washer 40 serving as a spring member between the closed end of the adjusting cup 24 and the annular top flange 36 resiliently holds the parts together. A screw driver slot 42 in the closed end of the adjusting cup 24 provides means to rotate the cup. (A similar slot 44 is present in the fixed cup 16, but is not used and hence is not necessary except to bring about production economies.)

It will be noted that the bevelled end faces 20 and 31 of the central cores 18 and 25 touch at only one angular position of the adjusting cup 24. Figure 1 shows the angular position of the adjusting cup 24 with respect to the fixed cup 16, in which the central cores 18 and 25 touch and the air gap is smallest, and hence the permeability of the entire flux path for the transformer, i. e. the inner and outer core elements, is greatest. If the adjusting cup 24 be rotated 180° the bevelled end faces 20 and 31 will be farthest apart and the air gap will be greatest and the permeability of the flux path the least.

Any suitable ferrite having low loss and high permeability characteristics may be used in the construction of the cup members 16 and 24. One that has proved to have desirable characteristics in addition to good temperature stability is of the following materials and may be made in the following manner and proportions: 24.2 grams of nickel oxide (NiO), 49.1 grams of zinc oxide (ZnO), 127 grams of ferric oxide (Fe₂O₃), and .2 gram of cobalt oxide (CoO), are mixed and milled with 250 cc. of methanol for four hours in a steel mill, approximately four inches by four inches inside diameter and depth; charged ½ full of ½ inch diameter steel balls; and revolved at 80 revolutions per minute. The material is then dried thoroughly at 120° centigrade, passed through a 20 mesh screen, and calcined in a fire clay crucible at 950° centigrade for one and one-half hours. It is then milled again with 150 cc. of methanol for 22 hours, again dried at 120° centigrade and passed through the 20 mesh screen. Binder for the material is made in the following manner: To every 100 grams of ferrite material, prepared as described above, 30 grams of water, 4 grams of "Cerumel C" wax emulsion (made by the Socony Vacuum Oil Company), and .5 gram of trigamine oleate (a one to one mixture of "Trigamine"—made by Glyco Products—and oleic acid—C₁₇H₃₃CO₂H), are added and thoroughly mixed. The mixture is then dried at 120° centigrade and screened again through a 20 mesh screen. Enough carbontetrachloride (CCl₄) is added to the material to just form a liquid mixture, boiled and stirred until the carbontetrachloride evaporates, is then passed through a 30 mesh screen, and then dried for one hour at 120° centigrade. The molding of the material is done at 9000 pounds per square inch, and the cups are fired in air at 1050°±20° centigrade for three hours and allowed to cool in the furnace as the furnace cools.

In operation, a fixed shunt capacitor 37, indicated

schematically, is used to form a tuned circuit with the primary of the transformer (or the secondary, if desired). The adjusting cup 24 is rotated by a screw driver (not shown) inserted in the slot 42 in the closed end of the cup 24 until the desired operating characteristics are obtained. Rotation or turning of the adjusting cup 24 to a different position changes the relative positions of the bevelled end faces 20 and 31 of the central cores 18 and 25 with respect to each other and hence changes the effective length of air gap in the flux path. Altering the flux path for the coils changes the inductance, the "Q," and the tuning of the transformer. Figure 3 is a graph of the variations of the "Q" of the primary coil of the transformer and the capacitance required to resonate the primary of the transformer at 455 kc. plotted against the angular position of the adjusting cup 24.

The mutual inductance between the primary and secondary windings is determined by the manner in which the coils are spaced on the coil form 14.

In Figure 4 a modification of the invention is shown wherein temperature compensation is provided without an appreciable loss in the "Q" of the transformer. Primary coils 10 and secondary coils 12 for the transformer are again disposed as desired on a form 14. The form 14 rests in a fixed ferrite cup 50 of hollow cylindrical design similar to that of Figure 1 with one end closed and with a central cylindrical core 52 having a bevelled end face 54 extending axially of and coextensive with the cup walls; and an identical adjusting cup 56 is fitted thereover, having a central core 58 with a bevelled end face 60.

In this embodiment, however, the open ends of the side walls of the cups have oppositely recessed and shouldered portions as shown to provide a lap joint between them. To this end the adjusting cup 56 has a relatively deep annular recess 62 in its open end, and the fixed cup 50 has an elongated cylindrical portion or shouldered end of reduced diameter 64 as its open end extending from the shoulder. The inner surface of the recess 62 on the adjusting cup 56 fits smoothly over the outer surface of the shouldered end 64 on the fixed cup 50 to form a lap or expansion joint. The lap joint in the walls of the cup members 50 and 56 allows temperature compensation without excessive flux leakage since there is always a relatively high permeability flux path through the lap joint.

An insulating washer 27 and mounting ring 30 (without the mounting lugs 32 shown in Figure 1) are held in place by the annular flanges 36 formed at either end of the outside case 34, and the fixed cup 50 is held from rotation by an indentation or bead 38 in the outside case 34 extending into a slot 66 in the side wall of the fixed cup 50. A spring washer 68, which may be of fiber, is held in compression interposed between one end of the form 14 and the inside of the closed end of the adjusting cup 56. It will be noted that in this embodiment there is no spring washer or other means to hold the cups 50 and 56 firmly together between the outside of the closed end of the adjusting cup 56 and the case 34, but rather the fiber washer 68 holds each cup 50 and 56 firmly against the flanges 36 of the outside case 34.

The mounting means for the transformer are a series of metal pins 39 molded or otherwise suitably imbedded in the fixed cup 50. The pins 39 are spaced so that they may be plugged into one of the miniature or subminiature type of tube sockets. The primary and secondary leads 28 and 29 are brought through the slot 66 and fastened by spot welding or other suitable means to the pins 39. It is possible to connect the transformer leads to the pins in this manner because the ferrite of which the cups are made has a very high electrical resistance. The pins 39 can be made of any suitable material, although Nichrome wire is preferred.

The inductance of this transformer is adjusted in a similar manner to that shown in Figure 1. Turning of

the adjusting cup by a screw driver (not shown) in a screw driver slot 70, rotates the bevelled end faces 54 and 60 of the central cores 52 and 58 with respect to each other thereby changing the effective length of the air gap, and hence the inductive characteristics of the transformer.

Ferrite has a positive temperature coefficient of permeability, and also, as the temperature rises the ferrite of which the cups 50 and 56 are made expands and thus tends to cause an increase in the inductance of the transformer windings; but the outer case 34 expands to a greater extent than the ferrite cups, the net result being that the cups 50 and 56 are pushed slightly farther apart by the compressed fiber washer 68 creating a larger air gap between the bevelled end faces 54 and 60 and substantially compensating for or nullifying the tendency to increase the inductance.

The previously described embodiments of the invention encompass intermediate-frequency transformers of the single tuned variety, that is, only one winding, the primary or the secondary of the transformer, has a capacitor associated therewith to form a tuned circuit. The other side of the transformer is left untuned. In case greater selectivity is desired than that which can be obtained with a single tuned transformer, it is the usual practice to use a double tuned transformer, that is, both primary and secondary windings have shunt tuning capacitors to form therewith tuned circuits as is well known.

Referring now to Figure 5, a double tuned intermediate-frequency transformer in accordance with the present invention includes a primary winding comprising coils 80 spaced on a primary coil form 82. The primary coil form and windings are enclosed by two ferrite cups as in the construction shown in Figure 1, being a primary fixed cup 84 and a primary adjusting cup 86. The primary fixed cup 84 has a central cylindrical core 88 integral with the closed end of the cup and coextensive with the cup axially thereof, and the central core 88 is provided with a bevelled end face 90. The primary adjusting cup 86 also has a corresponding central core 92 with a bevelled end face 94. Secondary coils 95 are spaced on a secondary coil form 97 and similarly enclosed in two ferrite cups, a secondary fixed cup 96 and a secondary adjusting cup 98. The secondary fixed cup 96 has a central cylindrical core 99 integral with the closed end of the cup and the core 99 has a bevelled end face 100. And the secondary adjusting cup 98 has a corresponding central core 102 with a bevelled end face 104.

The two pairs of cups are in axial alignment, with the closed end or bottom of the primary fixed cup 84 adjacent to the closed end or bottom of the secondary fixed cup 96. An upper cylindrical outer casing 106 and a lower cylindrical outer casing 108, preferably of some conducting material such as metal, are fitted from opposite ends over the combined cups and an outwardly projecting radial flange 111 on the lower casing 108 is crimped or otherwise fastened at the center to a similar flange 110 on the upper casing 106. The primary fixed cup 84 is held from rotation by an indentation 112 of the upper casing 106 into a slot 114 in the cup; and the secondary fixed cup 96 is held from rotation by a similar indentation 116 of the lower casing 108 into a slot 118 in the cup. A first spring washer 120 is interposed between the closed end of the primary adjusting cup 86 and an annular flange 122 on the upper case 106 and a second spring washer 124 is interposed between the closed end of the secondary adjusting cup 98 and an annular flange 126 on the lower case 108. The spring washers 120 and 124 provide axial pressure and serve to hold the cups firmly in engagement. Leads are taken from the primary windings 80 through the slot 114 in the primary fixed cup 84 and through a slot 130 in the upper casing 106. Secondary leads are taken from the secondary coils 95 through the slot 118 in the secondary fixed cup 96 and through a slot 133 in the lower casing 108. The unit can be mounted by any suit-

able means using the single flange formed by the junction of the two flanges 110 and 111 on the upper and lower casing 106 and 108.

In operation, the primary and secondary windings are provided with shunt tuning capacitors to form two tuned circuits. These capacitors are shown schematically at 107 and 109 respectively. The primary of the transformer may be tuned, that is, the tuning is adjusted, in a manner similar to that of the embodiment shown in Figure 1 by rotating the primary adjusting cup 86 by a screw driver (not shown) in a screw driver slot 136 in the closed end of the cup; and similarly the tuning of the secondary may be adjusted by rotating the secondary adjusting cup 98 in a similar manner, a screw driver slot 138 in the closed end by the cup being provided for this purpose. It is obvious that primary and secondary windings may be reversed as desired, the upper pair of cups and windings becoming the secondary of the transformer and the lower the primary of the transformer.

The mutual inductance or coupling between the primary and the secondary is achieved by the flux that is present in each of the fixed cups that are adjacent each other. Some of the primary flux of the transformer will leak through the end walls 97 and 93 of the fixed cups 84 and 96 transverse a path through the secondary flux path thereby providing the mutual coupling for the transformer. The amount of mutual inductance is varied by varying the thickness of one or both of the end walls 97 and 93 of fixed cups 84 and 96, respectively. The desired thickness for the end walls 97 and 93 can be obtained by molding the cup with the required thickness; or, in the interest of production economies, both adjusting and fixed cups may be made the same, and part of the end wall of the fixed cups may be ground off or otherwise cut off to secure the required thickness.

Miniature intermediate-frequency transformers embodying the invention are characterized by small physical size, low flux leakage, good shielding, and relatively high "Q." For example a practical transformer embodying the invention has been constructed with an overall length of $\frac{7}{16}$ inch and an overall diameter of $\frac{1}{32}$ inch. Because of its desirable characteristics such as a high "Q," broad tuning range, and stability it was found to be comparable to much larger conventional transformers. In addition only a very minimum of parts are required in the construction of such transformers.

What is claimed is:

1. An intermediate-frequency transformer comprising in combination; a pair of ferrite cup-like core members each having a central core element therein, integral with and extending from the bottom of the cup-like core member and having a bevelled end face at the free end of said central core element, one of said pair of core members having an annular recess around the inner periphery of the open end thereof, and the other of said core members having an annular shoulder and a cylindrical portion of reduced diameter around the outer periphery of the open end thereof; means including a cylindrical metal case having inwardly projecting flanges at either end thereof for positioning said cups in axial abutment with the inner surface of the recess on the one of said core members fitting around the outer surface of the cylindrical portion of reduced diameter on the other of said core members; a cylindrical coil form surrounding said cores; a compressive member interposed between one end of said coil form and the inside of the closed end of the cup member adjacent thereto; transformer windings disposed on said coil form; means for securing one of said core members to said case; and means for turning the other of said core members with respect to said secured cup.

2. An intermediate-frequency transformer according to claim 1 wherein the core member secured to said case has a plurality of outwardly projecting metal pins imbedded at one end of the core member and projecting outwardly

of the case in substantially parallel relation to each other to provide socket mounting prongs, and means providing electrical connections between said windings and said pins.

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5

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