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TEMPERATURE-COMPENSATED MAGNETIC-CORED INDUCTOR

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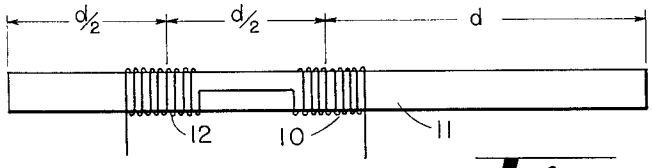


Fig 1

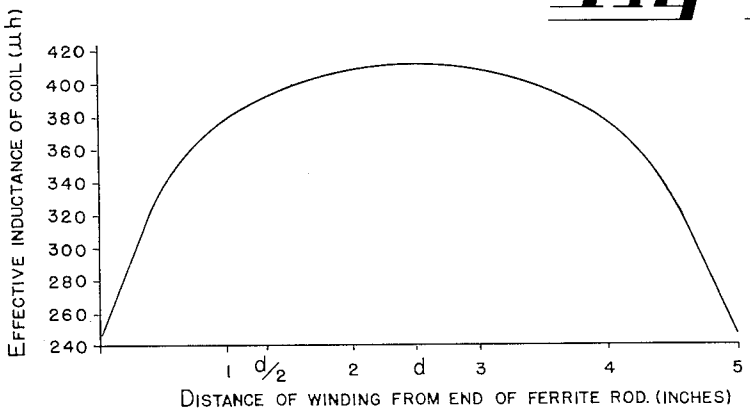


Fig 2

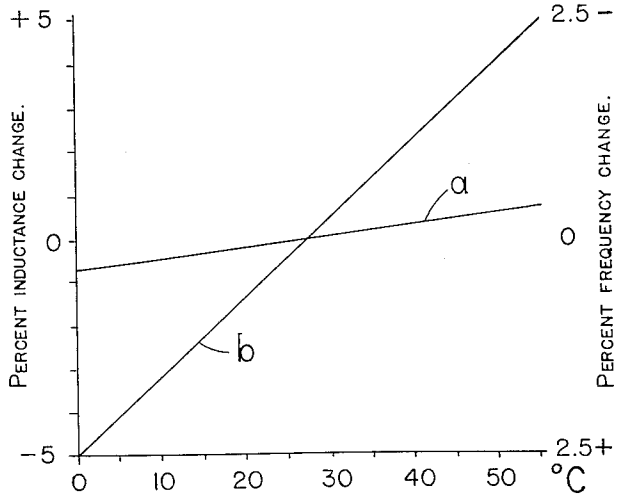


Fig 3

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TEMPERATURE-COMPENSATED MAGNETIC-CORED INDUCTOR

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The present invention relates generally to temperature-compensated high permeability inductors and, more particularly, to a high Q coil consisting of a tuned inductor wound on a ferrite rod and suitable for use in a tuned antenna circuit.

It is well known in the art that the inductance of a coil is a function of the permeability of its core. It is also well known that in ferrite cored antennae, permeability and effective Q vary, to a troublesome degree, with changes in temperature. Increased temperature results in the raising of the coil inductance while decreased temperature increases inductance, thus detuning the associated circuits. In practical embodiments, receivers using a ferrite cored loop antenna often suffer severe loss of sensitivity due to inductance change of the antenna coil as the temperature is either increased or decreased. This loss of sensitivity has been measured in the range of 20 db or more for the prior art ferrite rod antenna, and has been found to be due primarily to detuning of the antenna circuit because of the severe temperature dependence of the ferrite rod inductance.

The prior art teaches many methods for compensating inductance variation due to temperature change. Among these methods are included schemes for altering the capacitance of the associated circuit as the inductance changes in order to maintain a constant frequency response. It is recognized, however, that this method introduces many problems, since the amount of capacitance correction required is a complex function of frequency. Another scheme known in the art for compensating inductance change due to temperature variation involves the use of a coil and core which are relatively movable with changes in temperature. These types of apparatus have the inherent disadvantage of extra movable parts subjecting the apparatus to breakdown and higher costs.

This invention aims at accomplishing the same or greater orders of temperature stability as those achieved in the prior art, but without the necessity of mechanical movement. Broadly, this result is accomplished by means of apparatus comprising a pickup coil wound in a forward direction on an elongated ferrite core or rod and connected in series with a flux-cancelling coil wound in the reverse direction on the same rod and spaced therefrom, the spacing and number of turns being dictated by design considerations. As will be seen, this results in a configuration which automatically compensates for changes in permeability and Q due to changes in temperature, and which requires no moving parts or serious preloading.

It is an object of this invention, therefore, to provide a temperature-stable, high permeability, iron-cored inductor having no mechanically adjustable elements.

Another object of this invention is to provide a temperature-stable, high permeability, iron-cored inductor comprising an active coil wound on a ferrite rod adjacent a center portion thereof and connected in series with and spaced from a flux-cancelling coil wound in the reverse direction.

For a more complete understanding of the nature and other objects of this invention, reference should now be made to the following detailed description and to the accompanying drawings, in which:

FIG. 1 is a schematic representation of the preferred form of my invention;

FIG. 2 is a curve illustrating a typical inductance versus distance response of an inductor wound on a ferrite rod; and

FIG. 3 represents a comparison of the compensation results achieved by a typical prior art ferrite rod as compared with a ferrite rod constructed in accordance with my invention.

The inductor constructed in accordance with my invention comprises an active coil **10** wound in a forward direction on a ferrite rod **11**, and an auxiliary, temperature-compensating, flux-cancelling coil **12** wound on the rod **11** in the reverse direction. For reasons hereinafter to be explained, it will be noted that the center of coil **10** is positioned at approximately the center of the rod **11** at a distance d from each of the ends thereof while the center of the coil **12** is spaced at a position relatively near the end of the rod and in the example depicted is at a distance $d/2$ from the coil **10**. Also, in the example depicted both coils are provided with approximately the same number of turns; however, the relative number of turns in each winding depends upon physical position, the permeability and Q characteristics of the particular ferrite core and, additionally, upon their characteristic with temperature along the length of the rod. The rate of change or slope characteristic usually increases toward the end of the rod.

With the arrangement shown, it generally would be expected that the flux in coil **12** be equal to and 180° out of phase with the flux in coil **10**, thereby yielding for the coils a net inductance of zero. However, it has been found that sintered magnetic materials (ferrites) exhibit characteristics such that the inductance of a coil varies in accordance with its position on the material, and the inductance of the coil wound on a ferrite rod will be highest when positioned at the center of a rod. Because of this characteristic two coils, such as coils **10** and **12**, which are spaced apart on a ferrite rod and wound 180° out of phase, will yield a net active inductance with a very satisfactory Q.

FIG. 2 is a curve drawn to the same scale in inches as the core **11** illustrated in FIG. 1, and it represents the inductance-versus-coil position characteristics at fixed temperature. This curve represents the approximate response of an antenna coil actually reduced to practice in use with a receiver, and it illustrates that the inductance per turn of a coil increases rapidly as the coil approaches the center of the rod. Actual calculations from the curve show that the active coil spaced at a distance of 2.5 inches (d) from the end of the rod has an inductance of approximately 410 μh., while the auxiliary coil spaced at a distance of 1.25 inches ($d/2$) has a lesser inductance of approximately 390 μh. Thus, although the coils **10** and **12** are wound in opposite directions and have the same number of turns, complete cancellation of the inductance is not effected, but there results a net inductance which is the difference of the inductance in the two coils (in the instant example, approximately 30 μh.

Temperature stability results with this arrangement because it has also been found that the rate of change of inductance with temperature is greater at positions approaching the ends of the rods than it is in the center and, in fact, the rate of change of inductance versus temperature at a given position on the rod varies approximately as the reciprocal of the curve shown in FIG. 1. Stated another way, net change in permeability due to temperature variation is approximately the same in all positions along the rod. Thus, for a given change in temperature there results approximately equal inductance changes in the coils **10** and **12**. Since the coils **10** and **12** are wound in opposite directions, most of the change of inductance due to temperature variation in each of the coils is cancelled.

Basically, the means of improvement of temperature

stability in my improved ferrite core inductor is achieved by the principle that any change in permeability will cause the active coil 10 to vary but will also cause the inductance of the opposite coil 12 to vary in a similar manner. Since the total inductance is approximately the difference of the inductance in these two coils, the inductance changes tend to cancel each other, rather than becoming additive.

FIG. 3 comprises two curves comparing an antenna constructed in accordance with my invention (curve *a*) with an antenna having the same inductance but constructed in accordance with the teachings of the prior art (curve *b*). FIG. 3 illustrates that as the temperature varies, the antenna constructed in accordance with the prior art exhibits a 10% change in inductance and a corresponding 5% change in resonant frequency for temperature changes from 0° to 55° C. On the other hand, the antenna constructed in accordance with my invention shows only 1.5% change in inductance and a corresponding 0.75% change in resonant frequency over the same temperature range.

While this invention was reduced to practice primarily as an antenna, which is represented by the curve of FIG. 2, the invention need not be so limited. For example, the invention may apply equally well to magnetic-cored transformers, such as I.F. couplers with high reluctivity magnetic paths, or to any other embodiments where high permeability ferrite cored windings are employed. Moreover, while I disclose an inductor comprised of two coils spaced apart and having the same number of turns, it has been found that a number of coils, alternately aiding and opposing, will produce substantially the same frequency-stable characteristics. Also, while it has been found that greatest frequency stability with temperature change over a very wide range was observed when the number of forward turns is equal to the number of opposing turns, my invention also finds utility when the active and the auxiliary coils have an unequal number of turns. Practical considerations may justify a much lower inductance in coil 12 than in coil 10. This can be accomplished without serious loss in frequency stability by coil position and turns ratio. It is my intention, therefore, that my invention not be limited to the precise structure illustrated, but only by the appended claims as read in the light of the prior art.

Having thus described a preferred embodiment of my invention, what I now claim is:

1. A temperature-compensated inductor comprising: a magnetic core having inherent characteristics such that the permeability of said core is the greatest adjacent a center position thereof and decreases toward the ends and such that the rate of change of permeability in response to changes in temperature is greatest toward the ends of said core; a first coil fixedly positioned on said core adjacent said center position; a second coil connected in series with said first coil and fixedly positioned on said core at a position spaced from said first coil toward the end of said core, whereby the effective inductance of said second coil is less than the effective inductance of said first coil, said first coil and said second coil being wound on said core in opposite directions, whereby flux produced in said coils is 180° out of phase, and whereby changes in inductance in said inductor in response to changes in temperature are substantially reduced.

2. The invention as defined in claim 1 wherein said core is an elongated ferrite rod.

3. The invention as defined in claim 1 wherein said active and said auxiliary coils have the same number of turns.

4. An inductor comprising: an elongated magnetic core having characteristics such that the permeability of said core varies as a function of temperature, the rate of variation of permeability of said core due to temperature change being greatest adjacent the ends of said core, and the permeability of said core being greatest adjacent a center position thereof; a first coil positioned on said core adjacent said center position; and means for compensating for changes in inductance and Q of said first coil due to changes in temperature, said means comprising a second coil connected in series with said first coil and positioned a predetermined distance from said first coil, the effective inductance of said second coil being less than the effective inductance of said first coil, said first coil and said second coil being wound on said core in opposite directions whereby flux produced in said coils is 180° out of phase.

5. The invention as defined in claim 4 wherein said predetermined distance is selected by determining the position on said core where the rate of change in inductance of said second coil, due to temperature variation, will result in an over-all change in inductance approximately equal to the change in inductance of said first coil, due to said temperature variation.

6. The invention as defined in claim 4, wherein said predetermined distance is selected by determining the position on said core where the rate of change of inductance in said second coil due to temperature variations will result in a change in inductance opposite to the change in inductance of said first coil, tending to produce an over-all reduction in the change of inductance of said inductor due to said temperature changes.

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