TUNING AND MATCHING OF FILM INDUCTORS OR TRANSFORMERS WITH PARAMAGNETIC AND DIAMAGNETIC SUSPENSIONS

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Int. Cl............................. H01f 7/06

Field of Search................ 29/602, 607, 608, 609, 29/593; 336/233, 234; 117/234, 235, 240

References Cited
UNITED STATES PATENTS
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2,457,806 1/1949 Cripps .................. 336/233 UX
2,669,528 2/1954 Stelzer .................. 29/602 X

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ABSTRACT
Thin or thick film inductors or transformers are tuned and/or matched by the application of a blend of a paramagnetic or diamagnetic material or both mixed with a binder such as epoxy which binder matches the fabrication materials and processes of the inductors or transformers.

4 Claims, 5 Drawing Figures
1. TUNING AND MATCHING OF FILM INDUCTORS OR TRANSFORMERS WITH PARAMAGNETIC AND DAMAGNETIC SUSPENSIONS

This is a continuation, of application Ser. No. 212,193 filed Dec. 27, 1971, now abandoned.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention relates to process and apparatus for tuning and matching thin or thick film inductors or transformers more particularly to an improved method wherein the inductance of a coil or the coupling of a transformer is varied by the application of a blend of a paramagnetic or a diamagnetic material or both mixed with a binder which matches the fabrication processes and materials of the inductor or transformer.

2. Description of Prior Art

Film inductors have been used for several years in microwave applications and in general have been tuned/matched by using discrete ferrite/iron slugs attached to or in the substrate. Another method used to adjust an inductive device having a solid core has consisted of removing a portion of the core by the use of a flow of abrasive filled air.

U.S. Pat. No. 3,414,857, entitled "Coil With Adjustable Permeability" by Richard H. Barden, issued Dec. 3, 1968, discloses a method and apparatus for adjusting the permeability of ring-shaped cores. In this patent, there is shown an annular ring for a toroidal coil having an accurately extending internal void that extends for a substantial portion of the arcuate length of the ring. Access is provided to this void and a quantity of magnetizable material, discretely divided and dispersed in a settable medium, is injected into the void, without filling it, whereby further adjustment of the permeability can be made by injection of additional such material and medium.

Barden also shows an adjustment of the coil permeability by moving magnetic material in a discrete form through the hollow center of a toroidal core.

In applicant's invention, it is not necessary to have a toroidal core, or any core for that matter. The invention of the applicant is directed toward flat or planar coils where the blend of material used not only provides a core of high permeability with the application of paramagnetic material but also cores of low permeability by application of a diamagnetic material. In addition, the blend of the present invention can be used to distort the basic coils' magnetic field by placing or moving the paramagnetic or diamagnetic materials to other than the center of the coil.

Further, the device of Barden does not disclose the use of diamagnetic material but refers merely to the addition of a magnetic material inserted to adjust the permeability of the toroidal coil. The invention of the applicant does not restrict itself to toroids, nor does it require the addition of or subtraction of magnetic material since effectively the subtraction of the paramagnetic material may be accomplished by the addition of a diamagnetic material and vice versa.

Still further, the prior art method of Barden discloses only the process for adding a magnetic material to adjust the permeability of the coil, whereas the invention of the application discloses a method for up and/or down tuning of an inductor or matching of a transformer by the addition of either paramagnetic suspensions or diamagnetic suspensions whichever is required until a desired value is reached. Obviously, the invention of the applicant can be used either before or after the inductor/transformer has been installed into a circuit.

SUMMARY OF THE INVENTION

Briefly, the invention of the applicant comprises hardenable paramagnetic and diamagnetic materials and the process of their application to tune induction devices, and specifically to blends of either a paramagnetic material or a diamagnetic material in a fluid binder which blends are applied to tune circuits and then allowed to harden. Paramagnetic materials such as iron, ferrite, etc., or diamagnetic materials such as copper, gold, etc. are mixed with a binder such as epoxy, lacquer, acrylic, etc., which binder preferably matches the fabrication processes and materials of the inductor or transformer. The blend can also be mixed in a plastic binder and thus squirted on dropwise, extruded like toothpaste, or cut off like small string of spaghetti. The binder material may be catalytic setting, thermostetting, or air dried, depending upon the blend compatibility and use.

In practice, the circuit to be tuned or matched can be monitored by an oscilloscope or other device and the blend of material to be added to the circuit applied in a number of ways, such as dropwise or by the addition of appropriate sized spaghetti-like configuration. It is obvious that the method of application can be varied to meet the requirements of the circuit.

It is therefore an object of this invention to provide a new and novel method of tuning circuits.

It is another object of the present invention to provide a method of tuning inductors that negates the requirement of tuning the other components of the circuit, particularly if they lie within the commercial ± 20% tolerances.

It is another object of the present invention to provide a method wherein a circuit tuner can tune circuits with only a monitor such as an oscilloscope display and a blend of material.

It is still another object of the present invention to provide an accurate tuning capability for critical circuits such as color television IF strips wherein high accuracy is required to maximize the IF strips' band pass response.

These and additional objects of the present invention will become more apparent when taken in conjunction with the following description and drawings in which like characters indicate like parts.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates a method of application of the paramagnetic or diamagnetic blend with concurrent oscilloscope monitoring of the tuning/matching of the inductor/transformer.

FIGS. 2a – 2d illustrate various inductor configurations wherein the present invention may be used.

DESCRIPTION OF PREFERRED EMBODIMENT

FIG. 1 shows a circuit board 19 on which is mounted film inductors 10 through 18. Inductor 10 is shown
being tuned by the application of a blend of a paramagnetic or diamagnetic material or both mixed with a binder such as epoxy which matches the fabrication materials and processes of inductor 10. Applicator 21 is shown applying the material 24 for adjusting the inductance of coil 10. Coil 10 is shown connected to circuit 25, however, obviously the inductor could be monitored on an individual basis. 

Signal generator 22 may be a frequency sweep generator connected to the input of circuit 19. Monitor 20 can be an oscilloscope connected to the output of circuit 19. The oscilloscope would then have its horizontal axis driven by the sweep generator and its vertical axis driven by the output signal from circuit 19. With this arrangement the band pass wave shape of circuit 19 would be displayed on the oscilloscope. Coils 10 to 18 can then be adjusted to provide the desired band pass wave shape. 

If monitor 20 indicates it is necessary to decrease the resonant frequency of coil 10 then a paramagnetic material is added to coil 10 by applicator 21. If it is necessary to increase the resonant frequency of the coil, then a diamagnetic material is added. Occasionally for various circuit requirements, it may be desired to change or distort the basic magnetic field of the coil, in which case either a paramagnetic diamagnetic or blend of paramagnetic and diamagnetic material may be selectively positioned on the coil. 

Therefore, a core of high permeability (paramagnetic) or a core of low permeability (diamagnetic) can be provided, or the basic magnetic field can be distorted by selectively placing the magnetic material applied. For instance, the material may be placed to other than the magnetic center of the inductor. For fine adjustments the material applied can be decreased by scraping, sanding or other means practical for the specific circuit configuration. 

By selectively positioning a preselected combination of paramagnetic and diamagnetic materials, both the basic inductance of the coil as well as the magnetic field configuration may be simultaneously changed. Due to the binders or setting agents used, magnetic continuity, but not electrical continuity, is established between the inductor and the added material. This, however, is not to be construed as a limitation on the invention of the applicant as electrical continuity can be established by use of a conductive binder if it is desired to also vary the resistance of the inductor. 

FIG. 1 further shows the material 24 for adjusting the inductance of inductor 10 being applied dropwise, however, it is to be understood that other methods of application would be equally suitable. For instance, the blend can be mixed in a plastic or other thixotropic binder and thus extruded like toothpaste or cut off like small strings of spaghetti. 

It is also to be understood that although the inductor configurations are shown as circular spools, other configurations lend themselves equally well to the tuning and matching process disclosed herein. For instance FIG. 2 presents other flat or planar coil configurations which are equally suitable for the tuning/matching procedure disclosed herein. FIG. 2a shows a circular spiral, FIG. 2b a rectangular spiral, FIG. 2c a circular spiral with a variable line width, and FIG. 2d shows a meander configuration. 

In a typical configuration, the inductors are constructed using planar conductive film forming techniques such as vacuum evaporation or screen process printing on a substantial substrate material which material is compatible with the film forming process. The inductors may have various configurations but should preferably have an open or non-metalized center to avoid the efficiency robbing effects of magnetic flux crowding. 

to achieve the conductor skin depths required for optimum efficiency at particular frequencies, the basic conductors are plated using conventional low residual stress, copper, silver or gold plating processes. 
The inductors are then used singly or are stacked and interconnected in a series configuration. For transformers, they are stacked and interconnected to form the windings. More effective coupling may be designed into the transformer by stacking the coils within a cup made of a magnetic material. 

Series or parallel coupling using multilayer plastic or ceramic techniques may also be used. Lump elements may be produced by using metallic multilayers of resistive paramagnetic or diamagnetic materials. The same techniques used for coil fabrication can be used for the construction of transformers for coupling and impedance matching. 

Because the tuning/matching technique disclosed herein is a flexible process, it can be extended to almost all classes of inductors. 

The material used for tuning can be formulated in a variety of ways. Setting agents or binders have been used are catalytic setting such as polyesters or epoxies, photocatalytic setting such as polyvinyl, cinnamate, or polyolefins, thermosetting such as epoxies or silicones, and air drying such as acrylic or polylvinyls. Viscosity adjustments to meet the requirements of the dispensing equipment have been achieved by the addition of solvents or colloidal alumina/silica. The objective is to formulate a mixture, thixotropic in nature which will hold the applied configuration without slumping and will cure rapidly to a rigid adherent material. The diamagnetic or paramagnetic materials are added in a finely divided form to the setting agent forming the complete tuning material. Pure powdered materials such as copper, gold, zinc, or bismuth have been used as diamagnetic materials. However, alloys of the brass (copper and zinc) variety have been found to have the best diamagnetic properties. For paramagnetic tuning the commercial ferrites of nickel, zinc, and manganese, with characteristics matched to the frequency at which the coil is designed to operate, have been found to be more satisfactory than the pure materials such as iron, nickel and cobalt. 

A typical paramagnetic material with a vinyl binder can be formed as follows: 

<table>
<thead>
<tr>
<th>Polyvinyl Butyral</th>
<th>4%</th>
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<tbody>
<tr>
<td>Polyethylene Glycol</td>
<td>4%</td>
</tr>
<tr>
<td>Octyl Phthalate</td>
<td>4%</td>
</tr>
<tr>
<td>Ferrite Powder (100-200 mesh)</td>
<td>34%</td>
</tr>
<tr>
<td>Slowly add while blending, a solvent consisting of:</td>
<td></td>
</tr>
<tr>
<td>Trichloroethylene</td>
<td>39%</td>
</tr>
<tr>
<td>Ethanol</td>
<td>15%</td>
</tr>
</tbody>
</table>

The mixture cures to a rubber-like consistency when exposed to 100°C for 10 minutes. 

A typical diamagnetic material with an alkyd-melamine binder can be formed as follows: 

3,864,824
Coplex and Cyemel are trade names by American Cyanamid Corporation. The mixture cures to a rigid, hard material when exposed to 130°C for 10 minutes. Both of the above mixes form a viscous dispensible paste.

The chart below presents an example of how the inductance of a typical inductor of the type shown in FIG. 2b is varied with the application of a paramagnetic material to the inductor. The data was taken with an R, R meter at the television sound carrier intermediate frequency of 41.25 MHz. It is seen that the stepwise drop inductance of the paramagnetic material increases the inductance of the inductor. The change in parallel capacitance of the inductor is also shown.

<table>
<thead>
<tr>
<th>L (μh)</th>
<th>Δ%</th>
<th>Cp</th>
<th>No. of Drops</th>
</tr>
</thead>
<tbody>
<tr>
<td>482</td>
<td>0</td>
<td>-27.1</td>
<td>0</td>
</tr>
<tr>
<td>497</td>
<td>+1.7%</td>
<td>-26.3</td>
<td>2</td>
</tr>
<tr>
<td>507</td>
<td>+2.2%</td>
<td>-25.8</td>
<td>3</td>
</tr>
</tbody>
</table>

This invention thereby provides a process and apparatus for up and down tuning or matching of inductors or transformers which process is quick, cheap, and accurate and wherein the inductance of a coil or the coupling of a transformer is varied by the application of a blend of a paramagnetic (iron, nickel, cobalt, zinc, manganese) or diamagnetic, (copper, gold, zinc, bismuth) material, or both, mixed with a binder which binder matches the fabrication processes and materials of the inductor or the transformer.

The scope of this invention is not to be limited by the preferred embodiment which is shown in the drawings and described in the description, which embodiment is given by way of example and not of limitation, but limited only in accordance with the scope of the appended claims:

I claim:
1. A method of altering the inductance of an inductive device comprising the steps of:
   - measuring the inductance of said device;
   - selecting a suspension of either a paramagnetic material or a diamagnetic material, the material selected depending on the relationship of the measured inductance value of said device to a preselected inductance value;
   - incrementally applying to said device the selected material;
   - allowing said selected material to harden; and
   - again measuring the inductance of said device and applying a suspension of the other one of the paramagnetic and diamagnetic materials until said preselected inductance value is reached, said selecting step consisting of selecting the diamagnetic material when the measured inductance value of said device is greater than the preselected inductance value.

2. A method of altering the inductance of an inductive device comprising the steps of:
   - measuring the inductance of said device;
   - selecting a suspension of either a paramagnetic material or a diamagnetic material, the material selected depending on the relationship of the measured inductance value of said device to a preselected inductance value;
   - selecting said material from a diamagnetic group of materials consisting of copper, gold, zinc and bismuth when the measured inductance value exceeds the preselected inductance value;
   - incrementally applying to said device the selected materials; allowing said selected material to harden; and
   - again measuring the inductance of said device and applying a suspension of the other one of the paramagnetic and diamagnetic materials until said preselected inductance value is reached.

3. A method for decreasing the inductance of an inductive device comprising the steps of:
   - measuring the inductance of said device;
   - incrementally applying a hardenable diamagnetic material to said device;
   - allowing said material to harden; and
   - sequentially measuring the inductance of said device and applying increments of said diamagnetic material as a function of the measured inductance value of said device relative to a preselected inductance value until said preselected inductance value is measured.

4. The method of claim 3 further including after the measuring step, the step of:
   - selecting the diamagnetic material from the group consisting of copper, gold, zinc and bismuth.

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