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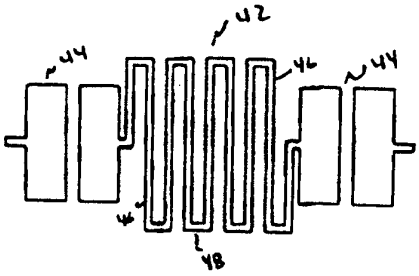
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(57) Abstract

Lumped element electrical components, such as inductors (24, 42, 52, 64, 74, 84, 92) and capacitors (22, 26, 44, 50, 60, 70, 80, 90), are formed to include high temperature superconducting materials. In the preferred embodiment, thin film epitaxial high temperature superconductors are patterned to form capacitors and inductors on low loss substrates. Preferably, a high temperature superconducting material or highly conductive material forms the ground plane on the back side of the substrate. Various inductor structures include a planar spiral (24), a zig-zag serpentine (42), a single coil (74), and a double coil (52, 64, 84, 92, 98). Narrow bandpass filters and high Q resonators are formed.

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DESCRIPTION

--HIGH TEMPERATURE SUPERCONDUCTOR LUMPED ELEMENTS AND CIRCUIT--.

Field of the Invention

This invention relates to electrical circuits including lumped elements, especially inductors and capacitors. More particularly, it relates to microwave circuits such as filters which include some superconducting components.

Background of the Invention

Electrical components come in various conventional forms, such as inductors, capacitors and resistors. A lumped electrical element is one whose physical size is substantially less than the wave length of the electromagnetic field passing through the element. A distributed element is one whose size is larger than that for a lumped element. As an example, a lumped element in the form of an inductor would have a physical size which is a relatively small faction of the wave length used with the circuit, typically less than 1/8 of the wavelength.

Inductors, capacitors and resistors have been grouped together into useful circuits. Of particular interest are resonant circuits and filters. Of most particular application here are filters useful in the microwave range, such as above 500 MHz.

Considering the case of conventional microwave filters, there have been basically three types. First, lumped element filters have used separately fabricated air wound inductors and parallel plate capacitors, wired together into a filter circuit. These conventional components are relatively small compared to the wave length, and accordingly, make for a fairly compact filters. However, the use of separate elements has proved to be difficult in manufacture, and resulting in large circuit to circuit differences. The second conventional filter structure utilizes mechanical distributed element

components. Coupled bars or rods are used to form transmission line networks which are arranged as a filter circuit. Ordinarily, the length of the bars or rods is ¼ or ½ of the wave length at the center frequency of the filter. Accordingly, the bars or rods can become quite sizeable, often being several inches long, resulting in filters over a foot in length. Third, printed distributed element filters have been used. Generally they comprise a single layer of metal traces printed on an insulating substrate, with a ground plane on the back of the substrate. The traces are arranged as transmission line networks to make a filter. Again, the size of these filters can become quite large. The structures also suffer from various responses at multiples of the center frequency.

Various thin-filmed lumped element structures have been proposed. Swanson U.S. Patent No. 4,881,050, issued November 14, 1989, discloses a thin-film microwave filter utilizing lumped elements. In particular, a capacitor π network utilizing spiral inductors and capacitors is disclosed. Generally, a multi-layer structure is utilized, a dielectric substrate having a ground plane on one side of the substrate and multiple thin-filmed metal layers and insulators on the other side. Filters are formed by configuring the metal and insulation layers to form capacitive π-networks and spiral inductors. Swanson U.S. Patent No. 5175518 entitled "Wide Percentage Band With Microwave Filter Network in Method of Manufacturing Same" discloses a lumped element thin-film based structure. Specifically, an alumina substrate has a ground plane on one side and multiple layer plate-like structures on the other side. A silicon nitride dielectric layer is deposited over the first plate on the substrate, and a second and third capacitor plates are deposited on the dielectric over the first plate.

Historically, such lumped element circuits were fabricated using normal, that is, non-superconducting

materials. These materials have an inherent loss, and a result, the circuits have various degree of lossiness. For resonant circuits, the loss is particularly critical. The Q of a device is a measure of its power dissipation or lossiness. Resonant circuits fabricated from normal metals have Q's at best on the order of a few hundred.

With the discovery of high temperature superconductivity in 1986, attempts have been made to fabricate electrical devices from these materials. The microwave properties of the high temperature superconductors has improved substantially since their discovery. Epitaxial superconductive thin films are now routinely formed and commercially available. See, e.g., R. B. Hammond, et al., "Epitaxial $Tl_2Ca_1Ba_2Cu_2O_8$ Thin Films With Low 9.6 GHz Surface Resistance at High Power and Above 77 K", Appl. Phy. Lett., Vol. 57, pp. 825-27, 1990. Various filter structures and resonators have been formed. Other discrete circuits for filters in the microwave region have been described. See, e.g., S. H. Talisa, et al., "Low-and High-Temperature Superconducting Microwave Filters," IEEE Transactions on Microwave Theory and Techniques, Vol. 39, No. 9, September 1991, pp. 1448-1554.

The need for compact, reliable narrow band filters has never been stronger. Of particular importance are applications in the telecommunications fields. As more users desire to use the microwave band, the use of narrow band filters will increase the number of users in the spectrum. Of particular interest is the area from 800 to 2,000 Mhz. In the United States, the 800 to 900 Mhz range is used for analog cellular communications. The personal communications services are planned for the 1,800 to 2,000 MHz range.

Despite the clear desirability of improved electrical circuits, including the known desirability of converting circuitry to include superconducting elements, efforts to date have been less than satisfactory in all regards. It has proved to be especially difficult in substituting high

temperature superconducting materials to form circuits without severely degrading the intrinsic Q of the superconducting film. These problems include circuit structure, radiative loss and tuning and have remained in spite of the clear desirability of an improved circuit.

Summary of the Invention

Novel lumped element inductors and capacitors are formed from high temperature superconducting materials alone or in combination with conventional materials. In the preferred embodiment, thin-film epitaxial high temperature superconductors are patterned to form lumped capacitors and inductors on low loss substrates. These include all those compatible with the formation of high temperature superconducting films (e.g., lanthanum aluminate, sapphire and magnesium oxide).

Various novel and advantageous structures are described. A planar spiral inductor comprises a spiral with the ends providing the circuit contacts. The planar spiral inductor may be formed from anywhere from a fraction of a turn to many turns. If necessary, a crossover may be provided from the inner end of the spiral to circuitry outside of the spiral inductor. The spiral inductor may be formed of any geometric shape, in the preferred embodiments being either circular or rectangular in construction.

A zig-zag inductor is formed from high temperature superconducting films. The pattern is formed in a meandering or serpentine pattern. Advantageously, this structure would not ordinarily require a crossover to provide connection at both ends of the lumped element. This structure has the added benefit that the opposing currents in adjacent sections of the inductor greatly reduce any losses due to radiative effects.

A double coil inductor is formed from high temperature superconducting materials. The inductor is formed surrounding a first input end and surrounds the output end

of the inductor. The inductors portions may be formed in any shape desired, in the preferred embodiment being formed in a rectangle or circular form.

A single coil inductor structure utilizes solely high temperature superconducting materials. One end of the lumped element inductor is circled by the inductor. The other end of the inductor is provided as an output contact.

Multi-layer structures utilize a high temperature superconductor film with coupling to the inductor via a multi-level structure. Capacitive coupling sections may be formed from normal metal for high temperature superconductor.

High Q structures may be formed with the disclosed devices. Resonators with Q greater than 1,000 are easily achievable. Further, narrow bandpass filters are conveniently formed.

Accordingly, it is an object of this invention to provide novel and highly advantageous structures for lumped element inductors and capacitors.

It is yet a further object of this invention to provide for lumped elements formed of high temperature superconductor materials, with or without the inclusion of normal metals.

It is yet a further object of this invention to provide for improved filters.

It is another object of this invention to provide for improved narrow bandpass filters for use in telecommunications.

It is yet a further object of this invention to provide lumped elements useful for high Q circuits.

It is yet a further object of this invention to provide structures which preserve the low loss nature of high temperature superconductors yet perform valuable electrical functions as inductors and capacitors.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 shows a circuit diagram of a π network.

Fig. 2 shows a plan view of a multi-turn planar spiral inductor.

Fig. 3 shows a circuit component representation of the structure of Fig. 2.

Fig. 4 shows a plan view of a zig-zag inductor.

Fig. 5 shows a plan view of a double coil inductor.

Fig. 6 shows a plan view of a single coil inductor.

Fig. 7 shows a plan view of an anti-symmetric single coil inductor structure.

Fig. 8 shows a plan view of a multi-layer resonator structure.

Fig. 9 shows a plan view of a multi-layer high temperature superconductor resonator structure.

Fig. 10 shows a schematic circuit for a lumped element filter.

Fig. 11 shows a plan view of a filter circuit similar to that of Fig. 10.

Fig. 12 shows the insertion loss and return loss as a function of frequency for the circuit of Fig. 11.

DETAILED DESCRIPTION OF THE INVENTION

Fig. 1 shows an electrical circuit for a π network 10. One or more π networks 10 may be combined as known to those skilled in the art. Generally, there is an input node 12 and an output node 14. An inductor 16 couples the input node 12 to the output node 14. The positive coupling to ground is performed by capacitors 18 coupling the ends of inductor 16 to the ground 20.

Any of the structures described herein may be formed using any type of superconducting materials. Preferably, high temperature superconducting materials, i.e., those which superconduct at or above 77K. The preferred materials are epitaxial superconductors, with low loss in the microwave and radio frequency range. Preferred superconductors include the thallium containing superconductors,

which generally include thallium, optionally calcium, barium and copper oxide, or the YBCO superconductors.

Fig. 2 shows a plan view of a multi-turn planar spiral inductor in accordance with this invention. Input capacitor 22 connects to spiral inductor 24 and provides output to capacitor 26. In the preferred embodiment, the capacitors 24 and 26 are formed from thin-film high temperature superconducting materials. The capacitors 22 and 24 are formed by the coupling capacitance between the simple pad structures shown. However, they may be of any desired shape as known to those still in the art, such as planer, inter-digital or multi-layers structures. Adjacent faces 28 define a gap 30 defining the space between the capacitor plates. Optionally, dielectric material may be placed in the gap 30. In the preferred embodiment, no additional material is provided between the faces 28. The inductor 24 is preferably formed from a thin-film epitaxial superconductor. The inductor 24 may be patterned with anywhere from a fraction of a turn to many turns. The spiral may continue optionally through to the center of the spiral.

While Fig. 2 shows a circular or spiral arrangement, the shape of the inductor may be of any form, with the preferred forms being spiral or rectangular. Connection to the inductor 24 may be direct, or as desired, via a crossover 32. The crossover 32 provides a connection from one end of the inductor 24 to the output capacitor 26. The crossover 32 may be formed through any conventional technique such as by utilizing normal metal bonding wires, metal air or dielectrically supported bridges, or multilayer high temperature superconductor crossovers. Additionally, all high temperature superconducting crossovers are possible via formation of crystal defects in the superconductor so as to render the material locally non-superconductive. See, e.g., "Superconducting Thin Film Crossovers and Method", Serial No. 07/197,175, filed July 20, 1992, incorporated herein by reference.

The structure of Fig. 2 shows an inductor 24 having 2.5 turns. In one actual device, the line width is 50 microns, the line spacing is 20 microns, resulting in a total inductance of about 18.6 nanoHenries at 0.85 GHz. The resistance of the high temperature superconductor line was about 1.2 milliOhms. In the preferred embodiment, the crossover 32 is formed using high temperature superconductor, such as multi-layer crossover structure. Performing the crossover from normal metals, such as gold or copper, the added inductor loss from the crossover together with the resistance of the contact resistance to the film can be relatively large. At this frequency, a 1 mil diameter bond wire can add an extra 10 milliOhms to the overall inductor loss. Accordingly, high temperature superconductor crossover 32 is preferred.

The structure of Fig. 2 is formed on a substrate. Preferably, the substrate should be chosen from the group of substrates that are compatible with the growth of low loss, high temperature superconducting films, including lanthanum aluminate, sapphire and magnesium oxide. Thallium containing superconductors formed on Lanthanum Aluminate provide good results. Films of thallium on lanthanum aluminate are commercially available. The backside of the substrate, that is, the side opposite that on which the capacitors 22 and 26 and inductor 24 have been formed, is preferably formed into a ground plane. In the most preferred embodiment, the ground plane comprises a high temperature superconductor plane. Optionally, the ground plane may be formed of normal metal, such as gold or high quality copper, though with some degradation in performance.

The self resonant frequency for the structure of Fig. 2 is four times higher than its operating frequency. Accordingly, this structure is particularly useful for simple filter structures. Other filter structures which have finite frequency transmission poles, such as elliptic type filters, can use the self-resonance property of these

inductors in the filter design. Very selective filters may be constructed without the addition of additional elements.

Fig. 3 shows a circuit diagram of the structure of Fig. 2. Input 34 is connected to capacitor 22. The output 36 is connected to capacitor 26. Inductor 24 is connected to capacitor 22 and capacitor 26 which couples to input 34 and output 36 respectively. Capacitor 38 represents the capacitance between the circuit elements and the ground plane represented as line 40.

Fig. 4 shows a plan view of a zig-zag type inductor. The inductor 42 is shown coupled to capacitor 44. The capacitor structure is as described in connection with Fig. 2 and need not be repeated here. The inductor 42 may be formed in any serpentine or zig-zag manner. Generally, long runs 46 of the inductor 42 are parallel to one another. End portions 48 provide the continuous path between runs 46. The structure of Fig. 4 generally would not require a crossover, such as shown as crossover 32 in Fig. 2. Accordingly, such a structure as shown in Fig. 4 has a much higher Q than all the other structures due to the serpentine nature of the structure and the lack of a crossover connection. Generally, this structure is particularly beneficial for low loss narrow band circuits where out of band performance is not overly critical. Particular applications include elliptical filters where self-resonance can be used to accurately place finite frequency poles of very nigh Q in a filter response.

The structure of Figs. 4 through 7 are generally as described with respect to Fig. 2 and will not be repeated in detail here. Generally, the structure is formed preferably from patterned thin-film high temperature superconductors formed on a substrate. A ground plane is provided on the backside of the substrate, preferably formed of high temperature superconductor or normal metals suitable for radio frequency or microwave application, such as gold or high quality copper.

Fig. 5 shows a plan view of a double coil inductor. A first input capacitor 50 is coupled to the conductor 52 and on out to the output capacitor 54. As described in connection with the structure of Fig. 2, the capacitors 50 and 54 may be of any desired shape, such as pad shaped, planar, inter-digital or multi-layer structure. The inductor 52 of Fig. 5 runs around one plate of the capacitor 50, through the gap 56. One or more passes through the gap 56 may be made as desired. The inductor 52 circumscribes one plate of output capacitor 54. Again, the inductor 52 may circumscribe the output capacitor via the gap 58 one or more times. The structure of Fig. 5 is particularly useful for high performance, narrow band filters which do not require strong coupling between adjacent resonators. Preferably, no crossovers are used, and accordingly, particularly higher Q's are available compared to structures in which crossovers are used. The structure of Fig. 5 may exhibit destructive coupling, and generally has a high self-resonance and high inductance per unit area. Again, the inductor 52 may be formed in any looping manner, with the preferred structure being rectangular or circular in form.

Fig. 6 shows a plan view of a single coil inductor in a symmetric mode. An input pad 60 may form one plate of a capacitor in any desired form, such as described in connection with Fig. 2. The pad 62 forms the other plate of the capacitor and provides connection to the inductor 64. Inductor 64 loops between the pad 60 and the pad 62. One or more loops may be made through the gap. The inductor 64 is connected to output pad 66. The inductor 64 may be formed in a looping manner, in the preferred embodiment being either rectangular or circular. The single coil symmetric inductor structure as described may be replicated again. As shown, the output pad 66 also provides the input pad function for the single coil inductor structure shown to the right. The same numerals are used to describe the corresponding elements in the

right-hand single coil inductor structure. The single coil inductor structure is well suited for higher frequencies, which generally require lower inductance, and narrow band widths that have low adjacent coupling between resonators.

Fig. 7 shows a plan view of a single coil inductor structure in an anti-symmetric mode. An input pad 70 couples to corresponding pad 72 which may be formed in any desired manner, such as pad structure, plate structure, inter-digital structure or multi-layer structure. The inductor 74 connects from pad 72 to output pad 76. One or more coils of the conductor may pass between input pad 70 and pad 72. The structure may be in any pattern desired, preferred embodiments are circular or rectangular. The output pad 76 optionally couples to pad 78 to form an output capacitor.

Fig. 8 shows a plan view of a multi-layer resonator structure. An input inductor 80 couples to a pad 82 through intermediate dielectric (not shown). The input pad 80 may be of an desired type, in the preferred embodiment being rectangular. The pad 82 provides the corresponding pad for the input capacitor structure. The inductor 84 couples to the pad 82 and then encircles the pad 82. One or more turns of the inductor 84 may be made around the pad 82 as desired. The inductor 84 is then preferably wound around the pad 86. The turns around the pad 82 and 86 may be of any desired shape, but in the preferred embodiment of rectangular or circular. The pad 86 then provides output to output pad 88 through a dielectric (not shown). The dielectric material may be any compatible with the other materials utilized for forming the structure of Fig. 8. Preferably, the dielectric is chosen from the group: lanthanum aluminate, sapphire, magnesium oxide, any metal fluoride, spinel, ceria, strontium titanate, barium titanate and polyimide.

Fig. 9 shows a plan view of a multi-layer all high temperature superconductor resonator structure. Input pad

90 connects to inductor 92 which groups around the input pad 90. One or more turns may be formed. While any looping arrangement is possible, the preferred structures are circular or rectangular. The inductor 92 terminates at pad 94. The pad 94 couples to pad 96 with intermediate dielectric (not shown). Pad 96 connects to inductor 98, inductor 98 circling the pad 96. One or more turns may be used as desired. Again, while any pattern may be used, circular or rectangular patterns are preferred. The inductor 98 connects to output pad 100. Structurally, the pad 90 inductor 92 and output pad 94 may be formed from one thin-film superconducting sheet. This may be backed upon a substrate (not shown). The substrate probably has a ground plane on its backside formed preferably of high temperature superconductor or optionally conventional metal forming a good conductor. The pad 96, inductor 98 and output pad 100 are preferably formed from thin-film superconductor on another layer, separated by a dielectric from the first layer, or on a separate substrate (not shown). The two patterns are then held in opposition to one another to form the plan view structure shown in Fig. 9.

The multi-layer structures of Fig. 8 and Fig. 9 may optionally utilize normal metals for one of the planes. The structures of Figs. 8 and 9 do not generally require interconnection between layers. Since physical interconnection is not required, the circuit will most likely have higher quality than circuits requiring interconnection. Generally, the structures are most advantageously used for wider band filters where the series capacitance of the elements is often required to be larger than the shunt capacitance.

Fig. 10 shows a electrical circuit diagram for a 10 GHz thin-film lumped element high temperature superconductor filter. The basic pattern consists of multiple π capacitor networks in series. Capacitive coupling is provided between the various π network portions. Input

102 is connected via input capacitor 104 to first π network 106. A second π network 108 is connected in series via the capacitor 110. Output capacitor 112 may then couple to yet further π networks as desired. In the 10 GHz filter, the input capacitor 104 had a capacitance of 88 femtoFarads, the inductance of the π networks was 1.59 nanoHenries. The coupling capacitor 110 had a capacitance of 11 femtoFarads. The output capacitor 112 had a capacitance of 18 femtoFarads.

Fig. 11 shows a plan view of a filter circuit, similar to that shown in the schematic in Fig. 10. Capacitors 114 use an inter-digital structure. Inductors 116 are rectangular in shape and comprise multiple turns. Non-superconducting crossovers are provided for inductors 116. The film was patterned from superconductor on a lanthanum aluminate substrate with an assumed relative dielectric constant of 24.

Fig. 12 shows the insertion loss and return loss as a function of frequency of the filter shown in Fig. 11.

EXPERIMENTAL RESULTS

Various structures described above have been fabricated and tested. The results are reported here.

The planar spiral structure of Fig. 2 was formed using a double sided thin-filmed superconductor on lanthanum aluminate. The coil was spiraled. Two and one half turns were used. The unloaded Q of the circuit was 3,215. The center resonant frequency was 936.497 Mhz.

The structure of Fig. 4 (having 6 long runs 46 as opposed to the 7 shown in Fig. 4) was fabricated with a gold back plane. The circuit was fabricated from thallium superconductor on lanthanum aluminate. The unloaded Q was measure as 7,647. The center frequency was measured as 1,315.53 MHz.

The double coil inductor structure of Fig. 5 was tested and provided an unloaded Q of 2,435. Gold was used

as a back plane material. The center frequency was 773.43 MHz.

The asymmetric single coil inductor structure of Fig. 7 provided an unloaded Q of 2,632. Gold provided the back planed. The center frequency was 1,039.97 MHz.

Although the foregoing invention has been described in some detail by way of illustration and example for purposes of clarity and understanding, it will be readily apparent to those of ordinary skill in the art in light of the teachings of this invention that certain changes and modifications may be made thereto without departing from the spirit or scope of the appended claims.

We claim:

1. A electrical circuit comprising:

a substrate having a first and a second face,

a superconducting lumped element formed on the first face, and

a ground plane formed on the second face.

2. The electrical circuit of claim 1 wherein the lumped element is a capacitor.

3. The electrical circuit of claim 1 wherein the lumped element is an inductor.

4. The electrical circuit of claim 1 wherein the superconductor is a high temperature superconductor.

5. The electrical circuit of claim 4 wherein the high temperature superconductor is a thallium containing superconductor.

6. The electrical circuit of claim 5 wherein the thallium containing superconductor is $Tl_2Ca_1Ba_2Cu_2O_8$.

7. The electrical circuit of claim 4 wherein the superconductor is epitaxial to the substrate.

8. The electrical circuit of claim 4 wherein the superconductor is a YBCO superconductor.

9. The electrical circuit of claim 1 wherein the substrate is chosen from the following group: lanthanum aluminate, sapphire and magnesium oxide.

10. The electrical circuit of claim 3 wherein the inductor is formed from a planar spiral.

11. The electrical circuit of claim 3 wherein the inductor is formed from a zig-zag pattern.

12. The electrical circuit of claim 3 wherein the inductor is formed from a single coil.

13. The electrical circuit of claim 3 wherein the inductor is formed from a double coil.

12. The electrical circuit of claim 1 further including

a second substrate having a first and a second face,

a superconducting lumped element formed on the first face of the second substrate, and

a ground plane formed on the second face of the second substrate,

said second substrate, lumped element and ground plane being held in opposition to said first substrate, lumped element and ground plane.

13. The electrical circuit of claim 12 wherein a dielectric is located between said first and second substrates.

14. The electrical circuit of claim 13 wherein the dielectric is chosen from the group consisting of: lanthanum aluminate, sapphire, magnesium oxide, metal fluoride, spinel, ceria, strontium titanate, barium titanate and polyimide.

15. A narrow bandpass filter comprising:

a substrate having a first face and a second face, the second face including a ground plane,

a input formed on the first face of the substrate,

a lumped inductor having a first end and a second end, said inductor including high temperature superconducting elements, the first end of the inductor being connected to the input, and

an output connected to the second end of the inductor.

AMENDED CLAIMS

[received by the International Bureau on 7 November 1994 (07.11.94); original claims 1-15 replaced by amended claims 1-31 (6 pages)]

1. An electrical element comprising:

a substrate having a first and a second face,

a high temperature superconducting lumped inductor having a zig-zag pattern disposed on the first face, and

a ground plane disposed on the second face.

2. The electrical element of claim 1 wherein the high temperature superconducting lumped inductor is a thallium containing superconductor composition.

3. The electrical element of claim 2 wherein the thallium containing superconductor composition is $Tl_2Ca_1Ba_2Cu_2O_8$.

4. The electrical element of claim 1 wherein the superconducting lumped inductor is epitaxial to the substrate in that the superconducting lumped inductor has a crystalline orientation which is fixed in relationship to the substrate.

5. The electrical element of claim 1 wherein the superconducting lumped inductor is a YBCO superconductor composition.

6. The electrical element of claim 1 wherein the substrate is selected from the group consisting of: lanthanum aluminate, sapphire and magnesium oxide.

7. A lumped element inductor comprising:

a support,

a superconductive serpentine conductor disposed on the support,

the serpentine conductor including:

an input,

a plurality of substantially parallel long runs having ends and including a first long run and a last long run, the input being connected to a first of the long runs,
a plurality of end portions, the end portions connecting in series the ends of adjacent long runs, and
an output connected to the last of the runs, and a ground plane disposed on the support the support having a first face.

8. The lumped element inductor of claim 7 wherein the serpentine conductor comprises a high temperature superconductor.

9. The lumped element inductor of claim 8 wherein the high temperature superconductor is a thallium containing superconductor composition.

10. The lumped element inductor of claim 9 wherein the thallium containing superconductor composition is $Tl_2Ca_1Ba_2Cu_2O_8$.

11. The lumped element inductor of claim 9 wherein the lumped inductor is epitaxial to the substrate in that it has a crystalline orientation which is fixed in relationship to the support.

12. The lumped element inductor of claim 8 wherein the lumped inductor is a YBCO superconductor composition.

13. The lumped element inductor of claim 8 wherein the support is selected from the group consisting of: lanthanum aluminate, sapphire and magnesium oxide.

14. The lumped element inductor of claim 8 further including a first capacitor coupled to the input of the serpentine conductor.

15. The lumped element inductor of claim 14 wherein the first capacitor is a parallel plate capacitor having a first and second plate, wherein the first plate is disposed on the first face of the support.

16. The lumped element inductor of claim 14 wherein the first capacitor is a planar capacitor having a first and second plate, each disposed on the first face of the support.

17. The lumped element inductor of claim 14 further including a second capacitor coupled to the output of the serpentine conductor.

18. The lumped element inductor of claim 17 wherein the second capacitor is a planar capacitor having a first and a second plate, the first plate being disposed on the first face of the support.

19. An electrical LC circuit comprising:

a substrate,

a capacitor having first and second plates each being disposed on the substrate, the first and second plates being spaced apart to define a gap therebetween, and

an inductor disposed on the substrate having a first end connected to the second plate of the capacitor, the inductor having at least one turn through the gap, and a terminal end.

20. The electrical LC circuit of claim 19 further comprising a second capacitor having a first and second

plate, wherein the first plate is disposed on the substrate connected to the terminal end of the inductor.

21. The electrical LC circuit of claim 20 wherein the first and second plates of the second capacitor are spaced apart to define a gap therebetween, and further comprising a second inductor, the second inductor having a first end connected to the second plate of the second capacitor, the second inductor having at least one turn through the gap of the second capacitor, and a terminal end.

22. The electrical LC circuit of claim 20 wherein the inductor includes at least one turn around the first plate of the second capacitor.

23. The electrical LC circuits of claims 19-22 further comprising a ground plane on the substrate.

24. The electrical LC circuits of claims 19-22 wherein the inductors and capacitors comprise high temperature superconductors.

25. An electrical LC circuit comprising:

a substrate,

a parallel plate capacitor having a first plate and a second plate, wherein the first plate is not disposed on the substrate and the second plate is disposed on the substrate,

an inductor disposed on the substrate, the inductor being connected to the second plate of the capacitor and having at least one turn around the second plate of the capacitor, and having a terminal end.

26. The electrical LC circuit of claim 25 further comprising a second inductor connected to the first plate of the capacitor.

27. The electrical LC circuit of claim 25 further comprising a second parallel plate capacitor having a first and second plate, wherein the second plate of the second parallel plate capacitor is disposed on the substrate, the terminal end of the inductor being connected to the second plate of the second parallel plate capacitor.

28. The electrical LC circuit of claim 27 wherein the inductor includes at least one turn around the second plate of the second parallel plate capacitor.

29. An electrical circuit comprising:

a first substrate having a first face and a second face,

a superconducting lumped element disposed on the first face, and

a ground plane disposed on the second face,

a second substrate having a first face and a second face,

a second superconducting lumped element disposed on the first face of the second substrate,

a ground plane formed on the second face of the second substrate,

the second lumped element disposed on the second substrate located in facing opposition to, and without direct electrical connection to, the first lumped element disposed on the first substrate.

30. The electrical circuit of claim 29 wherein a dielectric is located between said first and second substrates.

31. The electrical circuit of claim 30 wherein the dielectric is selected from the group consisting of: lanthanum aluminate, sapphire, magnesium oxide, metal fluoride, spinel, ceria, strontium titanate, barium titanate and polyimide.

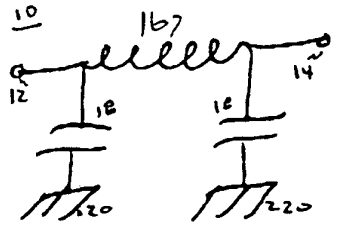


FIG. 1

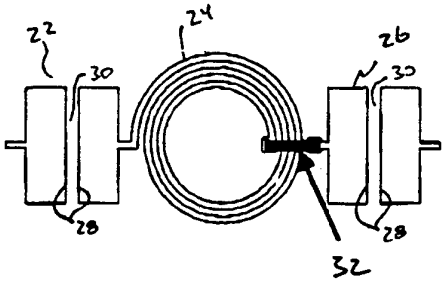


FIG. 2

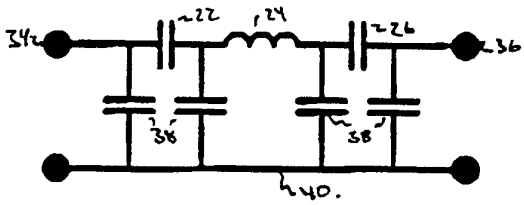


FIG. 3

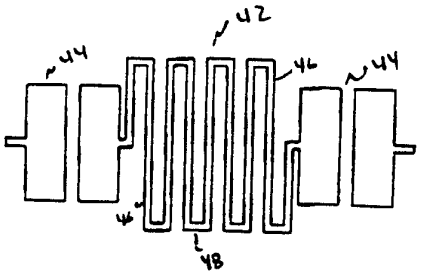


Fig. 4

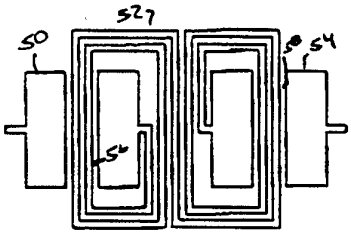


Fig. 5

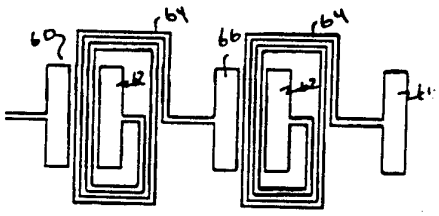


Fig. 6

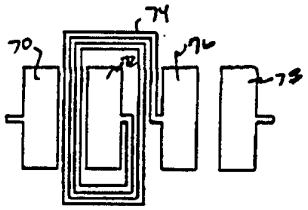


Fig. 7

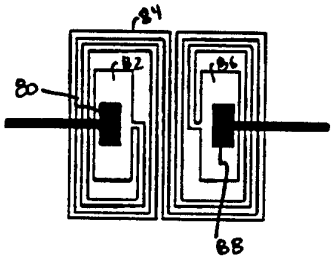


Fig. 8

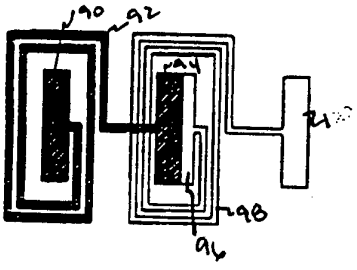


Fig 9

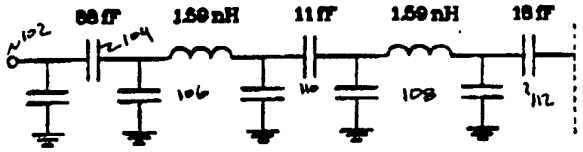


Fig. 10

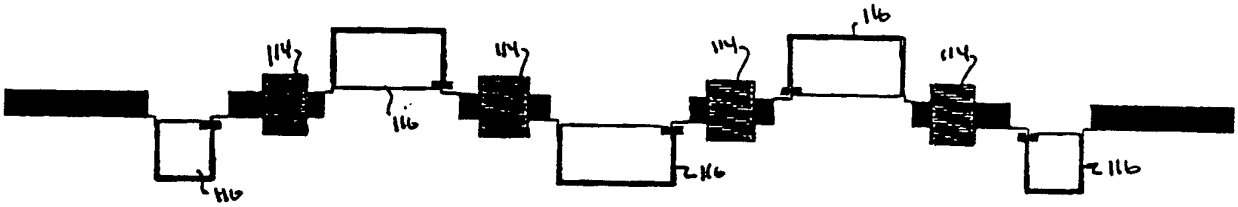


Fig. 11

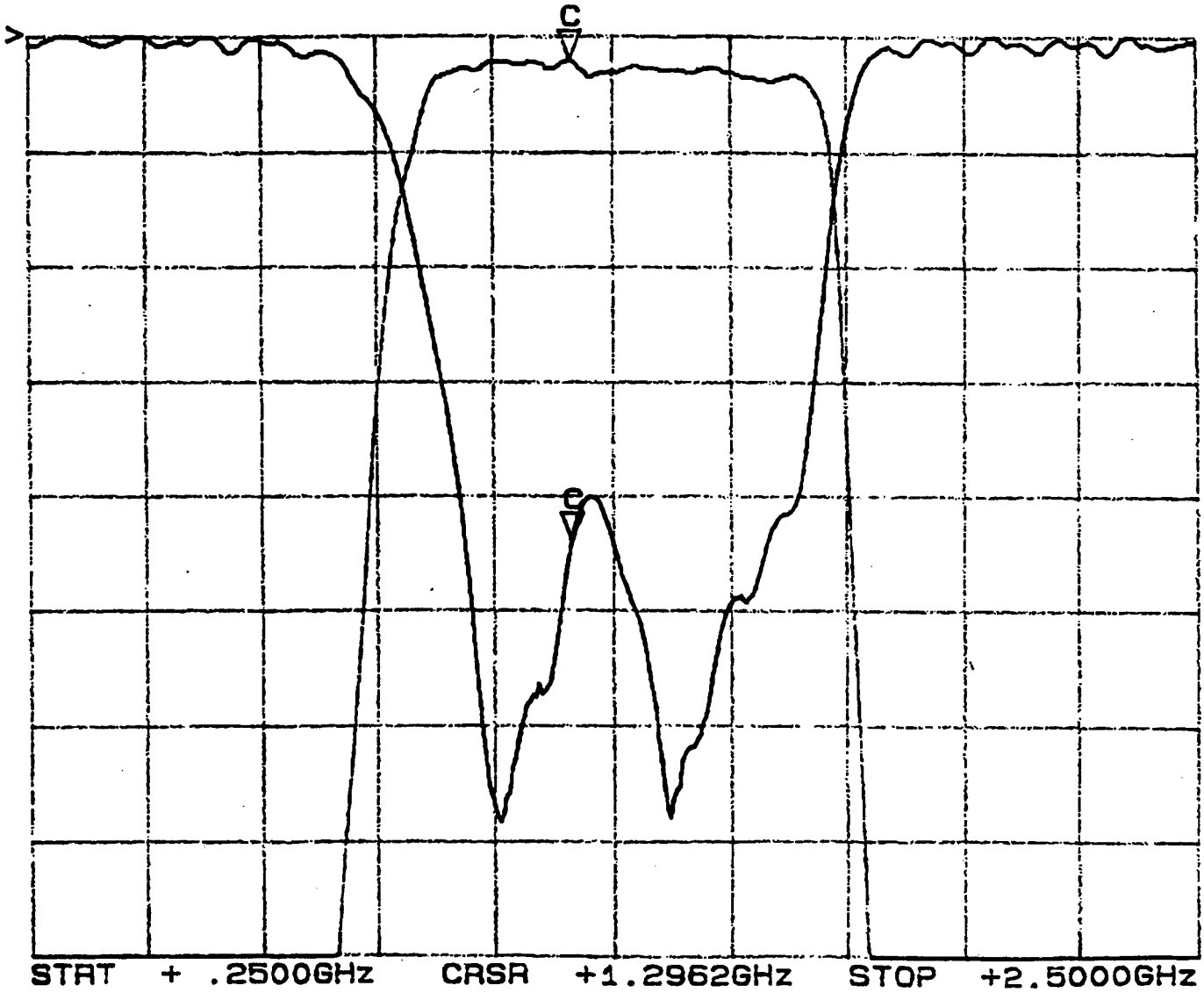


Fig 12

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US94/05577

A. CLASSIFICATION OF SUBJECT MATTER

IPC(5) :H03H 7/01; H01F 5/08

US CL : 333/99S, 185; 505/210, 211, 701, 705, 866; 336/Dig. 1

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 333/99S, 185; 505/210, 211, 204, 701, 705, 866; 336/Dig. 1

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP, A, 1-101716 (MAEDA) 19 APRIL 1989, see Abstract & figs. 4 & 5	1-4,10,13, 17
X	JP, A, 3-205904 (HIGAKI) 09 SEPTEMBER 1991, see Abstract & fig. 2	1-4,11
Y	JP, A, 64-74705 (TOSHIBA KK) 20 MARCH 1989, see Abstract & figs.1 & 2	1-4,8,11
Y	US, A, 5,175,518 (SWANSON, JR) 29 DECEMBER 1992, see fig, 3B & col 3, ls 3-47	1-4,11
Y	EP, A, 0357507 (OLSON ET AL) 07 MARCH 1990, see fig. 6, and col 4, ls 36-57 & col 13, l. 46 - col 14, l. 64	5-7,9

[X] Further documents are listed in the continuation of Box C. [ ] See patent family annex.

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"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
25 August 1994	SEP 06 1994
Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. NOT APPLICABLE	Authorized officer BENNY LEE Telephone No. (703) 308 4902

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/US94/0557 7

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US, A, 4,981,838 (WHITEHEAD) 01 JANUARY 1991, see fig. 5 & col 8, l. 58 - col 9, l. 11	1-4,8,10,12,17