

TITLE
RESONATORS FOR HIGH POWER
HIGH TEMPERATURE SUPERCONDUCTING DEVICES

5 **Background Of The Invention**

This invention is directed to TM_{0i0} mode ($i = 1, 2, 3, \dots$) circular and polygon shaped planar high temperature superconductor resonators having a hole in the center thereof, and their applications to high temperature superconducting filters, filter banks and multiplexers.

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Filter banks and multiplexers are widely used in telecommunications as channelizers, which separate or combine the incoming signals according to their frequencies. The basic building block of filters banks and multiplexers is a filter, which comprises a number of resonators as the frequency selecting element. For applications in telecommunication, the filters need to have narrow bandwidth, accurate center frequency, low insertion loss in the in-band, high rejection in the off-band, steep skirts at the edges of the in-band, compact size and high power handling capability. Conventional filters made from normal conductors are not well suited for telecommunication uses because of the high loss in the normal

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High temperature superconductors (HTS) planar filters have been made with excellent performance at low power. See Zhi-Yuan Shen, *High Temperature Superconducting Microwave Circuits*, Artech House, Boston, 1994, p. 113. While these HTS planar filters have utility in receivers, due to their very limited power handling capability, they are not well suited for use in transmitters. For application in transmitters, the filters must handle power ranging from ten watts to hundreds of watts. In commonly assigned, copending application no. 08/439,402, filed May 11, 1995, we disclose TM_{0i0} mode ($i = 1, 2, 3, \dots$) circular and polygon

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The center frequency accuracy is another important requirement, particularly for a narrow band filter. This is especially true for the filters in the so called "contiguous" multiplexer, such as that described in Zhi-Yuan Shen, *supra* at page 120, and in a multi-pole filter, where loss of center frequency accuracy will severely degrade performance. Unfortunately, the frequency of HTS resonators in a filter may deviate from the design value due to circuit fabrication tolerances and

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the uncontrollable variations in the substrate such as the thickness changes or "twin boundary." See Zhi-Yuan Shen, *supra* at 12.

In commonly assigned, copending application no. 08/227,437, filed April 14, 1994 we disclose planar HTS filters in a "stacked form", in which the individual HTS resonators are stacked vertically and coupled via holes or slots in the ground plates. Coupling, however, is only provided between adjacent resonators. Certain type of filters, such as the "elliptical frequency response" bandpass filter, require "jump-over" coupling, that is, coupling between resonators that are spaced from each other by one intermediate resonator.

Summary Of The Invention

Basically speaking, the invention comprises TM_{0i0} mode planar high temperature superconductor resonator, where i is a whole integer ≥ 1 , comprising a shaped high temperature superconductor film and at least one high temperature superconductor ground plate deposited on opposite sides of at least one dielectric substrate; wherein the shaped high temperature superconductor film has an aperture in the center thereof and has a shape selected from the group consisting of a circle and a polygon. In a microstrip line form embodiment, the resonators comprise a single ground plate and a single dielectric substrate. In a strip line form, two substrates, each having a ground plate deposited thereon, are used and the shaped high temperature superconductor film is sandwiched between the substrates to form resonator having a ground plate/substrate/HTS film/substrate/ground plate structure.

The resonators are particularly useful in frequency tuning, that is, changing the resonator frequency to optimize the performance of the filter and in providing jump-over coupling between next-to-adjacent resonators for filters with elliptical frequency response.

Brief Description Of The Drawings

Figure 1(a) - 1(b) are schematic illustrations of an embodiment of the TM_{0i0} mode ($i = 1, 2, 3, \dots$) planar resonator of this invention in the microstrip line configuration, in which Figure 1(a) shows the front view and Figure 1(b) shows the cross sectional view.

Figure 2(a) - 2(c) are graphic representations of the current and the magnetic field distributions of the resonators of this invention operating in the TM_{010} mode.

TM₀₂₀ mode, and TM₀₃₀ mode as shown in Figure 2(a), Figure 2(b), and Figure 2(c), respectively.

5 Figure 3(a) - 3(c) are graphic representations of the current and the magnetic field distributions of a typical prior art circular-shape resonator, operating in the TM₀₁₀ mode, TM₀₂₀ mode, and TM₀₃₀ mode as shown in Figure 3(a), Figure 3(b), and Figure 3(c), respectively.

10 Figure 4(a) - 4(b) are schematic illustrations of another embodiment of the resonator of this invention in the strip line configuration, in which Figure 4(a) shows the A-A cut view and Figure 4(b) shows the cross sectional view.

15 Figure 5(a) - 5(b) are schematic illustrations of an octagon shape HTS planar resonator of this invention in the microstrip line configuration, in which Figure 5(a) shows the front view and Figure 5(b) shows the cross sectional view.

20 Figure 6(a) - 6(b) are schematic illustrations of another embodiment of the octagon shape resonator of this invention in the strip line configuration, in which Figure 6(a) shows the A-A cut view and Figure 6(b) shows the cross sectional view.

25 Figure 7(a) - 7(c) are schematic illustrations of a 3-pole HTS filter having a TM₀₁₀ mode resonator of this invention as a frequency tuning device, in which Figure 7(a) shows the front view, Figure 7(b) shows cross sectional view, and Figure 7(c) shows the back view.

30 Figure 8(a) - 8(f) are schematic illustrations of a 3-pole HTS filter in the stacked form having a TM₀₁₀ mode resonator of this invention for jump-over coupling between non-adjacent resonators, in which Figure 8(a) shows the cross sectional view, and Figure 8(b), 8(c), 8(d), 8(e), and 8(f) show the B-B, C-C, D-D, E-E, and F-F cut views, respectively.

35 Figure 9(a) - 9(b) are schematic illustrations of a high power 3-pole HTS filter having a TM₀₁₀ mode resonator of this invention as a frequency tuning device, in which Figure 9(a) is a front view thereof and Figure 9(b) is a back view thereof.

Figure 10 is a graph of the S_{21} versus frequency response curves for the HTS filter of Figure 9(a) - 9(b) at six different transmitting power levels.

Detailed Description of The Embodiments

In a broad sense, the present invention comprises a planar TM_{0i0} mode (where i is a whole integer ≥ 1) HTS resonator comprising a circular or polygonal HTS film, the film having a centrally located aperture and at least one ground plate deposited on at least one substrate. Circular and octagon shapes are preferred for the HTS film. The aperture can be circular or polygonal and need not be the same shape as the HTS film. The term "circular" as used herein is not to be understood to require a perfect circle. Rather, imperfect circles; that is, circles in which differences in the diameter of the circle are less than 1%, are also included. Similarly, the term "polygon" is to be understood to mean any equal side and equal angle polygons having at least five sides.

With reference being made to Figure 1, one embodiment of a resonator of this invention is illustrated schematically and comprises a circular HTS film 21 having a central aperture 24 therein and an HTS ground plate 23 deposited on opposite sides of a substrate 22. The HTS materials used for the HTS film and the HTS ground plate are preferably selected from high temperature superconductors with a transition temperature greater than 80°K and a conductivity one hundred times greater than pure copper. $YBa_2Cu_3O_{7-\delta}$, $Tl_2Ba_2CaCu_2O_8$ and $(Tl,Pb)Sr_2Ca_2Cu_3O_9$ most preferred as the HTS materials of choice. The substrate may be any dielectric substrate commonly employed in HTS devices. Most preferred are dielectric materials with a loss tangent less than 10^{-3} .

With reference now being made to Figure 2, illustrated therein are graphic representations of the radial direction current J_ρ and the circular direction magnetic field H_ϕ as functions of the radial distance ρ from the center of the resonator of this invention operating in the TM_{010} mode (Figure 2(a)), TM_{020} mode (Figure 2(b)), and TM_{030} mode (Figure 2(c)).

Circular planar HTS TM_{0i0} mode resonators, where i is a whole integer ≥ 1 , are known in the art. Figure 3(a) - 3(c) are graphic representations of the radial direction current J_ρ and the circular direction magnetic field H_ϕ as functions of the radial distance ρ from the center of a typical circular HTS resonator of the prior art operating in the TM_{010} mode, TM_{020} mode, and TM_{030} mode, shown in Figure 3(a), Figure 3(b), and Figure 3(c), respectively. By comparing the J_ρ , H_ϕ versus ρ curves in Figure 2 to those in Figure 3, it can be seen that the resonators with a central aperture (Figure 2) have a region corresponding to the

central aperture which is free of the resonator's fields and that the electromagnetic fields are confined within the HTS pattern.

Figure 4(a) - 4(b) show another embodiment of the circular resonator in the strip line configuration. As seen therein, the resonator in this embodiment comprises a
5 circular HTS film 31 having a central aperture 34 therein sandwiched between substrates 32a, 32b, each substrate further comprising an HTS ground plate 33a, 33b, respectively.

Figure 5(a) - 5(b) illustrate an embodiment of the resonators of this invention, wherein an octoganal HTS film 51 having an octoganal central aperture 54 therein and an HTS ground plate 53 are deposited on opposite sides of a substrate 52.

Yet another embodiment of the resonators of this invention are shown in Figures
15 6(a) and 6(b). In this embodiment, also in strip line configuration similar to the embodiment shown in Figures 4(a) and 4(b), the resonator comprises an octogonal HTS film 61 having an octogonal aperture 64 therein sandwiched between two substrates 62a and 62b, each substrate 62a, 62b having an ground plate 63a, 63b, respectively, deposited thereon.

Figure 7 illustrates a TM_{010} mode HTS high power 3-pole filter incorporating a resonator of this invention therein. As seen in Figure 7, the 3-pole filter comprises a substrate 70 having a plurality of HTS films 72a, 73, 72b deposited on one side thereof and an HTS ground plate 71 deposited on the opposite side thereof (see
25 Figure 7(b)). In the embodiment shown, films 72a and 72b represent prior art circular HTS resonators and film 73, having central aperture 74 therein, represents a resonator of this invention.

With particular reference to Figure 7(c), the input coupling circuit for the filter
30 comprises an opening 75a in the ground plate 71 to provide room for the remaining coupling circuits, an input center line 76a in the coplanar line form, and a branch line 77a coupled to resonator 72a. The output coupling circuit comprises an opening 75b in the ground plate 71 to provide room for the remaining coupling circuits, an output center line 76b in the coplanar line form, and a branch line 77b
35 coupled to resonator 72b. The inter-resonator coupling circuits comprises two openings 78a and 78b in the ground plate 71, and two coupling center lines 79a and 79b in the coplanar line form to provide coupling resonator 72a to resonator 73, and resonator 73 to resonator 72b, respectively.

- For a 3-pole filter, the resonant frequency of three resonators comprising the filter must be precisely equal to their designed values. In reality, the resonant frequency can vary due to many uncontrollable factors. Therefore, it is very desirable to
- 5 have some means to tune the resonant frequency of individual resonator. It is known, for example, that changing the radius of a prior art circular HTS resonator will change its frequency, but it is very difficult to change the radius, and thus tune the frequency, of a circular resonator after it has been fabricated.
- 10 In the embodiment of the 3-pole filter shown in Figure 7, the resonator of this invention comprises means for tuning the resonant frequency of the filter. In particular, the frequency of a circular resonator, according to the present invention, can readily be increased by providing an aperture in the center of the resonator. This can be readily accomplished by use of a high power laser,
- 15 photolithographic etching, or shadow mask etching.

Figure 8 illustrates yet another 3-pole TM_{0i0} mode ($i = 1, 2, 3, \dots$) HTS filter having a stacked configuration which incorporates the resonator of this invention. The 3-pole filter is divided into three sections: the input section, the middle

20 section and the output section.

The input section comprises an HTS circuit (see Figure 8(b)) sandwiched between substrate 80a (having ground plate 81a deposited on one side thereof) and substrate 80b. With reference to Figure 8(b), the HTS circuit comprises a circular

25 HTS resonator 82a and an input coupling circuit 83a deposited on substrate 80b. The middle section comprises the HTS circuit pattern shown in Figure 8(d) sandwiched between two substrates, 80c, 80d. The circuit pattern for the middle section, shown in Figure 8(d), comprises an HTS resonator 84 having aperture 85 in the center thereof and a circular HTS dot 86 concentric with aperture 85 and resonator 84 deposited on substrate 80d. The output section comprises an HTS

30 circuit (see Figure 8(f)) sandwiched between substrates 80f (having ground plate 81b deposited on one side thereof) and substrate 80e. The HTS circuit for the output section, shown in Figure 8(f), comprises a circular HTS resonator 82b and an output coupling circuit 83b deposited on substrate 80f. The HTS ground plate

35 87a having center coupling means 88a (see Figure 8(c)) separates the input section and middle section. A similar ground plate 87b having center coupling means 88b (see Figure 8(e)) separates the middle section and the output section. In this respect, the ground plate 87a has shared functionality between the input section

and the middle section and ground plate 87b has shared functionality between the middle section and the output section. Coupling means 88a provides coupling between resonator 82a and resonator 84, whereas coupling means 88b provides coupling between resonator 84 and resonator 82b. In addition, coupling means
5 88a and 88b, together with aperture 85 in resonator 84, provide coupling between resonator 82a and resonator 82b, as explained more fully below.

With particular reference being made again to Figure 8(d), the resonator 84 having central aperture 85 comprises means for coupling between resonator 82a and
10 resonator 82b. It will be appreciated that such coupling is aptly referred to as "jump-over" coupling because resonators 82a and 82b are not adjacent to one another, but in fact are separated by intermediate resonator 84. Thus, coupling from resonator 82a to resonator 82b requires a "jump" over the intermediate resonator 84. This "jump-over" coupling application of the present invention is
15 particularly advantageous for use in elliptical frequency response filters, which in turn have the advantage of having very steep skirts.

As noted earlier with reference to Figure 2, the electromagnetic field of the TM_{0i0} mode ($i = 1, 2, 3, \dots$) in the resonator are confined to the HTS film itself and the
20 central aperture in the resonator is free of electromagnetic fields generated by the resonator. This "free space" is thus available for use in coupling non-adjacent resonators. With particular reference to the stacked filter shown in Figure 8(a) - 8(f), the electromagnetic fields are confined within the area of the HTS film 84 and the central aperture 85 provides a space free of electromagnetic fields, which
25 can be used as the space for the "jump-over" coupling between resonators 82a and 82b, through the coupling means 88a on ground plate 87a (see Figure 8(c)) and coupling means 88b on ground plates 87b (see Figure 8(e)). The concentric HTS dot 86 in aperture 85 (see Figure 8(d)) provides another dimension to vary the coupling strength among these resonators. In summary, the coupling strength
30 between and among resonator 82a, 84 and 82b, can be adjusted by varying the diameter of coupling means 88a and 88b, the aperture 85, and the HTS dot 86.

Example

A high power 3-pole TM_{010} mode HTS filter was prepared by depositing double-
35 sided $Tl_2Ba_2CaCu_2O_8$ HTS thin films on both sides of a 40.8 mm x 17.2 mm x 0.508 mm $LaAlO_3$ substrate. Using a standard bi-level photolithographic process and ion beam milling, a filter having the structure shown in Figure 9(a) and 9(b) was prepared, in which 90 is the substrate; 91a and 91b are octagonal shaped

resonators; 92 is an octagonal shaped resonator having a central aperture 93 therein; 94 is the ground plate; opening 95a, coplanar center line 96a and T-type coupling branch line 97a collectively form the input coupling circuit; opening 95b, coplanar center line 96b and T-type coupling branch line 97b collectively form the
5 output coupling circuit; and openings 98a and 98b comprise the inter-resonator coupling circuits.

The filter was housed in a copper case with SMA compatible input and output connectors and the filter was tested at 77°K. The diameter of central aperture 93
10 in resonator 92 was increased (using photolithography ion beam milling) in 24-micron increments until optimum performance was obtained. The filter was then tested at power levels of 1.7 watts, 20 watts, 40 watts, 50 watts 62 watts and 74 watts. The measured S_{21} versus frequency response curves at all six power levels are shown in Figure 10. As seen in Figure 10, the six curves lay on top of one
15 another without notable performance degradation, even in the fine vertical scale of 1dB/Div.

**WHAT IS CLAIMED IS:**

THIS SHEET HAS BEEN REPLACED

1. A TM_{0i0} mode planar high temperature superconductor resonator, where i is a whole integer ≥ 1 , in the microstrip line form comprising a shaped high temperature superconductor film and at least one high temperature
5 superconductor ground plate deposited on opposite sides of a dielectric substrate; wherein said shaped high temperature superconductor film has an aperture in the center thereof and has a shape selected from the group consisting of a circle and a polygon.
- 10 2. A TM_{0i0} mode planar high temperature superconductor resonator, where i is a whole integer ≥ 1 , in the strip line form comprising, in order,
 - (a) a first high temperature superconducting ground plate;
 - (b) a first dielectric substrate;
 - 15 (c) a shaped high temperature superconductor film;
 - (d) a second dielectric substrate; and
 - (e) a second high temperature superconductor ground plate;wherein said shaped high temperature superconductor film has an aperture in the center thereof and has a shape selected from the group consisting of
20 a circle and a polygon.
3. The resonator of claim 1 or 2, wherein the shaped high temperature superconductor film has a circular shape.
- 25 4. The resonator of claim 1 or 2, wherein the shaped high temperature superconductor film has a polygon shape.
5. The resonator of claim 3, wherein the shaped high temperature superconductor film has an octagon shape.
- 30 6. The resonators of claim 1 or 2, further comprising a second high temperature film concentrically located relative to the aperture in the center of the shaped high temperature superconductor film.

This Sheet Has Been Replaced

