High-Temperature Superconducting Bandpass Spiral Filter

C. K. Ong, Linfeng Chen, Jian Lu, C. Y. Tan, and B. T. G. Tan

***Abstract*— We report a new type of microstrip bandpass spiral filter structure, which exhibits much smaller size than other existing miniaturized bandpass filter structures, and is particularly useful in developing high-temperature superconducting (HTS) compact filters for cellular communication systems. A prototype three-stage HTS bandpass spiral filter with center frequency of 633 MHz was designed and fabricated on a 20 mm × 8 mm × 0.5 mm $\mathrm{LaAlO_3}$ substrate. The measurement results of the spiral filter have good agreements with its electromagnetic full-wave simulation results.**

***Index Terms*—Dual-spiral resonator, high-temperature superconductivity, microstrip bandpass filter, miniaturization, spiral filter.**

I. Introduction

THE miniaturization of microstrip bandpass filters at UHF-band is of great importance in the development of cellular communication systems. A conventional microstrip bandpass filter with half-wavelength $(\lambda/2)$ resonators can be miniaturized by folding its straight rectangular ribbon $(\lambda/2)$ resonators [1]. The length of a folded $(\lambda/2)$ resonator, called hairpin resonator, is usually less than $(\lambda/4)$. According to the orientations of hairpin resonators, filters consisting of hairpin resonators can be generally classified into two categories: hairpin filters [1] and hairpin-comb filters [2]. Replacing the hairpin resonators with miniaturized hairpin resonators can further miniaturize the filters. Makimoto *et al.* proposed a type of miniaturized hairpin resonator, a split-ring resonator, consisting of a transmission line and a lumped-element capacitor, and the split-ring resonator was later improved by replacing its lumped element capacitors with parallel-coupled lines [3]. The structure of the miniaturized hairpin resonators can be further modified [4]. Usually, the transmission line is very thin, and the gap between the parallel-coupled lines is very narrow. So the performances of such filters are sensitive to their fabrication procedures. Besides, the hairpin filter and hairpin-comb filter, a pseudointerdigital bandpass filter structure was also proposed in [5]. Such a filter has a size similar to that of the conventional interdigital bandpass filter, so it still occupies large space at UHF band.

In this letter, we propose a new type of bandpass spiral filter structure consisting of dual-spiral resonators. Such spiral filter structure is more compact than the existing compact filter structures, and it can be easily made using microstrip fabrication techniques.

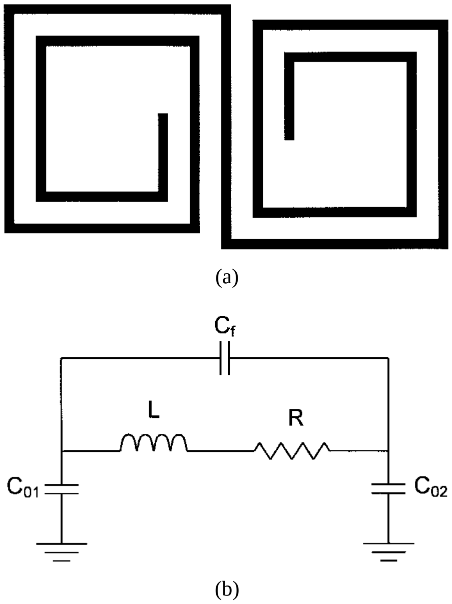

Fig. 1. (a) Dual-spiral resonator and (b) its lumped-element equivalent model.

II. Dual-Spiral Resonators

The most widely used two types of planar spirals are rectangular spirals and circular spirals. It was demonstrated that the two types of spirals have similar performances. But in practice, rectangular spirals seem more advantageous over circular ones for their simplicity of construction and their more efficient utilization of a limited area [6]. In this letter, we concentrate our interests on rectangular spirals.

Although planar spirals are often used in inductors, transformers, couplers, and antennas, they have obvious advantages as electrically small resonators [7]–[10]. However, it seems difficult to develop filters using the spiral cavity resonator structure presented in [8]. Though a conceptional diagram of compact filter using spiral resonators as resonator elements was proposed in [7], fabrication of such filter is of technical challenges.

Here we propose a new type of spiral resonator, dual-spiral resonator, which could be used for developing compact spiral filter. As shown in Fig. 1(a), a dual-spiral resonator consists of two spirals connected in series. The distribution nature of a dual-spiral resonator can be expressed by a lumped-

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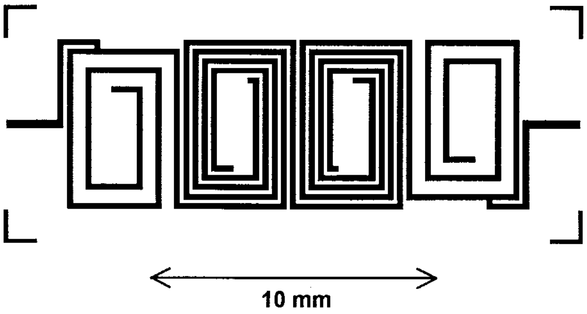


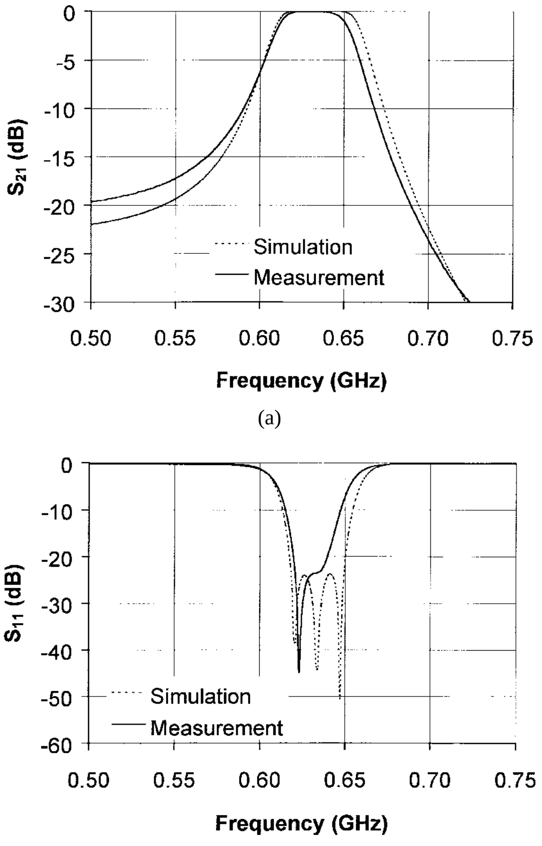
Fig. 2. Circuit layout of a three-stage bandpass spiral filter.

element equivalent model shown in Fig. 1(b). Besides its lumped-element inductance L and its loss R, a dual-spiral has distributed capacitance: feedback capacitance (C_f), and capacitance to ground (C_{01} and C_{02}). Here C_{01} and C_{02} represent the capacitance of the two spirals in the dual spiral to the ground, respectively. The inductance L includes the inductance of the two spirals in the dual-spiral and the mutual inductance between them. The loss R of the dual-spiral includes two parts: the resistance of the conducting strips and the ground, and the dielectric dissipation of the substrate. The dual-spiral resonator shown in Fig. 1 resonates at certain frequencies determined by L, C_{01}, C_{02}, and C_f. The tight coupling between the adjacent lines provides higher inductance and capacitance than the straight rectangular ribbon with equivalent length and width. At the same resonant frequency, spiral resonators have a much smaller size than conventional straight rectangular ribbon resonators and hairpin resonators.

As shown in Fig. 2, two adjacent dual-spiral resonators are coupled through two spirals winded together, called a spiral coupler. The two spirals in a spiral coupler come from the two adjacent dual-spiral resonators, respectively. The coupling mechanisms of a spiral coupler includes inductive coupling mainly due to the mutual inductance of the two spirals in the spiral coupler, and capacitive coupling mainly due to the fringe fields of the strips of the two spirals.

III. SPIRAL FILTERS

A three-stage spiral filter with center frequency of 633 MHz is developed as a prototype. Fig. 2 shows the circuit layout of the filter, in which, the input and output couplings are provided by tapped-line connections. It should be noted that at present, the resonant properties of dual-spiral resonators and the coupling mechanisms between the dual-spiral resonators have not been systematically investigated, so no simple synthesizing method is available for spiral filter design. Fortunately, powerful electromagnetic simulators are commercially available, so we could easily design spiral filters directly using electromagnetic field simulations. In our design, we use a full-wave electromagnetic simulator, IE3D package from Zeland Software, Inc. In our simulations, type II HTS thin films with thickness of 0.000 50 mm and penetration depth of 0.000 15 mm are chosen as conductors for strips and ground, and the substrate is 0.5 mm thick, with dielectric constant 24 and loss tangent 1×10^{-5}.



(a)

(b)

Fig. 3. Comparisons of (a) S_{21} and (b) S_{11} between the measurement results and simulation results of the bandpass spiral filter.

The spiral filter shown in Fig. 2 is fabricated on an 8 mm × 20 mm × 0.5 mm $LaAlO_3$ substrate with both sides coated with YBCO. The thickness of the YBCO thin films is about 5000 Angstroms. At 77 K, the surface resistance of the YBCO thin films is about 0.9 mΩ at 10.65 GHz [11]. Traditional photolithography techniques with 1% H_3PO_3 wet etching are used to pattern the circuit on one side. The microwave measurements are conducted on a HP8722D Network Analyzer. In the measurements, the spiral filter is at 77 K, and the test port power of the Network Analyzer is -10 dBm. The measurement results of the filter are shown in Fig. 3. The insertion loss of the filter is less than 0.1 dB.

Fig. 3 shows that the experimental measurement results have good agreements with the full-wave simulation results. However differences, though slight, exist between the measurement results and simulation results. We may due such differences to following possibilities: 1) mismatches at the input and output ports between microstrip lines and SMA connectors; 2) tolerances of the dielectric constant, loss tangent, and thickness of the substrate; 3) tolerances of the thickness and penetration of the HTS thin films; 4) uncertainties in the fabrication procedure; and 5) uncertainties of the electromagnetic full wave simulator.

IV. DISCUSSIONS

In structure, the spiral filter reported in this letter is analogous to hairpin-comb filters except that the building units of the latter are parallel line couplers while those of the former are spiral couplers. In this letter, the design of the filter is based on analyzing methods, while systematic synthesizing methods for designing spiral filters are yet to be developed. Finally, we like to point out that, though all the circuits discussed in this letter are in microstrip configuration, the proposed spiral filter structure can also be realized in stripline and coplanar-line configurations.

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