A dual-band HTS filter using modified dual-spiral resonators

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This paper presents a symmetric dual-band filter with a centre frequency of 887 MHz. The filter uses modified structure of dual spiral resonators with interdigital capacitive load. At the same resonant frequency, the resonator can occupy area of less than 2.75% the area of the square loop resonator. Moreover, the resonator has a very low sensitivity to substrate thickness. The resonator structure also allows two types of couplings and, hence, allows application of cross-couplings with different signs to the direct couplings.

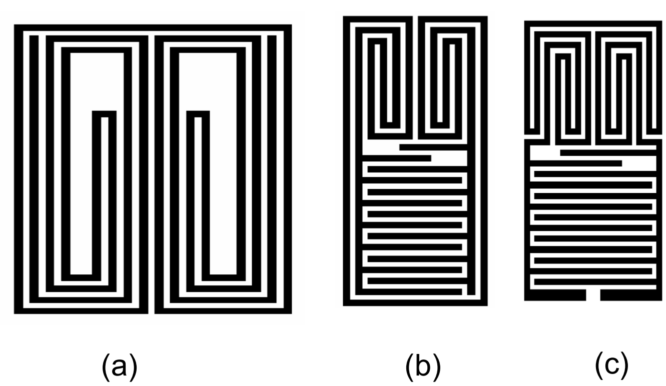


Fig. 1. (a) Dual spiral-in-spiral-out resonator; (b) Dual spiral-in-spiral-out resonator with capacitive load; (c) Modified capacitive-loaded spiral-in-spiral-out resonator.

Introduction: Planar resonators are the building blocks of planar bandpass and bandstop filters. The low surface resistance of High-Temperature Superconductors (HTS) allows the investigation of new miniaturized structures consisting of planar resonators.

The miniaturization can be achieved by folding, meandering, and/or capacitive-loading the microstrip straight resonators [1]. HTS spiral resonators usually exhibit a much smaller size and have a higher unloaded quality factor than the conventional hairpin resonators [2]. Cross couplings between non-adjacent resonators can be applied in the same manner to achieve a multi-band bandpass filter [3]. To this end, transmission zeros are located within the passband of a bandpass filter, thus, dividing it into smaller passbands [4].

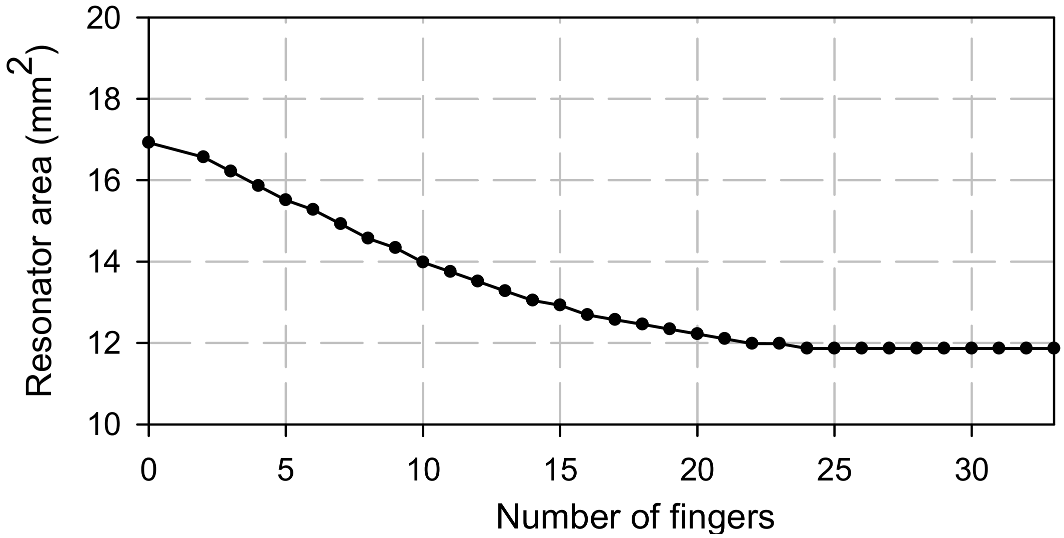
In [5], Zhou introduced a highly miniaturized dual-spiral resonator with capacitive load. A method of achieving negative cross-couplings has been introduced later by the same author by connecting the coupled pair of resonators with a crossing microstrip line [6]. In this circuit the resonators need to be well spaced from each other to make electric coupling dominant. This restricts the application of this type of cross-coupling to certain topologies. This paper introduces a modification of the resonator structure, which allows an alternative to the negative coupling.

In section II, the effect of capacitive loading on dual spiral resonators is discussed. The new structure, which allows electric couplings, is also presented. In section III, a new filter with the modified resonators is introduced. This filter exhibits dual-band characteristics by optimizing the locations of the transmission and reflection zeros using algorithm explained in [4].

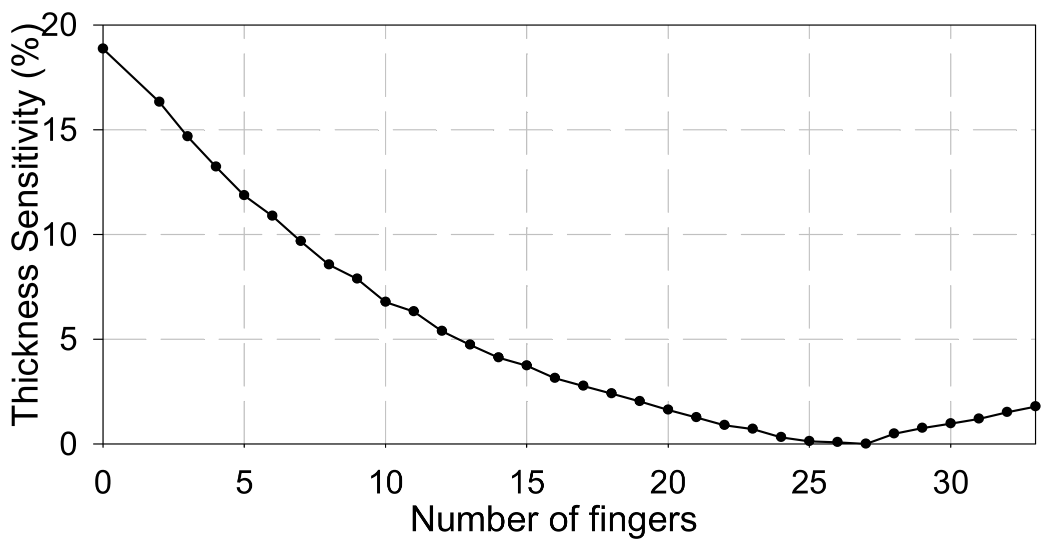
Dual Spiral Resonators: Capacitive-loading has been used to miniaturize half-wavelength square loop resonators. The resultant resonators can occupy area of less than 51% the area of the square loop resonator [7]. Zhou in [5] has applied the same principle to miniaturize dual-spiral resonators (Fig. 1.(a)). The capacitive-loaded resonator (Fig. 1.(b)) has a very low sensitivity to substrate thickness. It is reported that a change of 10 μm in the substrate thickness shifts the centre frequency (610 MHz) by only 33 kHz. The resonator has the interesting property of minimizing the far field radiation [5]. Moreover, the spurious harmonics at $2f_0$ cancels each other and the first spurious resonances are at frequency higher than $3f_0$ [5].

Considering all the advantages that the capacitive-loaded dual-spiral resonator has, the resonator structure in Fig. 1(b) has been modified to allow the edges of the dual-spiral to not be enclosed within the resonator structure (see Fig. 1(c)). This permits the use of the same mechanism of electric/magnetic couplings as in hairpin resonators [8].

In this section, the capacitive loading of a dual-spiral resonator has been investigated further by using a similar method to the one reported in [9]. Firstly, a dual-spiral resonator has been designed to have a centre frequency of 610 MHz on an MgO substrate with thickness *h* = 0.5 mm. Then, Interdigital capacitors were added with different numbers of fingers (from 2 to 33). Fig. 2. (a) shows the area of the resonator in mm^2 versus the number of fingers. It can be seen that when number of fingers is between 22 and 33, the resonator can be miniaturized to 71% of the original size. Fig. 2. (b) shows the sensitivity to substrate thickness versus the number of fingers. Thickness sensitivity has been measured as a ratio of variation in centre frequency per millimeter of substrate thickness as follows,



(a)



(b)

Fig. 2. (a) Area of capacitive-loaded dual-spiral resonator versus the number of interdigital fingers for a fixed frequency of 610 MHz (b) The thickness sensitivity versus number of interdigital fingers.

$$Sensitivity = \frac{\Delta f_0}{\Delta h \times f_0} \times 100\%, \quad (1)$$

where Δf_0 is the variation of the resonant frequency, Δh is the variation in substrate thickness in millimeter and f_0 is the centre frequency with the substrate thickness equal to h = 0.5 mm. From Fig. 2(b), it can easily be seen that by adding the appropriate capacitive load, zero sensitivity to substrate thickness can be achieved. In this case, if the number of fingers is 26, the resonators are insensitive to variation in substrate thickness.

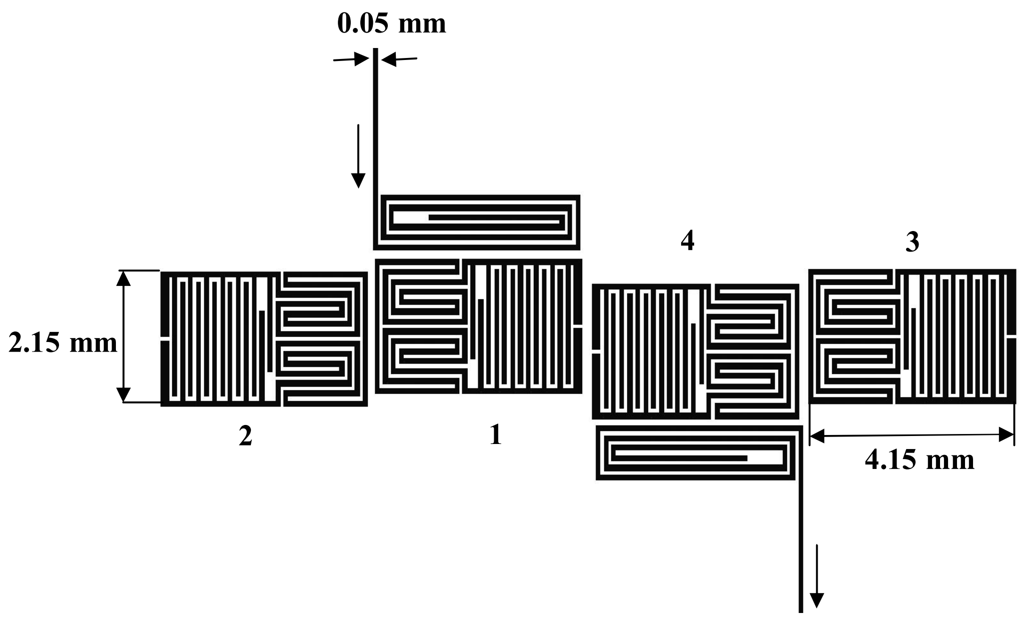


Fig. 3. Four-pole dual band filter layout.

Dual-Band Filter

A) Specifications: A four-pole filter has been designed to have a dual bandpass response with the following specifications:

First passband: 879-886.4 MHz,

Second passband: 887.6-895 MHz

Passband return loss: -23 dB

Stopband reflection loss: -30 dB

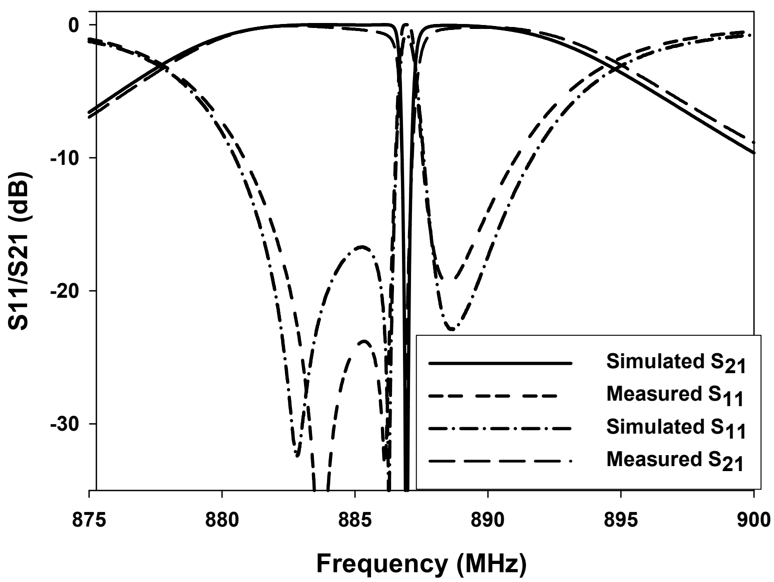


Fig. 4. Measured insertion and reflection losses of the 4-pole dual-band filter and the simulated responses.

Two transmission zeros can be achieved by cross-coupling the 1st and 4th resonators. The location of these zeros can be optimized to achieve the requisite filtering functions. The general coupling matrix has been built using the method developed by Cameron [10]. The matrix is synthesized again to achieve canonical topology using optimization [11].

The resultant normalized coupling coefficients are,

$M_{12} = 0.00576$, $M_{23} = 3.47\text{E-}05 \approx 0$,

$M_{34} = 0.00576$, $M_{14} = \text{-}0.01364$,

$Q_{e1} = Q_{e2} = 80.74$,

where M_{ij} is the coupling coefficient between resonators *i* and *j*. Q_{e1} and Q_{e2} are the input and output external quality factors, respectively. The filter layout is shown in Fig. 3.

B) Fabrication: The substrate used is MgO with a thickness of 0.5 mm and a chip size of 21 mm × 9 mm using YBCO thin film on both sides of the substrate. The filter has been simulated using Sonnet software with a resolution of 50 μm × 50 μm.

C) Measurement Results: The experimental results are depicted in Fig. 4. alongside the simulated response. The resultant centre frequency is shifted down by 6.23 MHz compared to the simulated one. The filter has been tuned with dielectric tuning screws at 40K.

Conclusion: A novel HTS resonator has been introduced. The new resonator can achieve two types of couplings. The resonator has been designed to have zero sensitivity to variation of substrate thickness. A novel dual-band filter has been designed using the new resonator. The measurement results agree with the simulated ones.

Acknowledgement: The authors would like to thank D. Holdom for patterning the HTS circuit, Mr C. Ansell for his technical support, P. Suherman and G. Nicholson for their help.

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