Compact Dual-Mode Filters for HTS Satellite Communication Systems

Z. M. Hejazi, *Member, IEEE*, P. S. Excell, *Senior Member, IEEE*, and Z. Jiang

***Abstract*— Novel compact dual-mode narrow bandpass microstrip filters using degenerate modes in multizigzag arms of square loop resonators were analyzed as realized in superconducting 2- and 4-pole versions and found to have high performance, selectivity, and substantial size reduction, compared with current designs. A 2-pole copper filter, scaled nearly eight times larger to operate at a center frequency of 142 MHz and bandwidth of 1.4%, was fabricated, tested, and compared with the prediction of a CAD tool to validate predictions for other analyzed designs. The agreement was found to be good.**

***Index Terms*—Dual-mode filters, narrow passband, planar circuits, superconductors.**

I. Introduction

In dual-mode filters (DMF's), two orthogonal modes occur at the resonant frequency. These can be coupled if the symmetry of the resonator is perturbed in some way (e.g., by a notch/stub in a ring resonator). The splitting level of the two modes is modified either by the angle of asymmetry between the coupling lines or the size of the perturbation notch/stub. The general picture of the phenomena is the same when a ring, disk or a square patch is used [1]. DMF's have been widely used in satellite communications because of their advantages in applications requiring high-quality narrow or medium bandwidth filters with small size, low mass, low loss, and elliptic-function response. However, most of the efforts before the discovery of high-temperature superconducting (HTS) materials were focused on the development and miniaturization of dual-mode dielectric-loaded resonator filters, but one major drawback of dielectric filters has been their spurious characteristics above the passband and the need of an additional low-pass filter and tuning screws, which will increase the insertion loss (IL), complexity, weight, and cost [2]. The emerging new HTS technology has provided a solution for further miniaturization of dual-mode planar filters with superior performance in lower frequency bands, having important applications in the next generation of satellite and communication systems. Ring/disc/square patches were adapted and realized for DMF's using HTS materials in [1]; multiplexers employing square patch dual-mode HTS filters were demonstrated in [3]; and a new dual-mode microstrip filter made of a 2-pole square loop resonator was proposed in [4]. Further miniaturization was achieved with a microstrip DMF made of a 2-pole meander loop resonator [5].

In this letter, a novel design is proposed for maximum miniaturization and with a narrower bandwidth. This is achieved by making each arm of a square loop resonator to have multiple meanders with different depths, so the entire area inside the loop is almost filled with transmission lines. The conductor width of the proposed resonators is fully uniform (except at the perturbation). This offers great simplification to the design and optimization process. This type of DMF can be considered as a "folded up" square cavity with magnetic walls.

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II. Configuration and Design Tool

A full-wave three-dimensional electromagnetic simulator with integral optimization tool [6] was used for the design and simulation of various DMF's of this type. The layouts of optimized microstrip multizigzag square loop DMF's with one and two resonators are shown in Fig. 1. As the filter arms are identical, the only parameters to be optimized are the input/output coupling level s_1, the main coupling line between two filters s_2, the mode-modifying patch in the corner d, and the separation between the two filters d_1. The dimensions of the first filter, used in Fig. 1(a) and (b), are (all in millimeters): $w = 0.150, a = 1.2, b = 0.8, c_1 = 0.96, c_2 = 2.9$, $w_1 = 7.5, w_2 = 10, s_1 = 3.8, s_2 = 10$, and $d_1 = 2.4$. In the 2-pole filter, $d = 0.64$ mm and in the 4-pole filter $d = 0.56$ mm. The 2- and 4-pole filters were designed and analyzed as realized in superconducting microstrip on $LaAlO_3$ substrate in a copper shield case. The second 2-pole filter with more steps in each arm [Fig. 1(c) and (d)] was analyzed in several forms: one actual-size with superconducting microstrip on $LaAlO_3$ substrate and copper shield, and two others scaled nearly eight times larger with either (fictitious) superconducting or copper microstrip on RT/Duroid substrate ($\varepsilon_r = 10.2$ and height $= 1.27$ mm), with and without a shield case, for test and comparison purposes. The actual-size superconducting filter has the dimensions $w = 0.159, a = 1.9, b = 0.48$, $c_1 = 1.52, c_2 = 2.48, c_3 = 3.43 w_1 = 7.98$, $w_2 = 10, s_1 = 4.3$, and $d = 0.8$. The scaled-up filters have the dimensions $w = 1.27, a = 13.96, b = 3.8, c_1 = 10.8$, $c_2 = 18.4, c_3 = 26, w_1 = 60.9, w_2 = 71.1, s_1 = 30.4$, and $d = 3.8$ mm. In the scaled filter with five meanders per side [Fig. 1(c) and (d)], additional coupling stubs were needed and the meanders were made tighter as shown in Fig. 1(c). The gap in the actual-size filter was small enough (0.08 mm), so only the central coupling stub was enough to provide sufficient coupling capacitance.

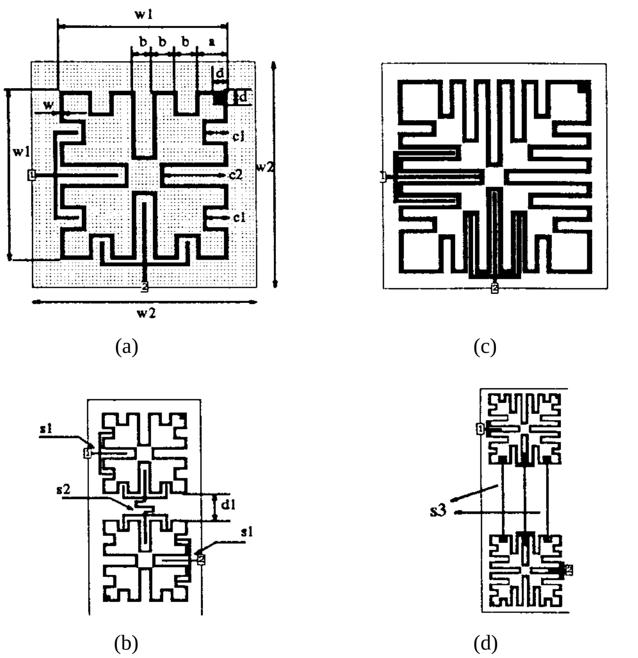


Fig. 1. Layouts of 2- and 4-pole microstrip dual-mode filters with three and five meanders in each arm.

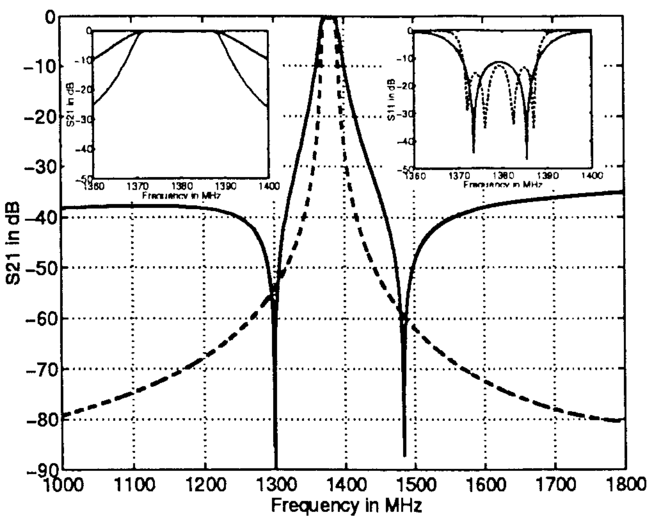


Fig. 2. Computed transmission and return loss responses of a 2- and 4-pole DMF's with maximum ripple of 0.25 dB and bandwidth of 1.37%. ——: 2-pole filter. – – –: 4-pole filter.

III. Computational and Experimental Results

The computed transmission responses of superconducting 2- and 4-pole filters having three meanders in each arm on $LaAlO_3$ substrate with $\varepsilon_r = 24$ are shown in Fig. 2. The filter has a bandwidth of 1.37% and f_o of 1.38 GHz. At passband, the ripple is 0.25 dB. In contrast with the 2-pole filter, Fig. 2 shows a significant increase in the skirt's sharpness in the response of the 4-pole filter. However, the 4-pole filter does not show elliptic-function response because there is no coupling between nonadjacent resonators. This can easily be achieved if two additional coupling stubs are inserted as shown in Fig. 1(d). The 2-pole filter, as can be seen, has an elliptic function response with well-defined transmission zeros above and below the passband. All four resonances of the four split and coupled modes can be clearly seen in the enlarged portions of transmission and return loss responses in Fig. 2.

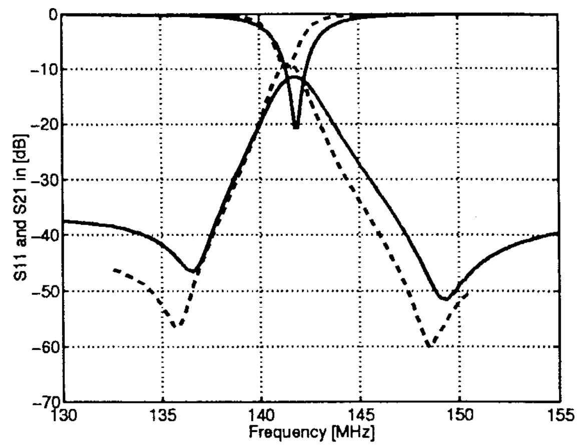


Fig. 3. Measured and simulated frequency responses of the scaled-up 2-pole dual-mode copper filter [Fig. 1(c)] without a shield case. ——: Experimental. – – –: Computed.

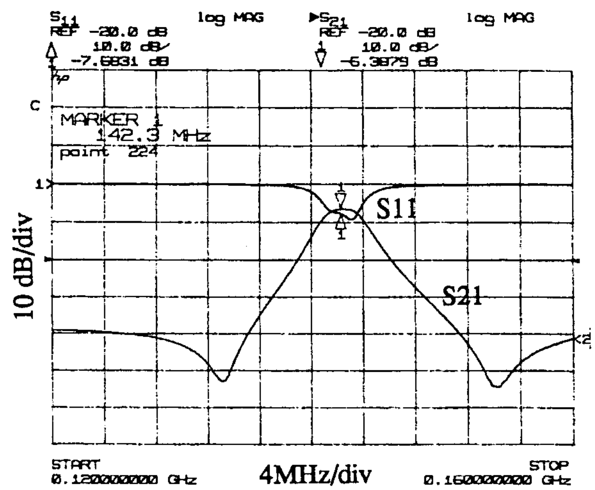
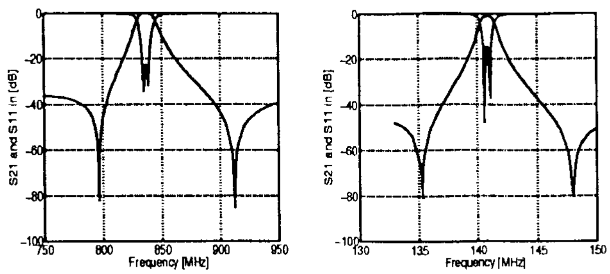


Fig. 4. Measured frequency response of the scaled-up 2-pole dual-mode copper filter [Fig. 1(c)] when a top lid is placed above the filter.

The scaled 2-pole DMF [Fig. 1(c)] was fabricated with copper conductor on RT/Duroid substrate, tested, and compared with the simulation results of an identical filter as shown in Fig. 3. As expected, for a copper filter operating at the lower center frequency of 142 MHz, the IL at midband frequency was about 10 dB without a shield case, corresponding to a Q_o of nearly 150. The passband shape is rounded out, as expected for conventional microstrip [3]. When a copper top plate is placed 6 mm above the circuit, IL reduces to 6.4 dB $(Q_o \approx 200)$ and the passband shape improves, as shown in Fig. 4, because the filter dimensions were optimized along with a shield case which has its own effects on the splitting level and radiation loss. This implies that most of the losses are due to the conductor. Using a superconductor, these losses could be drastically reduced. The simulated results shown in Fig. 3 indicate a good agreement between the computed and measured results except a small shift in f_o and IL which are due to manufacturing tolerance and additional losses of the



(a) (b)

Fig. 5. Computed frequency responses of the actual and scaled 2-pole dual-mode superconducting filter [Fig. 1(c)] on (a) $LaAlO_3$ and (b) RT/Duroid substrates, respectively.

external connecting lines, respectively. This good agreement validates the computed performance of the other filters.

The computed responses of the scaled-up 2-pole DMF shown in Fig. 1(c), realized in fictitious superconductor on RT/Duroid substrate, is presented in Fig. 5(b). The IL at midband frequency is 1.2 dB, while it is 0.05 dB for the actual-size filter on $LaAlO_3$ substrate, shown in Fig. 5(a). If the scale factor of eight is taken into account, it can be found that the Duroid substrate contributes to the IL with 0.1 dB (1.2/8) in contrast with $LaAlO_3$ substrate. This is much less than the loss due to the conventional conductor (≈6 dB) as shown in the measured copper shielded filter on Duroid (see Fig. 4).

To show the considerable size reduction of these proposed filters, approximate formulae for the circuit surface areas needed to accommodate ring, disk, square patch, and square loop resonators given by [4] were used. The surface area occupied by the 3-meander 2-pole filter in Fig. 1(a) is $A = 56$ mm^2. Correspondingly, $A_{\rm ring} = 474$ mm^2, $A_{\rm disk} = 1609$ mm^2, $A_{\rm sqpatch} = 1173$ mm^2, and $A_{\rm sqloop} = 293$ mm^2. The size reduction is 8.46, 28.7, 20.9, and 5.2 times against the ring, disk, square patch, and square loop resonators, respectively. Applying the same expressions, the size reduction achieved by the 5-meander filter of Fig. 1(c) is almost doubled.

IV. Conclusion

A novel compact filter design has been proposed, achieving miniaturization by factors of up to 29 times (3-meander filter) and up to 68 times (5-meander filter) at subgigahertz frequencies with a good rectangular transmission characteristic. This is achieved by using degenerate modes of multimeander square loop resonators, such that the entire area inside the loop was almost filled. The proposed filters offer advantages of simplification and miniaturization, compared with traditional designs.

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