Dual-Mode and Quad-Mode Möbius Bandpass Filters

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***Abstract* — Dual-mode and quad-mode Möbius wire-loaded cavity resonators are being developed for compact bandpass filter applications. Initial results on tuned filters indicate that excellent filter characteristics can be attained in devices that are significantly smaller than traditional wire loaded cavity technology. A novel quad-mode Möbius resonator is presented which occupies the same volume as a dual-mode Möbius resonator. Precisely-controlled dielectric loading of dual-mode Möbius wire loaded bandpass filters has been recently implemented. The passband characteristics are quite encouraging despite the limited tuning used to date.**

I. Introduction

Dual-mode Möbius resonators utilizing a geometrical deformation of a transmission line to obtain a four-fold reduction in volume have been previously introduced [1, 2]. These resonators result from projecting a transmission line onto a non-orientable surface. A Möbius strip is the prototypical non-orientable surface. Although traditionally referred to as one-sided surfaces, non-orientable surfaces are those for which the concept of left and right are globally nonsensical [3].

The non-orientable nature of the surface results in an apparent periodic alternation between left and right as the center circle of a Möbius strip is traversed. If a transmission line is projected onto a non-orientable surface with phasing required to sustain the electromagnetic oscillation along the path length associated with reversal of left and right, a resonant condition occurs with a volume reduction of a factor of four over conventional wire-loaded designs [1, 2].

An alternative way of visualizing the dominant modes is to consider that a transmission line projected onto a Möbius strip has a 180° twist of the geometry of the transmission line which yields a phase reversal of the fields when the transmission line ends are joined. The additional phase shift due to the twist yields a resonance when the transmission line circumference is equal to a half wavelength. When realized with a twin conductor transmission line, the conductor can be visualized as the edge of the Möbius strip and an electric field flux line can be considered as the non-orientable surface.

The intrinsic transmission zeros of the Möbius resonator are employed to realize bandpass filters with elliptic-type characteristics.

Previous publications described the unique properties of Möbius resontors and demonstrated their potential advantages [1, 2]. This paper extends this work to realize compact bandpass filters employing these resonators.

II. Dual-Mode and Quad-Mode Möbius Bandpass Filters

The Möbius wire structure was formed from 0.141-inch diameter copper wire and has a mean diameter of 7.87 cm. Glass fiber reinforced dielectric boards, joined in the shape of an “x”, were used to position the Möbius wire resonator in the center of a cavity. To develop techniques for tuning Möbius wire loaded cavity resonators, a low frequency cylindrical cavity was designed with an internal diameter of 11.43 cm and a height of 3.175 cm. The resultant Möbius wire resonator and dielectric support are shown in Figure 1. Tuning screws in the top plate and side walls of the cavity were used to adjust the resonant frequencies and the coupling between modes in order to adjust the placement of the poles and zeros. A high degree of symmetry in the passband shape in Figure 2 around the 550 MHz center frequency is demonstrated. The solid and dashed lines are the result of two different tunings. In the first, a goal of 10 dB return loss was chosen. In the second, 15 dB return loss was selected. In both cases the center frequency is maintained and a desirable near-symmetrical elliptic-type filter response is obtained.

The limitation in the present implementation is revealed when examining the out-of-band response above the passband. As can be seen in Figure 3, capacitive coupling to the Möbius wire resonator results in strong coupling to a mode at about twice the fundamental Möbius mode. However, at this frequency, a Möbius mode does not exist. Instead, an anti-resonance occurs as a result of the 180° twist in combination with the wavelength being approximately equal to the circumference. The observed modes are a result of generalized even modes with respect to the cavity wall. Techniques to minimize the excitation of these modes are being pursued.

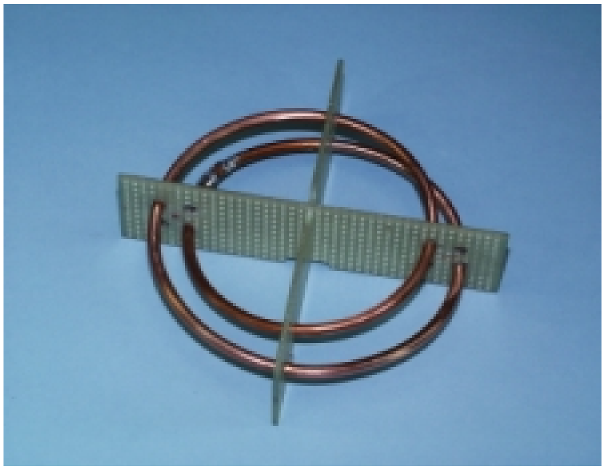

Fig. 1. Photograph of the dual-mode Möbius wire structure which is placed in a 11.43-cm-diameter 3.175-cm-high cylindrical aluminum cavity.

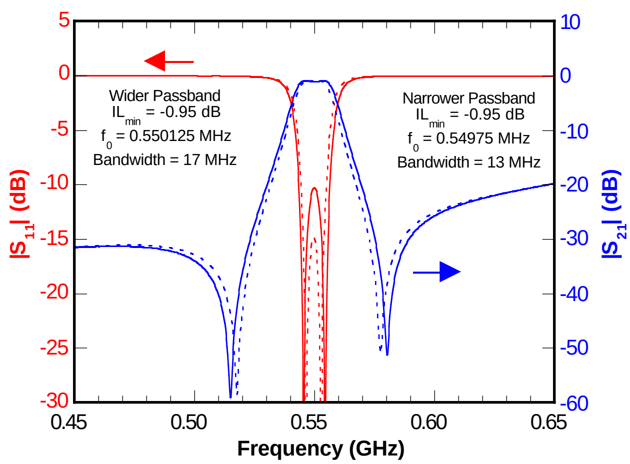

Fig. 2. Response of the dual-mode Möbius filter when tuned for two different bandwidths.

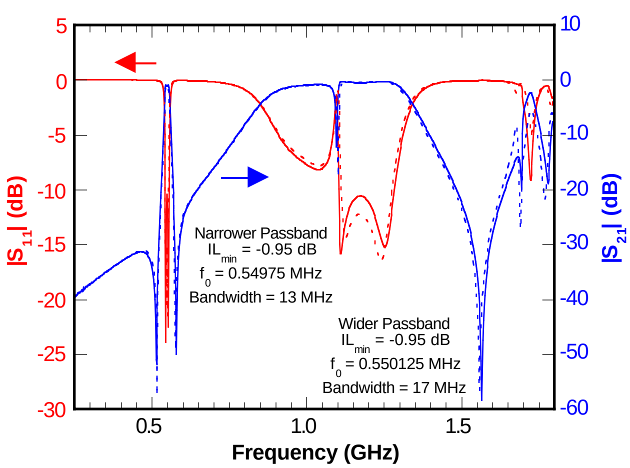

Fig. 3. Out-of-band response of the dual-mode Möbius filter when tuned for two different bandwidths.

A quad-mode resonator can be realized by interleaving two identical dual-mode Möbius wire resonators. Topologically, this is characteristic of a structure that has two "sides" and two "edges". The quad-mode resonator was fabricated by assembling two Möbius strips which intersect along their center circles and for which the local cross section results in the electric fields being orthogonal. In essence, the quad-mode resonator contains two dual-mode resonators occupying the same region in space and for which the fields are locally orthogonal. In the terminology [3] of Lens Spaces, a dual-mode Möbius resonator is a substantial embedded surface in Lens Space [2,1] and two dual-mode Möbius resonators that intersect along their center circles are substantial embedded surface in Lens Space [4,2]. By definition [3], Lens Space [4,2] degenerates to Lens Space [2,1].

Figure 4 is a photograph of a quad-mode resonator consisting of two dual-mode Möbius resonators which occupy the same volume. Note that the structure in Figure 4 is two interleaved dual-mode wire resonators of the type shown in Figure 1, in which one resonator has been rotated about its center by 180° with respect to the other resonator. Interleaving the resonators in this fashion results in the local fields being orthogonal, resulting in a quad-mode structure.

When the structure in Figure 4 is inserted in the same cavity and weak coupling is used, each of the four modes is clearly evident as shown in Figure 5. The substantial splitting between modes is due to the differences in parasitic coupling between modes and the cavity walls, as well as inaccuracies in the machining and assembly of the structure. The intrinsic transmission zeros are also evident in Figure 5.

Since the volume occupied by the quad-mode resonator is the same as the dual-mode resonator an attempt was made to tune a quad-mode resonator with a set of tuning screws designed to tune a dual-mode structure. Not surprisingly, an ideal response could not be obtained. However, a reasonably good passband response was achieved subject to a few restrictions. Some lumped capacitances were added internal to the cavity to modify the mode coupling beyond the range obtainable with the tuning screws. As a consequence, the resonant frequencies and hence, the filter center frequency is reduced slightly. Although a symmetric response could not be achieved, the best passband characteristics obtained are shown in Figure 6. Tuning limitations preclude placing a transmission zero on each side of the passband. Although the tuning was limited, it was fortunate that two transmission zeros could be placed above the passband. This helps offset the out-of-band response caused by coupling to higher frequency modes noted in Figure 3 for the dual-mode filter.

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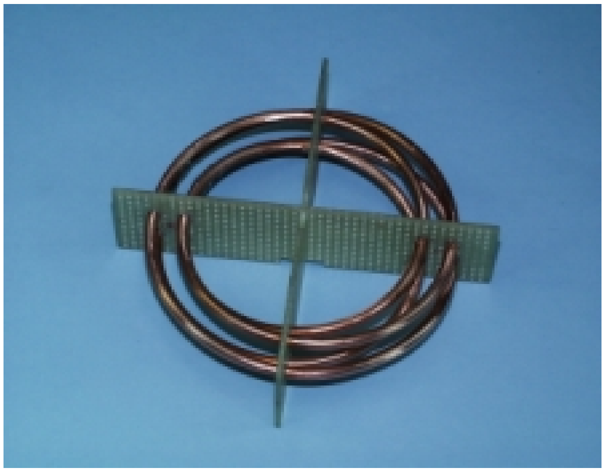

Fig. 4. Photograph of the quad-mode Möbius wire structure which is placed in a 11.43-cm-diameter 3.175-cm-high cylindrical aluminum cavity.

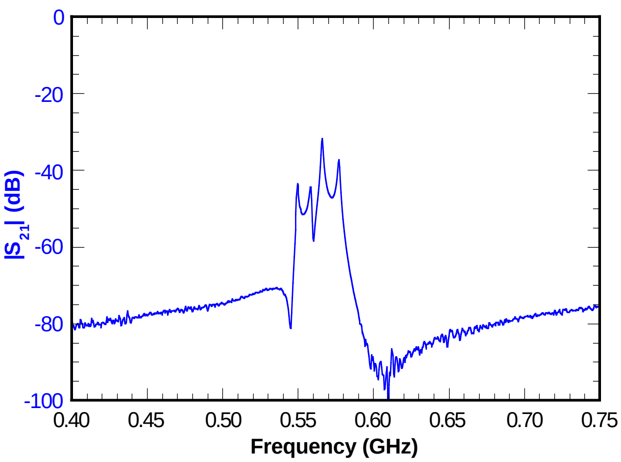

Fig. 5. Response of the quad-mode Möbius resonator when loosely coupled.

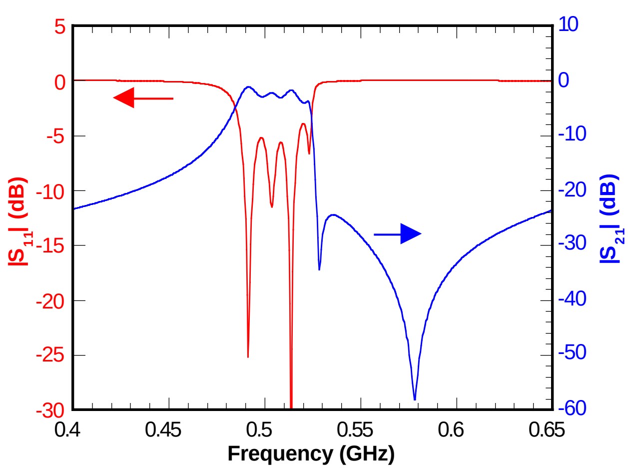

Fig. 6. Response of the quad-mode Möbius filter tuned for two transmission zeros above the passband.

III. Dielectrically Loaded Dual-Mode Möbius Bandpass Filters

A number of dielectric Möbius resonator test structures have been fabricated using alumina ceramics, in conjunction with small diameter gold or platinum metal wire. A parallel loop geometry was employed since it can be accurately fabricated and modeled. Alumina was chosen for initial testing because of its excellent microwave performance, high thermal conductivity and relatively large dielectric constant.

Increasing complexity was used to bind the “sandwich-type” ceramics using Teflon, ceramic binder and finally mechanical ceramic threaded components. Complicated ceramic shapes were fabricated using both conventional ceramic processing methods and laser etching.

Figure 7 shows several of the fabricated dielectrically loaded Möbius wire resonators. The alumina disk diameter was 1 cm and the diameter of the conductor path was approximately 0.8 cm. Beginning at the top left and then proceeding clockwise are:

a. an alumina resonator with gold wire, 1 mm loop separation, ceramics bound using Teflon,

b. an alumina resonator with gold wire, 1 mm loop separation, ceramics bound using ceramic cement, the metal wire is completely incased in ceramic cement,

c. an alumina resonator with gold wire, 0.5 mm loop separation, ceramics bound using ceramic cement,

d an alumina resonator with gold wire, 1.5 mm loop separation, ceramics bound using ceramic cement.

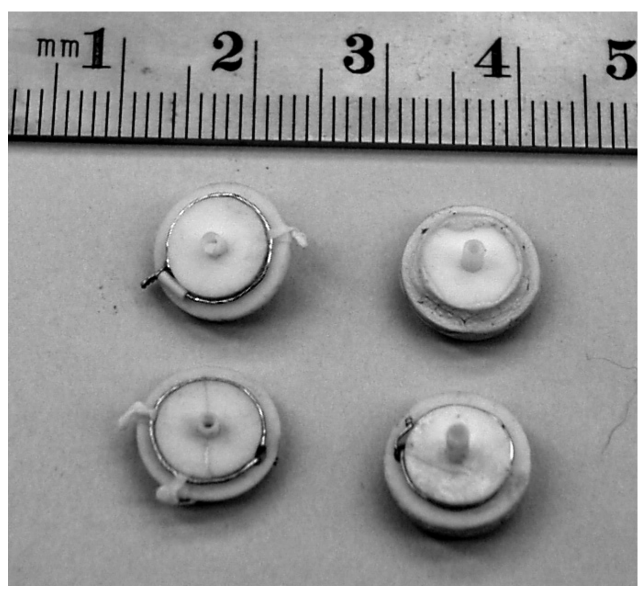

Fig. 7 Alumina and gold wire Möbius resonators.

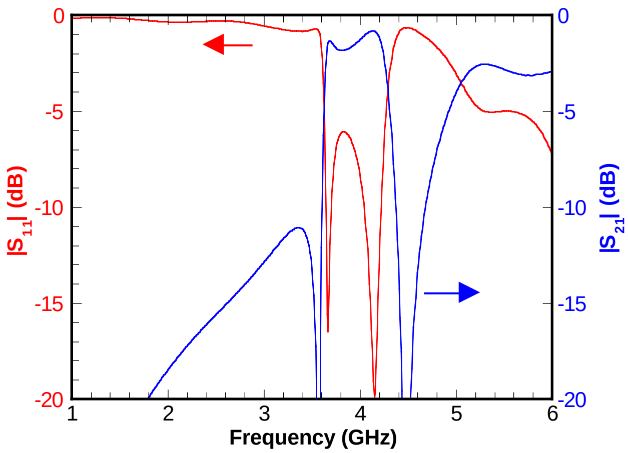

Fig. 8 Untuned bandpass filter response using the alumina and gold wire Möbius resonator in the lower left of Figure 7.

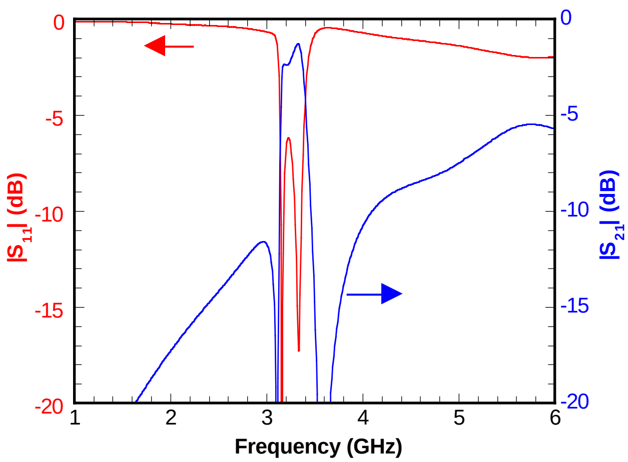

Fig. 9 Untuned bandpass filter response using the alumina and gold wire Möbius resonator in the lower right of Figure 7.

These resonators were placed in a ~1.25 cm diameter cavity that did not have provisions for tuning screws. Hence, tuning was limited to adjusting the input and output coupling and the angular orientation of the resonator in the cavity. The best results obtained are shown in Figures 8 and 9 for the resonator in the lower left and lower right, respectively, of Figure 6. Although the in-band and out-of-band responses are not adequate for system needs, these results were obtained without implementation of tuning the coupling between modes. Achieving a response resembling a "bandpass filter" was considered quite encouraging, considering the small sizes involved. Work is underway to develop dielectric tuning of these structures so that the performance of these devices can be improved to meet communication system requirements.

IV. Conclusion

A symmetric bandpass filter with two poles and two transmission zeros has been developed using a tuned dual-mode Möbius resonator configuration. The center frequency is 550 MHz. A quad-mode resonator, consisting of two interleaved dual-mode resonators was introduced as a means of realizing a more compact higher order filter. An asymmetric four-pole bandpass filter was tuned using this quad-mode resonator geometry. Although ideal passband characteristics were not achieved due to tuning limitations inherent in the cavity housing design, this prototype quad-mode filter yielded encouraging results.

The incorporation of dielectric loading with Möbius wire resonators was also successfully demonstrated. A reasonable passband response was obtained, despite the limited tuning available. These encouraging results indicate that this technology can be used to develop compact high-performance filters. Future efforts will focus on developing methods to suppress the excitation of the higher order modes and improve tuning.

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