NOVEL HELICAL RESONATOR FILTER STRUCTURES

S. J. Fiedziuszko, R. S. Kwok

Space Systems/LORAL
3825 Fabian Way, Palo Alto, CA 94303

ABSTRACT

Helical resonator filters are well-known and widely used at lower microwave frequencies. Two novel helical resonator filter configurations for applications in wireless and satellite communication systems are described in this paper. This includes miniature filters utilizing single mode, high dielectric constant material loaded helical resonators, as well as higher order dual mode helical resonator loaded cavities. Both configurations can be used to realize advanced filters with non-adjacent couplings. The basic filter configurations are discussed and experimental results are presented.

INTRODUCTION

As a microwave structure, the helix finds many applications in traveling-wave tubes, antennas, and delay lines. At lower frequencies, helical resonators operating in a fundamental mode (resembling a coaxial, quarter-wave resonator) are often used. Unfortunately, the Helmholtz equation is not separable in helical coordinates [l], and an analytical, rigorous solution for the general helix has not yet been obtained (to the authors' knowledge). Various simplifying assumptions (e.g. sheath helix) have been used successfully in the past, however, a significant theoretical work needs to be completed to explore the full potential of the helix structure. Analyzing the available field solutions for the sheath helix, we notice that these solutions are remarkably similar to the field solutions for the dielectric rod waveguide. Therefore, in many microwave structures utilizing devices based on a dielectric waveguide (e.g. dielectric resonators), helical resonators with potentially significant size reduction, especially at lower microwave frequencies, can be introduced.

HELICAL RESONATORS

A generalized helical resonator loaded cavity is shown in Figure 1. Specific design guidelines for fundamental mode resonators are readily available in literatures [2-4]. The field solutions for the sheath helix can be found in [1,5,6]. The dominant fundamental mode (n=0) is used in the proposed designs for single mode dielectric loaded helical resonator filters. Higher order modes (n>0), usually hybrid modes, are utilized in dual mode helical resonator loaded cavity filter structures described in this paper.

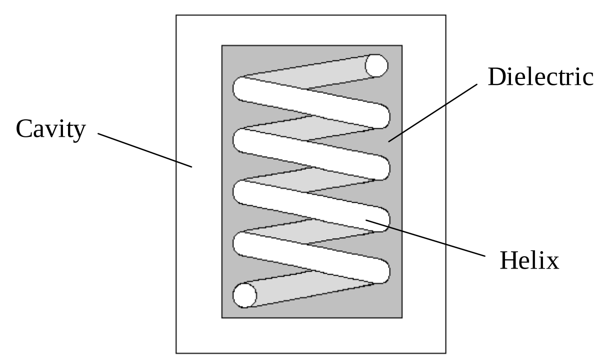

Fig. 1 – Generalized helical resonator loaded cavity with dielectric loading.

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SINGLE MODE DIELECTRIC LOADED HELICAL RESONATOR FILTERS

The basic idea for this particular structure is to utilize high dielectric constant, low loss, temperature stable ceramics to realize single mode helical resonators as described in [2-4]. This enables a significant reduction in resonator size and provides needed temperature compensation. Ultimately, the ceramic core can be metallized, forming a spiral conductor (a similar manufacturing process is currently used to produce lower Q, larger coaxial ceramic resonators). Design of the filter mainly follows the guidelines from Zverev [2], except that in our case, the resonator height of a quarter-wave is scaled by the effective dielectric constant. This is approximated by using the standard formula of an inverted microstrip. As an example, a resonator was designed for 230 MHz. At this frequency and chosen geometry, the effective dielectric constant and unloaded Q factor was estimated to be 4.6 and 500, respectively.

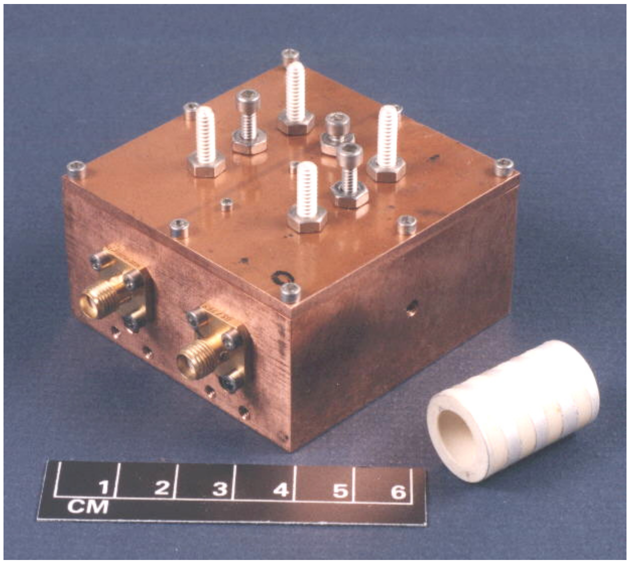

Fig. 2 – Single mode helical resonator with dielectric loading (four pole filter with metallized high dielectric constant ceramic tube helical resonators)

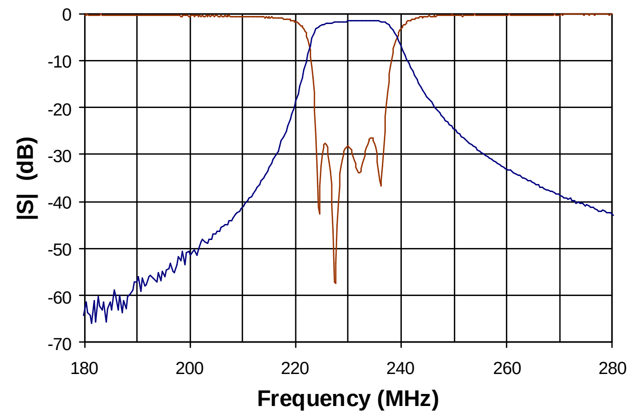

Fig. 3 – Measured response of a single mode helical resonator filter with dielectric loading (Chebyshev response, 4-pole, 13 MHz bandwidth, 1.7 dB insertion loss).

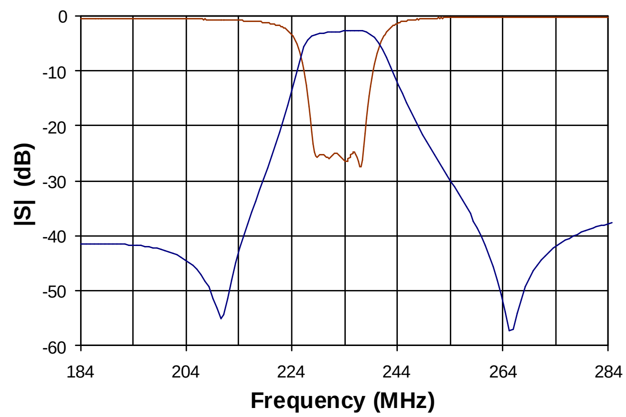

Fig. 4 – Measured response of a single mode helical resonator filter with dielectric loading (quasi-elliptical response, 4-pole, 10 MHz bandwidth, 2.7 dB insertion loss).

The resonators with OD=0.62", ID=0.4", with metallized stripe of 0.12" wide, and pitch=0.24", were realized using a ceramic tube of dielectric constant=37. Several 4-pole filters were built (Figure 2). Measured results for Chebyshev response and quasi-elliptical response filters are shown in Figures 3 and 4. Since this was a proof-of concept design, no attempt to maximize the Q factor has been made. In spite of this, reasonable Q factors (150-200) have been obtained for these frequencies. The filter structures are very simple and can be scaled to higher frequencies with significantly improved Q factor. The flexibility of the structure also supports the generalized quasi-elliptical filter designs with symmetrical or asymmetrical response.

DUAL MODE HELICAL RESONATOR LOADED CAVITY FILTERS

Dual mode structures are widely used to realize high performance filters. Typical structures include: air cavity [7], dielectric resonator loaded cavity [8], and metal resonator loaded cavity [9,10]. In this paper, we propose the use of the half-wavelength helix loaded cavity to realize dual mode filter structure. The guided wavelength can be approximated by numerically solving the transcendental eigenvalue equation of a sheath helix in [1]. Similar to the dielectric resonator loaded cavity, the lowest order eigenstate of a helical resonator loaded cavity which displays the duality nature of the electromagnetic field pattern is the n=1 mode, even though the field distributions of the two cases are very much different.

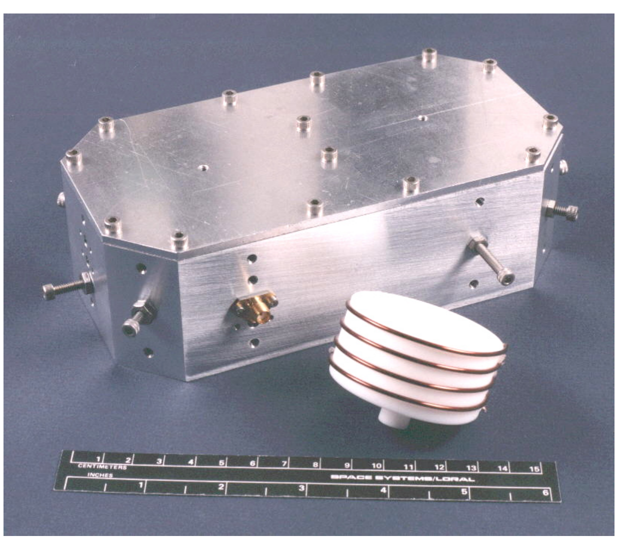

Fig. 5 – Dual mode helical resonator loaded cavity filter (copper helical resonators on teflon core, bare aluminum cavities).

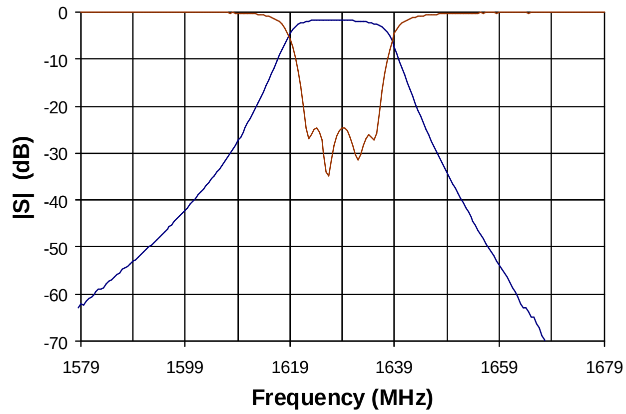

Fig. 6 – Measured response of a dual mode helical resonator loaded cavity filter (Chebyshev response, 4-pole, 14 MHz bandwidth, 1.7 dB insertion loss).

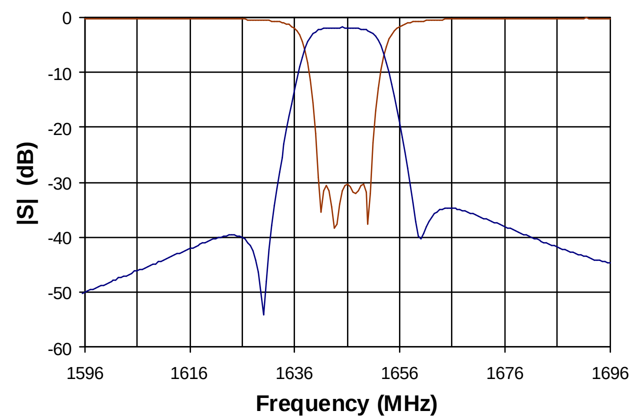

Fig. 7 – Measured response of a dual mode helical resonator loaded cavity filter (quasi-elliptical response, 4-pole, 10 MHz bandwidth, 1.8 dB insertion loss).

Since in this case, higher order modes in helix are used, the helical resonator is larger than that of the single mode designs. However, a much higher Q factor can be obtained. The helical resonators used for dual mode filters (Figure 5) were manufactured from 4.5 turns of copper wire (AWG #15) on a teflon core of 2" diameter and l" high. The measured responses of the realized 4-pole Chebyshev and quasi-elliptical filters are shown in Figures 6 and 7 respectively for n=1 mode. Excellent results have been obtained, clearly demonstrating the dual mode operation of the filters.

Similar to the single mode experiments, unplated metal housing and tuning screws were used for this proof-of-concept trial. The measured unloaded Q factor of 1500 can be improved by silver plating of the parts and further optimized by using different aspect ratio and geometry of the helix. In addition, the relatively light weight and small size advantage of this filter structure could be enhanced by utilizing high dielectric constant materials as illustrated in Figure 1 and demonstrated in the single mode experiments.

CONCLUSIONS

Novel configurations for high performance helical filters have been demonstrated. Since helix structures are not well understood, this opens a new area for investigation of these very promising microwave structures. Excellent results have been obtained in this initial work and substantial improvement is expected. These structures may find applications in rapidly growing cellular systems and PCS.

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REFERENCES

[1] R. E. Collin, "*Field Theory of Guided Waves*", McGraw-Hill, New York, 1960.

[2] A. I. Zverev, "*Handbook of Filter Synthesis*", Ch.9, Wiley & Sons, New York, 1976.

[3] P. Vizmuller, "*Filters with Helical and Folded Helical Resonators*", Artech House, Norwood, MA., 1987.

[4] W. W. Macalpine, R. O. Schildknecht, "Coaxial Resonators with Helical Inner Conductor", *Proc. IRE*, pp.2099-2105, 1959.

[5] J. R. Pierce, "*Traveling Wave Tubes*", D. Van Nostrand Co., Princeton, NJ., 1950.

[6] S. Sensiper, "Electromagnetic Wave Propagation on Helical Structures", *Proc. IRE*, pp.149-161, 1955.

[7] A. E. Atia, A. E. Williams, "Narrow Bandpass Waveguide Filters", *IEEE Trans. on Microwave Theory and Techniques*, vol. MTT-20, pp.258-265, April 1972.

[8] S. J. Fiedziuszko, "Dual Mode Dielectric Resonator Loaded Cavity Filters", *IEEE Trans. on Microwave Theory and Techniques*, vol. MTT-30, pp.1311-1316, September 1982.

[9] S. J. Fiedziuszko, J. A. Curtis, "Plural-mode Stacked Resonator Filter Including Superconductive Material Resonators", US Patent 5,484,764, January 16, 1996.

[10] C. Wang, K. A. Zaki, A. E. Atia, "Dual-Mode Conductor-Loaded Cavity Filters", *IEEE Trans. on Microwave Theory and Techniques*, vol. MTT-45, pp.1240-1246, August 1997.