Lumped-Element Conductor-loaded Cavity Resonators

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Abstract - **In this paper, we present a novel conductor-loaded cavity resonator having the form of L and C lumped-element resonators. The resonator is derived by modifying traditional split-ring resonators. The proposed lumped-element resonator offers more than 85% size reduction in comparison with split-ring resonators. In addition, the proposed resonator eliminates the need to use the dielectric support that is typically required for split-ring resonators. An 800 MHz 3-pole filter was designed, built and tested. The experimental results obtained verify the validity of the proposed concept.**

I. INTRODUCTION

The split-ring resonator was first proposed in 1976 [1] as an accelerating structure. The resonator was implemented in [2]-[4] and more recently in [5] to construct filters for low frequency applications. The resonator consists of a rectangular plate bent to form a cylinder with a gap running from the top to the bottom of the cylinder at the ends of the bent plate. The resonator is then inserted in a larger metallic cavity to provide shielding. The typical characteristic dimensions are of the order of 1/10 of the resonant wavelength, and typical Q's are of the order 2000-3000 at L band. A dielectric support structure is typically required to support the resonator inside the cavity. This in turn degrades Q and increases the mechanical design complexity of the structure.

In this paper we modify the split-ring resonator to construct a resonator that is more than 85 % smaller in size than conventional split-ring resonators while resonating at the same frequency. The proposed resonator also eliminates the need to use the dielectric support structure. The resonator is machined in the form of an iris. Coupling between the resonators is achieved by a spacer having the same cross section as the cavity enclosure. An 800 MHz filter is designed, built and tested. The filter has the dimensions of 12mmx24mmx50mm. The filter is assembled the same way traditional waveguide filters are assembled.

II. PROPOSED RESONATOR

Fig. 1a illustrates the traditional split-ring resonator. The resonant frequencies of the first three modes of the split-ring resonator mounted in an enclosure of dimensions 24mmx24mmx20mm are given in Table 1. The resonant frequencies are calculated using the ANSOFT HFSS software package [6].

TABLE 1.
The resonant frequency of the first three modes of a The split ring resonator shown in Fig 1a G=0.26mm,R= 7.5mm, W= 1mm, L=10mm, and enclosure dimensions of (24mmx24mmx20mm)

Mode	Resonance Frequency	Q
Mode 1	1.81 GHz	2520
Mode 2	5.41 GHz	4390
Mode 3	5.87 GHz	4600

The split-ring resonator can be viewed as a lumped element resonator consisting of a shunt capacitor and inductor. In order to decrease the resonant frequency, one can increase the capacitor surface area. This can be achieved by bending the loop as shown in Fig. 1b. The resonant frequencies of the first three modes of the resultant resonator are given in Table 2. It can be seen that the resonant frequency is reduced from 1.81 GHz to 0.74 GHz while having the same enclosure dimensions.

TABLE 2.
The resonant frequency of the first three modes of the resonator shown in Fig. 1b G=0.26mm,R= 7.5mm, W= 1mm, L=10mm and enclosure dimensions of (24mmx24mmx20mm)

Mode	Resonance Frequency	Q
Mode 1	0.74 GHz	1260
Mode 2	4.16 GHz	2940
Mode 3	5.44 GHz	3250

Fig. 1c shows the electromagnetic field distribution in the gap of the resonator shown in Fig. 1b. By applying

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the concept of electric wall symmetry, the resonator size can be reduced by 50 % without a change in the resonant frequency as shown in Fig. 1c. The resonant frequencies of the resultant resonator, which is shown in Fig. 1d, are given in Table 3. It can be shown that indeed the resonant frequency of mode 1 and mode 3 almost stay the same while mode 2 is suppressed. In comparison between Tables 2 and 3, it is noted that the Q value has been decreased from 1260 to 1100. Such a Q value is compatible to the typical Q value of helical filters at the same frequency range. It should also be noted that the structure is amenable to superconductor technology through thick film coating allowing the possibility of designing small size high Q filters.

To make machining the resonator easier, the lumped-element resonator has been modified as shown in Fig. 2. The resonant frequencies of the first two modes of the modified lumped-element resonator in Fig 2 are shown in Table 4. A slight reduction in resonant frequency has been observed.

The comparison between Tables 1 and 4 shows that one can modify the original split-ring resonator to achieve a resonator that is smaller in size while resonating at lower frequency. The dimensions of a traditional split-ring resonator that operates at 710MHz is 50mmx50mmx20mm while the dimensions of the proposed resonator having the same gap distance as shown in Fig. 2 are only 24mmx12mmx20mm, which represents more than 85% size reduction.

TABLE 3.
The resonance frequency of the first two modes of the resonator shown in Fig. 1d G/2=0.13 mm, R= 7.5 mm, W= 1mm, L=10 mm and enclosure dimensions of (24mmx12mmx20mm)

Mode	Resonance Frequency	Q
First Mode	0.74 GHz	1100
Second Mode	5.48 GHz	2387

TABLE 4.
The resonance frequency of the first two modes of the resonator shown in Fig. 2 G/2=0.13mm, W= 1mm, L=10mm and enclosure dimensions of (24mmx12mmx20mm)

Mode	Resonance Frequency	Q
First Mode	710 MHz	1050
Second Mode	5.34 GHz	1780

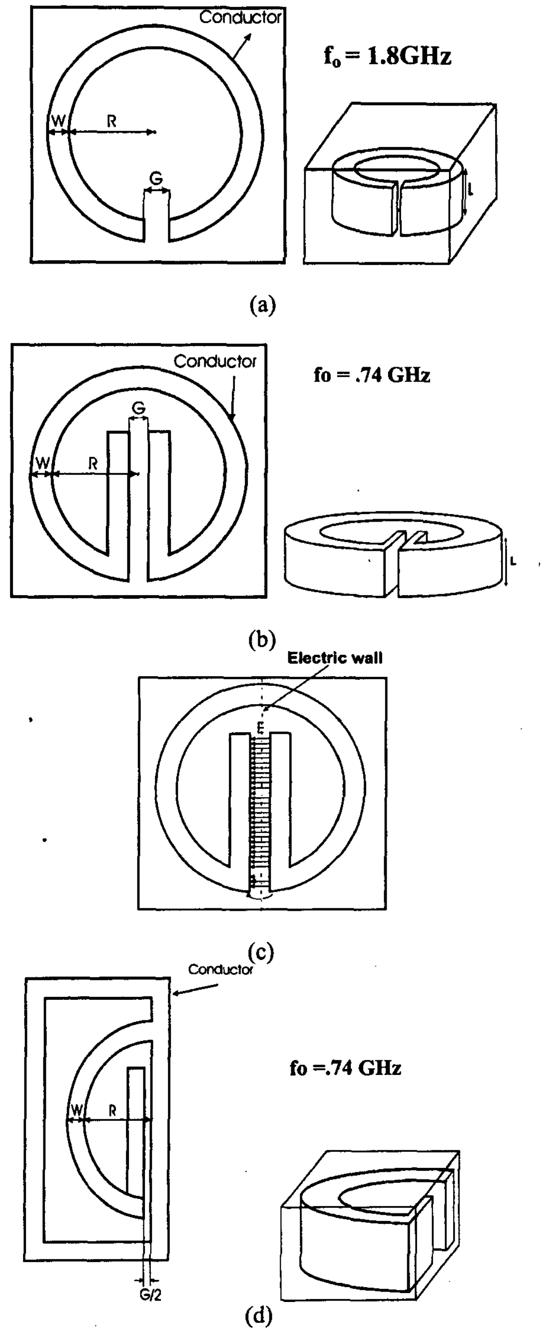

Fig. 1. (a) Traditional split-ring resonator (b) the modified split-ring resonator (c) electric field distribution (d) Half-cut resonator

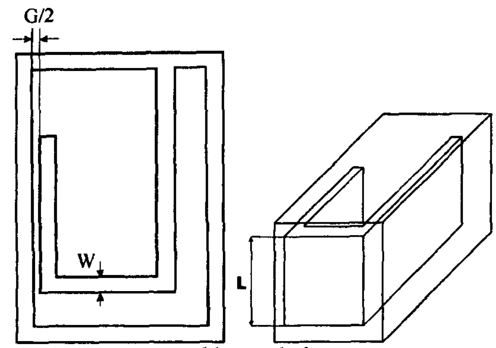

Fig. 2. The proposed lumped-element resonator

III. FILTER REALIZATION

To verify the concept proposed in this paper, a three-pole Chebyshev function filter with center frequency of 800MHz and bandwidth of 10Mhz was designed, constructed, and tested. The coupling coefficient between the resonators can be obtained by

$$k = \frac{f_e^2 - f_m^2}{f_e^2 + f_m^2}$$

where f_e and f_m are respectively the resonant frequencies of the cavity resonators when an electric/magnetic wall is put between the resonators respectively. Fig. 3 shows the coupling coefficient verses distance between the resonators. Using this coupling data, the distance between the resonators can be calculated.

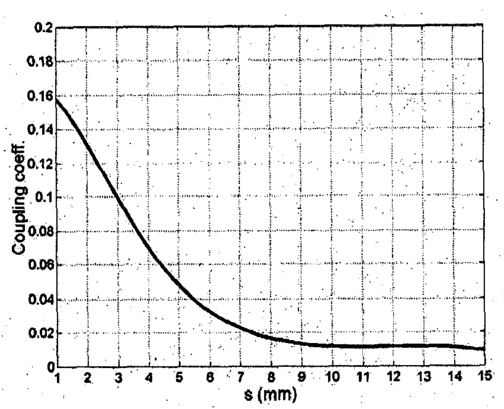

Fig. 3. Coupling coefficient verses the separation between the resonators.

Fig. 4 shows the structure of the proposed lumped element resonator, while Fig. 5 illustrates how the resonator and coupling section are assembled. The 800MHz filter can be assembled the same way that traditional waveguide filters are assembled. Fig. 6 illustrates the structure of the three-pole filter. The measured frequency response of the filter (un-plated) is shown in Fig. 7, while Fig. 8 shows the measured spurious performance of the filter, which indicates a spurious free window of 4GHz.

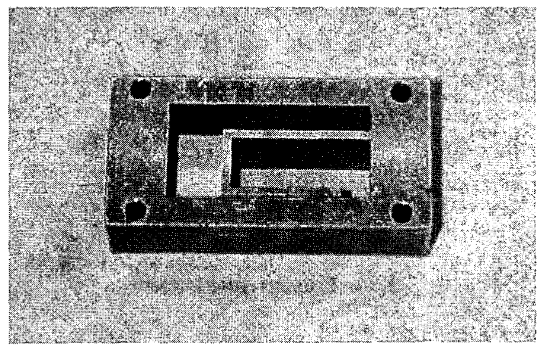
Fig. 4. The proposed lumped element resonator

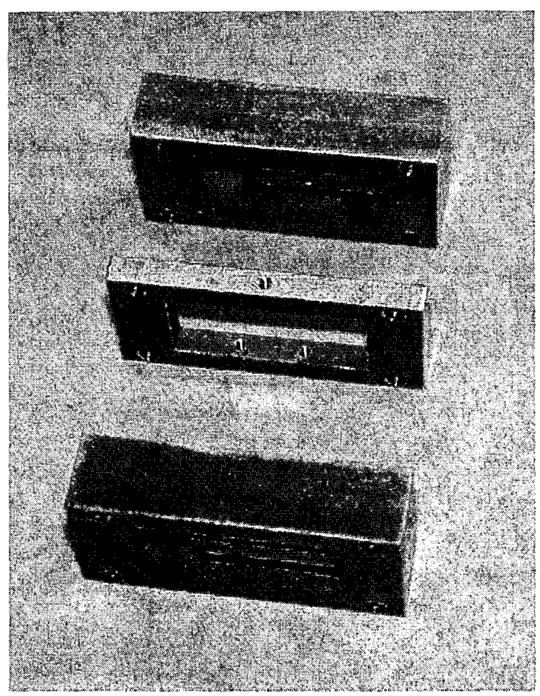
Fig. 5. A three-pole filter employing the proposed lumped-element resonator.

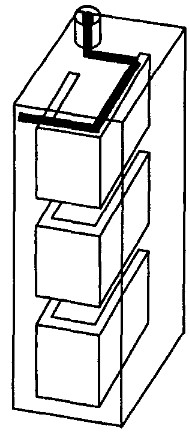

Fig. 6. The schematic of a three-pole filter using the proposed lumped-element resonator

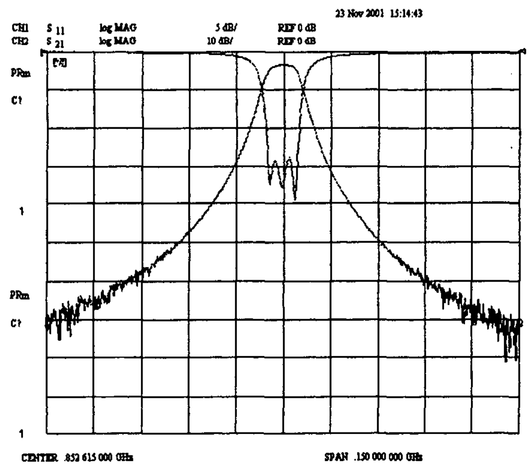

Fig. 8. The measured frequency response of the 3-pole modified lumped element conductor loaded cavity resonator filter shown in Fig. 6.

IV. CONCLUSION

The paper has presented a novel configuration for conductor-loaded cavity resonators. To our knowledge, this is the smallest metallic cavity resonator that has been built at 800MHz. The filter has a spurious free window of 4 GHz. Using this resonator, a three-pole filter has been designed, fabricated and tested. The measured data verify the validity of the proposed concept.

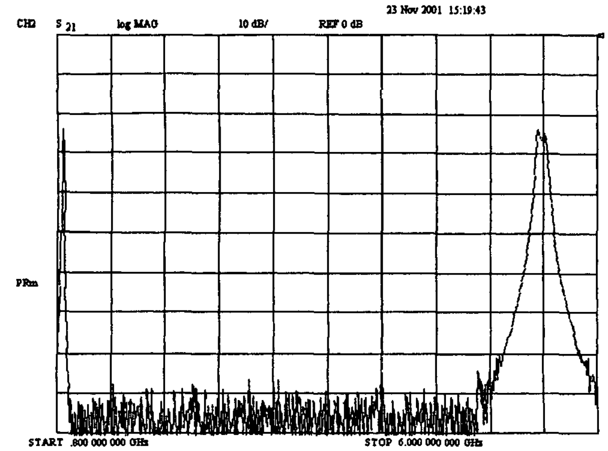

Fig. 8. The measured spurious performance of the three-pole filter

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