HIGH Q TE01 MODE DR CAVITY FILTERS FOR WIRELESS BASE STATIONS

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ABSTRACT

This paper summarizes the state-of-the-art of high Q TE01 mode DR cavity filters for PCS wireless base station applications. The mode chart and cavity Q are computed for typical commercial available DR materials. New approach to suppress the spurious response of the DR cavity filter is proposed and the advantage is analyzed. Experimental 8-pole and 6-pole quasi-elliptic function filters show the typical performances. Special techniques on cross-coupling techniques are used to realize a three-pole elliptic function and a 5-pole canonical asymmetric filter. The 5-pole pole canonical asymmetric filter, we believe, is never been realized before.

I. INTRODUCTION

Dielectric resonator (DR) cavity filters have been used for satellite communications since the early 1980s due to their high Q (>10,000) and compact size. The temperature stability [1], [2], [3] and the employment of dual-mode HE11 are regarded as major breakthroughs for DR cavity filters [4], [5]. The single TE01 mode cavities didn't attract much attention for satellite applications, due to the fact that it provided no significant advantage over an air-filled cylindrical dual-mode cavity [6] if transmission zeros could not be implemented in the stop band.

However, the TE01 mode filter with planar layout, as in Fig. 1, offers many advantages over an in-line configuration. The cost of each individual filter and the issue of mass production are much more crucial than volume and weight in wireless base station applications. In the authors' opinion, the electrical performance of the state-of-the-art TE01 mode DR filter almost can match the performance of the HE11 dual-mode DR filter because the cross-coupling techniques have been developed to implement quasi-elliptic function filters. Also, asymmetric filter response with multiple transmission zeros in stop band have been successfully implemented. TE01 single mode filters offer the advantages of design simplicity, flexibility in layout options and low-cost manufacturing over HE11 dual-mode filters; the corresponding drawbacks are greater size and weight.

The interest of this paper is to present the foundations of TE01 mode DR cavity filter and technology innovations for PCS wireless base station applications. In II, the aspects of the cavity design are presented, including mode chart, dielectric Q and compromises in cavity design. The coupling iris design is described in III. A direct cascading of a wide-band combline filter is suggested to provide spurious suppression and the advantage is analyzed in IV. Several design examples are shown in V. VI is the conclusions.

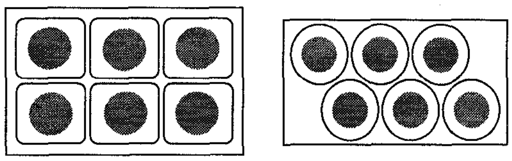


Fig. 1 Planar filter layouts for high Q TE01 mode cavity filter.

II. CAVITY PERFORMANCE AND DESIGN

Size/Volume and Materials

For high Q microwave filters, the cavity electrical performances, size and weight should be assessed simultaneously. This is due to the fact that the high Q microwave filters always occupy a significant amount of space in a transceiver subsystem, especially in L-band.

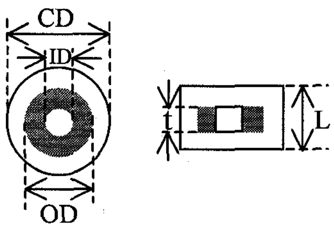


Fig. 2 Configuration of TE01 mode DR cavity

The configuration of a TE01 mode DR cavity is shown in Fig. 2. The conductive enclosure can be circular or rectangular cavity. In order to reduce the conductor loss, the DR puck should not be too close to the enclosure. The cavity diameter (CD) usually is greater than 1.5 times the

DR diameter (OD) and the height of the cavity (L) is about 3 times that of DR thickness (t). The cavity volume and unloaded Q, Q_u (theoretical or measured) for several typical designs of cavity resonators at PCS frequencies are summarized in Table 1. For a DR cavity, the TE01 mode is the fundamental mode and has the smallest size. The HE11 mode can be the first high order mode but one physical HE11 mode cavity can be used twice electrically and thus result in a smaller filter size.

Cavity Type	Volume (in^3)	Cavity Qu
Cylindrical TE11 dual-mode cavity	87.2/2	29,500[1]
Rectangular TE01 mode cavity	43.3	19,200[1]
Coaxial cavity	1.4	3,000[2]
Combline /Evanescent mode cavity	3.8	6,000[2]
DR TE01 mode cavity # 1 (ε_r = 44.0)	5.2	18,500[3]
DR TE01 mode cavity # 2 (ε_r = 29.5)	7.9	30,700[3]
DR HE11mode cavity # 1 (ε_r = 44.0)	6.1/2	20,000[3]
DR HE11mode cavity # 2 (ε_r = 29.5)	9.8/2	29,500[3]

1: theory; 2: estimated; 3: measured (with puck supported by low density form support)

Table 1 Volume and cavity unloaded Q for some high Q cavities at PCS frequencies

Table 2 summarizes the measured resonator dielectric Q (i.e. 1/loss tangent), Q_d, for some commercially available materials. Table 2 is obtained by subtracting the enclosed conductor loss from measured TE01 DR cavity Q. The DR puck is supported by low density form to obtain the measured cavity Q to retrieve Q_d in Table 2, while the enclosure Q is computed by rigorous mode-matching technique. The materials A and D in Table 2 are used for the computations of DR cavity size and Q_u (theory) in Table 1.

	ε_r	Qd (measured)	Measured fo (MHz)	Measured Qf
A	44.0	22,000	1800	39.6K
B	36.3	16,800	1943	32,6 K
C	34.0	23,800	1900	45.2 K
D	29.5	47,600	1778	84.6 K
E	21.0	52,000	1944	102.2 K

*: f in GHz

Table 2 Measured dielectric Q of some commercial materials

Cavity Design

The design of a TE01 mode DR cavity should include cavity Q_u, size and spurious responses. In this paper, they are computed by a rigorous radial mode-matching technique [7], [8]. The cavity Q_u, size and spurious responses are dictated by the DR aspect ratio, which is defined as the ratio of DR diameter (OD) to DR thickness (t), as shown in Fig. 2. The aspect ratio of the DR cavity should be properly chosen, otherwise the high order modes may be too close to the working mode [9], [10]. Mode charts [7], [8] have been proposed to design DR cavities. It is also well known that to open a hole in the center of TE01 mode DR [7], [8], [11] can increase the spurious free region of the cavity. The mode charts of a solid and ring DR with dielectric constant of 44 are shown in Fig. 3 and 4. The results suggest that the aspect ratio of the TE01 mode DR (ε_r = 44.0) cavity can be chosen around 2.5 to optimize the spurious and cavity Q. The diameter of the center hole can be opened up to 35% of the DR diameter to improve the spurious free region up to 1.45 f_0. Too small an enclosure will degrade the cavity Q_u significantly and too big the enclosure will move the TM01 mode closer to fundamental one.

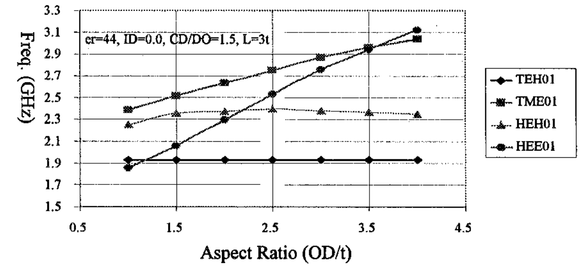


Fig.3 Mode chart the TE01 mode solid DR (ε_r=44.0) cavity

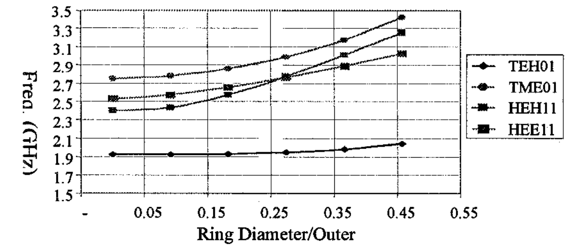


Fig.4 Mode chart the TE01 mode ring DR (ε_r=44.0) cavity

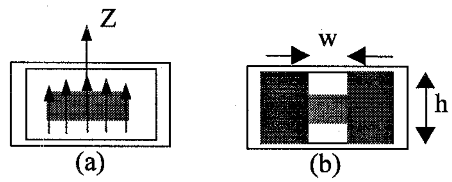


Fig. 5(a) Magnetic field on the side wall
(b) Suggested coupling iris structure

III. COUPLING IRIS DESIGN

The iris structure design for coupled cavities should consider the electromagnetic field alignment. The iris should be open at the location of maximum magnetic field and also parallel to its direction [12]. For planar structure of TE01 mode cavity filters, as shown in Fig. 1, the iris is opened along the z-direction, as shown in Fig. 5 (a). The suggested coupling structure is depicted in Fig. 5 (b). It is found that the iris width ***w*** should not be too wide in order to keep the frequency of the coupled TM01 mode away from that of the TE01 mode. The TM01 mode has much stronger coupling than the TE01 mode and the width of the iris is the direction that the magnetic fields align. Rigorous mode-matching technique [13] or an empirical approach can obtain the dimensions of the iris.

IV. SPURIOUS SUPPRESSION DEVICES

As the results show in II, the spurious free region of the TE01 mode DR cavity can be about 1.4 times the operating frequency. A spurious-free region up to the second or third harmonics is usually required for communication systems, i.e. about 6 GHz for PCS frequencies. A low pass filter can be used to suppress the spurious response. Alternately, mixing metallic resonators with DR resonators [14], [15] can improve the spurious performance significantly with the cost of degradation of overall filter Q. Here, we propose to cascade a 4-pole wide-band (140 to 180 MHz) combline filter with the DR filter to eliminate the spurious response. The advantage of the 1st approach is that no additional volume/space is required. The effective filter Q and insertion loss of at the center frequency of these two approaches are calculated and shown in Fig. 7. Assume that the resonator unloaded Q is 12,000 for the DR cavity and 3,000 for the metallic cavity. The results in Fig. 7 show that the degradation of the filter Q at filter center frequency by approach I could be from 25 to 50% for typical applications, while the approach II is 5 to 25%. The approach I can reduce filter size significantly with slight increase in insertion loss for a low order filter. For high order filters, the cavity Q is much more important, and thus approach II is a much better choice. According to our experiences, a 4-pole combline filter with cross section of 1.0"x1.0" can limit the spurious of the filter to below -80dB up to 6.0 GHz with extra loss less than 0.15 dB. This loss can match that of a low pass filter, while the simple integration makes it very cost effective.

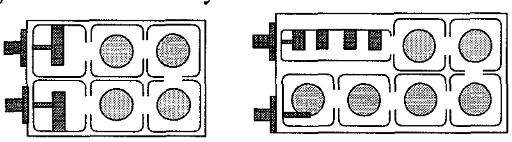


Fig. 6 (a) Approach I and (b) Approach II to Improve DR cavity spurious performance

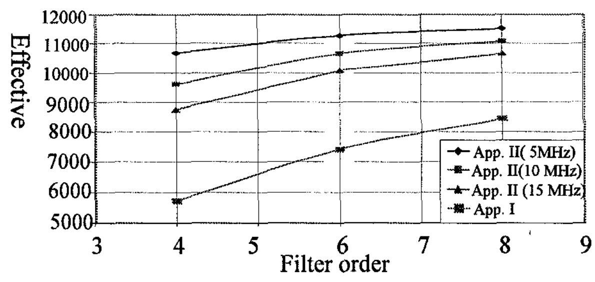


Fig. 7 Effective cavity for approach I and II for Tchebyscheff filters at PCS.

V. Design Examples

Example I & II 6-pole and 8-pole quasi-elliptic function filters

The results of a 6-pole with 5 MHz bandwidth and 8-pole 15 MHz bandwidth quasi-elliptic function filters at PCS frequencies are shown in Fig. 8 and 9. A metallic rod realizes the negative cross coupling. The 6-pole filter is realized by high Q DR puck and the effective unloaded Q is 24,500. A 4-pole 160 MHz combline filter is directly coupled to the 15 MHz DR filter to suppress the spurious of the DR cavity.

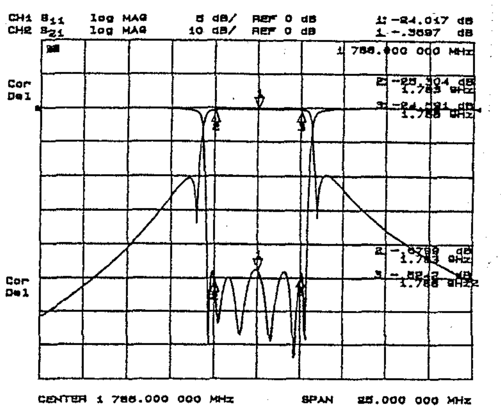


Fig. 8 Measured frequency response of a 6-pole quasi-elliptic function filter

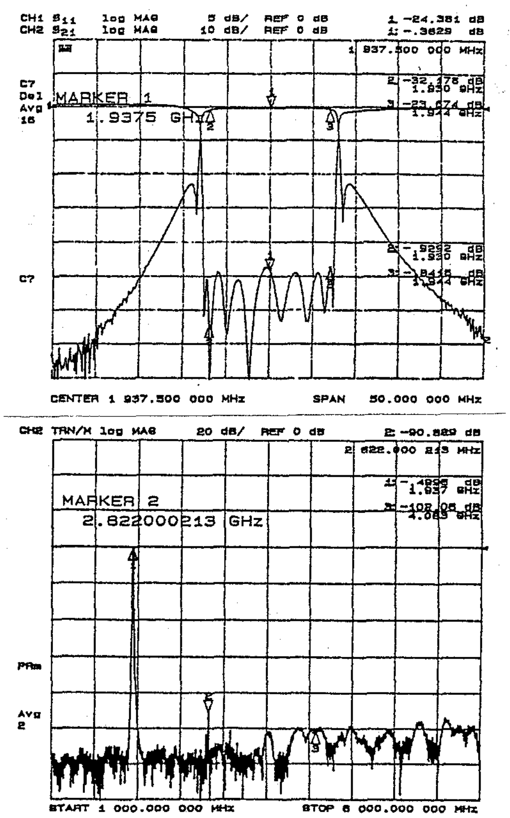


Fig. 9 Measured response of an 8-pole quasi-elliptic function filter.

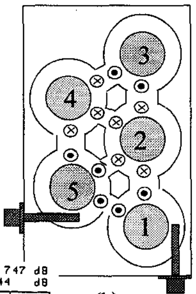
Example III. 5-pole canonical asymmetric filter with asymmetric response

The synthesis of the canonical asymmetric filter with asymmetric response has been demonstrated in [16], [17]. But the realized filter in the public domain is limited to the case of one transmission zero, to the authors' knowledge. The coupling matrix and practical filter layout of a 5-pole canonical asymmetric filter are shown in Fig. 10(a), (b). The direction of the magnetic field of the cavity sidewall is also shown in Fig. 10 (b) to justify that M_{24}, M_{25} and M_{15} are all implemented by coupling irises. The measured results are shown in Fig. 10(c).

$$R_A = R_B = 1.3000$$

$$\begin{bmatrix} -0.011 & 1.012 & 0 & 0 & -0.109 \\ 1.012 & -0.011 & 0.333 & -0.493 & 0.461 \\ 0 & 0.333 & -0.536 & 0.204 & 0 \\ 0 & -0.493 & 0.204 & -0.264 & 0.901 \\ -0.109 & 0.461 & 0 & 0.901 & -0.014 \end{bmatrix}$$

(a)



(b)

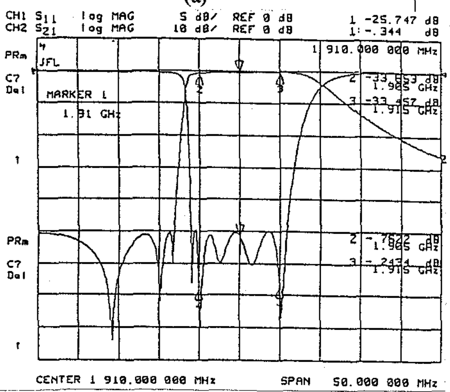


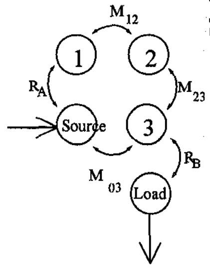
Fig. 10 (a) Coupling matrix of the 5-pole filter (b) Physical layout of the filter (c) Measured response.

Example IV. 3-pole elliptic function filter

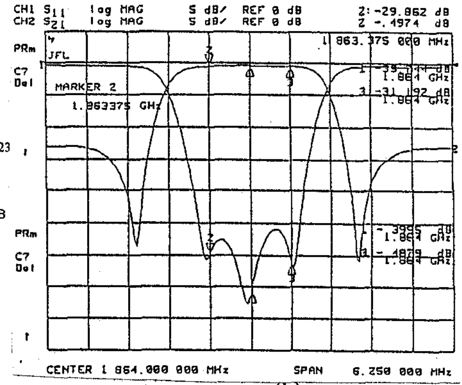
A true odd order elliptic function filter requires non-adjacent coupling between the source or load to an internal resonator. This type of filter has not been realized in DR filter yet. The schematic of a 3-pole elliptic function filter shown in Fig. 11(a), while the measured response is shown in Fig. 11(b).

VI. CONCLUSIONS

This paper presents the performance of high Q TE01 mode cavity filters for PCS applications. DR material, DR cavity and coupling design are described. A direct cascading of a 4-pole wide band combline filter to the DR filter is suggested for spurious suppression and its advantage is analyzed. Design examples with excellent measured performance are presented. The 6 and 8-pole quasi-elliptic function filters show typical performances, while a 5-pole canonical asymmetric filter with asymmetric response is believed to be new design for DR cavity filter technology.



(a)



(b)

Fig. 11 (a) A 3-pole elliptic function filter (b) Measured response.

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