Design of Triple Mode $TE_{01\delta}$ Resonator Transmission Filters

Vanessa Walker, *Member, IEEE,* and Ian C. Hunter, *Senior Member, IEEE*

***Abstract*—The use of triple mode $TE_{01\delta}$ cubic resonators for the design of transmission mode filters is presented. Frequency tuning and coupling between modes are studied experimentally. The tunability of all inter-cavity couplings, necessary for the realization of a wide range of transfer functions, is demonstrated with a 6th degree, 5 MHz wide filter at 2 GHz. With an insertion loss of 0.7 dB in a volume of 260 cm^3, the filter presents a 2 : 1 volume reduction over conventional $TE_{01\delta}$ filters.**

***Index Terms*—Dielectric resonator filters, triple mode.**

I. INTRODUCTION

OVER the last two decades, the use of high permittivity materials has been extensively studied to develop lower loss and smaller resonator structures. Narrow band filter applications demanding very high unloaded Q factors (Qu) [1] now widely use the $TE_{01\delta}$ mode resonator. In 1982, Fiedziuszko introduced the dual mode $HE_{11\delta}$ dielectric resonator filter [2], which offers further volume reduction. The same mode can be used to form a triple mode resonator by making the $HE_{11\delta}$ and $TM_{01\delta}$ modes degenerate [3]. However, these resonators do not normally operate with their fundamental resonance and do not offer the volume reduction obtainable from a triply degenerate $TE_{01\delta}$ mode resonator.

A triple mode $TE_{01\delta}$ resonator consisting of three intersecting discs was presented in [4]. It was shown in [5] that a dielectric cube also supports a triply degenerate $TE_{01\delta}$ mode (or $TE_{11\delta}$ in rectangular coordinates). This simpler shape was used to realize a hybrid reflection mode filter. However, this type of filter only allows the realization of symmetrical transfer functions.

The aim of this letter is to study the use of the dielectric cube resonator for conventional transmission mode bandpass filters. The coupling of modes between cavities is considered whereas previous publications have only dealt with single cavities. Optimal ways of realizing frequency tuning and intra-cavity couplings are presented.

II. FREQUENCY TUNING

The resonator consisted of a cube of ceramic material of relative permittivity 44 located at the center of a cubic aluminum enclosure by means of an alumina support as shown in Fig. 1. A test cavity exhibited a triple mode resonance at 2.006 GHz with a Qu of 18 800.

Manuscript received April 11, 2001; revised March 21, 2002. The review of this letter was arranged by Associate Editor Dr. Ruediger Vahldieck.

The authors are with Filtronic Plc, Saltaire, West Yorkshire, U.K., and also with the Electronic and Electrical Engineering Department, University of Leeds, Leeds, West Yorkshire, U.K. (e-mail: vanessaw@filct.com; eenich@elec-eng.leeds.ac.uk).

Publisher Item Identifier S 1531-1309(02)05766-5.

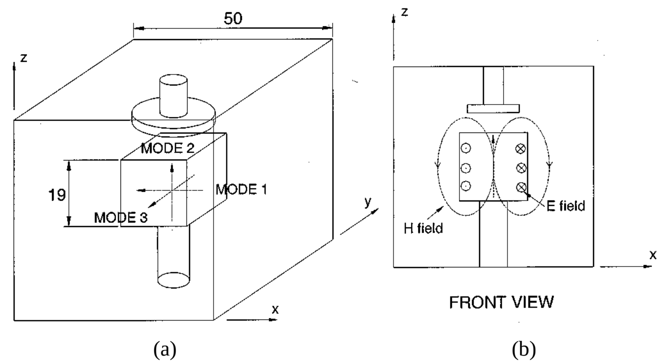

Fig. 1. (a) Frequency tuning and (b) field representation of mode 2. Modes are represented by an arrow along their symmetry axis.

The frequency tuning mechanisms must provide independent tuning of each of the modes. However their secondary effect is to create some unwanted coupling between modes within the same cavity by breaking the triple degeneracy of the resonator. For practical tuning of the filter, these spurious couplings must be minimized.

A dielectric tuning disc positioned as in Fig. 1 decreased the frequency of mode 2 as for a single mode $TE_{01\delta}$ resonator. However, it also tuned modes 1 and 3 by the same amount unless the disc diameter was significantly larger than the dielectric cube width. Only then, with the disc overlapping the regions of maximum electric fields as indicated in Fig. 1, could some differential tuning (up to 12 MHz) be achieved. Unfortunately, tuning discs this large also generated up to 1 MHz of spurious couplings.

Metal tuning discs were found to be the only alternative. They were mounted on an insulating screw so as not to perturb the $TM_{01\delta}$ mode. 10 MHz of independent tuning was achieved without creating any significant coupling but was accompanied by a decrease of the Qu of the tuned mode by 8.6%. Fig. 2 summarizes the variation of the resonant frequencies of the three modes with the different types of tuning discs.

III. INTRA-CAVITY COUPLINGS

In [5], the intra-cavity couplings were realized by conducting loops located opposite the frequency tuning discs. This is not possible in the case of multi-cavity filters, where at least two walls of each cavity are required for external couplings. No other location is adequate for a metal or dielectric insert to create the values of coupling necessary for a 5 MHz wide filter. As a result, most of the coupling needed to be created by discontinuities on the dielectric cube itself, such as chamfers as shown in Fig. 3 [6]. The sign of the coupling depended on the position of the

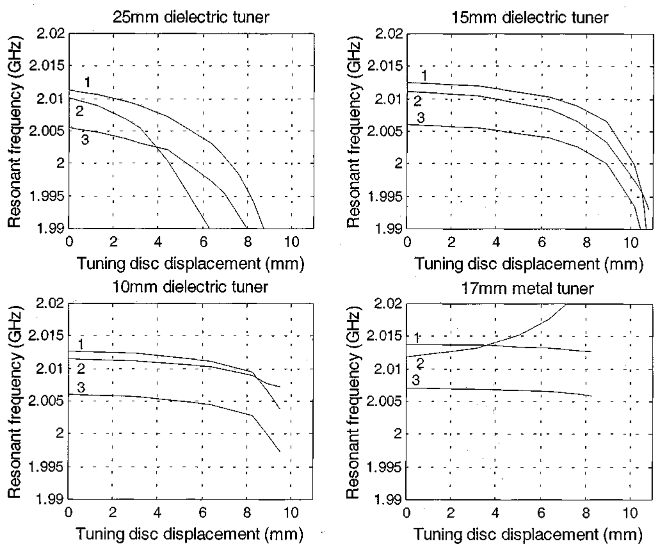

Fig. 2. Variation of modes resonant frequencies with displacement of tuning disc from cavity wall. Modes numbered as in Fig. 1. Dielectric cube: ε_r 44, length 19 mm. Cavity: length 50 mm.

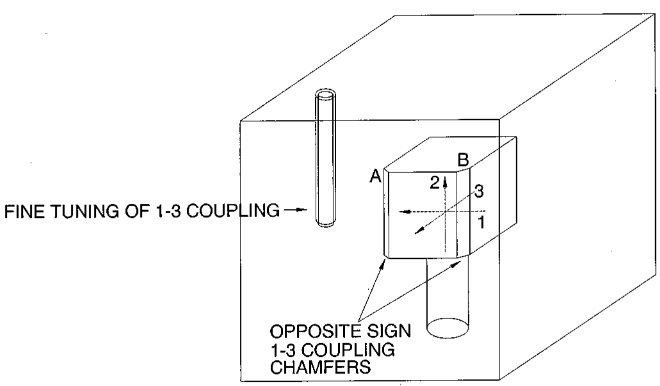

Fig. 3. Intra-cavity coupling mechanism.

chamfer. Additional fine tuning up to 1 MHz was achieved by inserting metal screws parallel to the chamfer. The screw in Fig. 3 decreased the coupling created by chamfer A and increased that of chamfer B. Tuning screws in these positions can also cancel any spurious couplings which could exist between modes.

IV. Inter-Cavity Couplings

Within each cavity, a cross-coupling of any sign between modes 1 and 3 is readily realizable by machining chamfers along all three axis of a cube, allowing the realization of asymmetrical filter responses. Further cross-couplings are realizable through inter-cavity couplings. Independent couplings through the same wall were realized by creating apertures which predominantly couple only one set of modes [1], [2].

A 5 MHz bandwidth sixth degree generalized Chebyshev bandpass filter with 30 dB rejection 1 MHz from either side of the passband was constructed. The prototype used a 2–5 cross-coupling [7]. The filter configuration is described in Fig. 4. TEM transformers resonating above the passband coupled into mode 1 and out of mode 6. As the sign of the coupling through the irises cannot be chosen, the chamfers were positioned so that the cross-coupling created a pair of

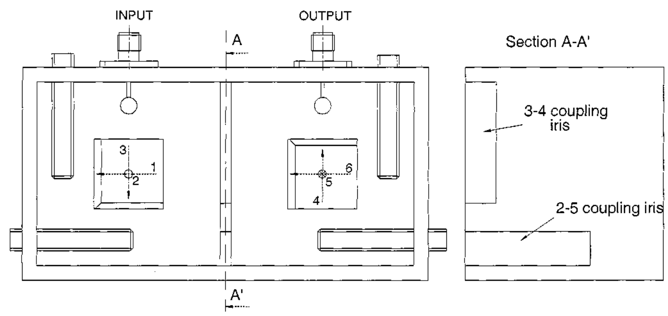

Fig. 4. The 2–5 cross-coupled filter layout.

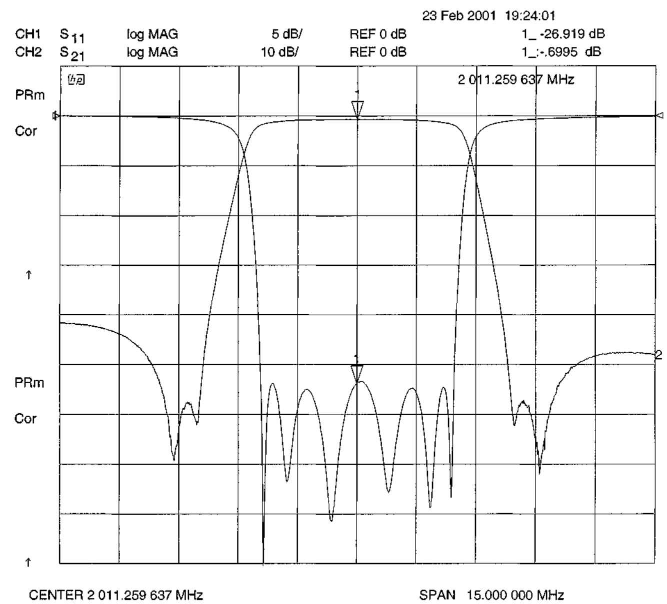

Fig. 5. Response of 2–5 cross-coupled filter.

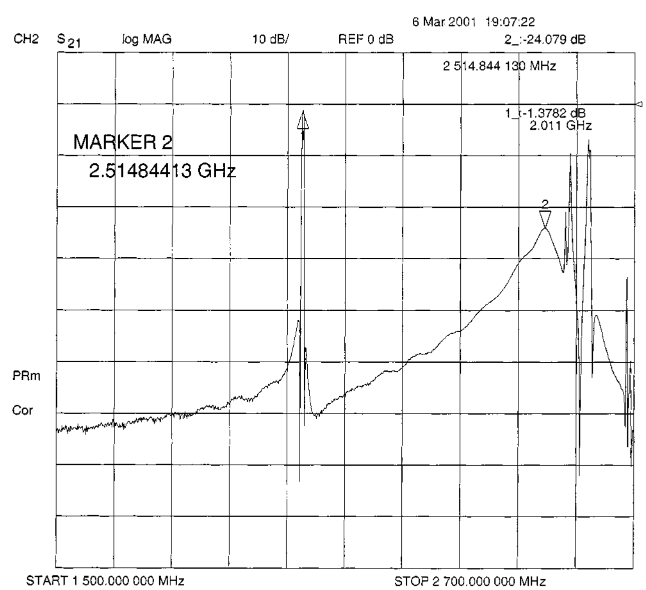

Fig. 6. Wide-band response of 2–5 cross-coupled filter.

finite real frequency transmission zeros. The filter response is shown in Fig. 5. A Q reduction of 15% relative to the initial Qu of the resonator was observed. Fig. 6 shows the wide-band

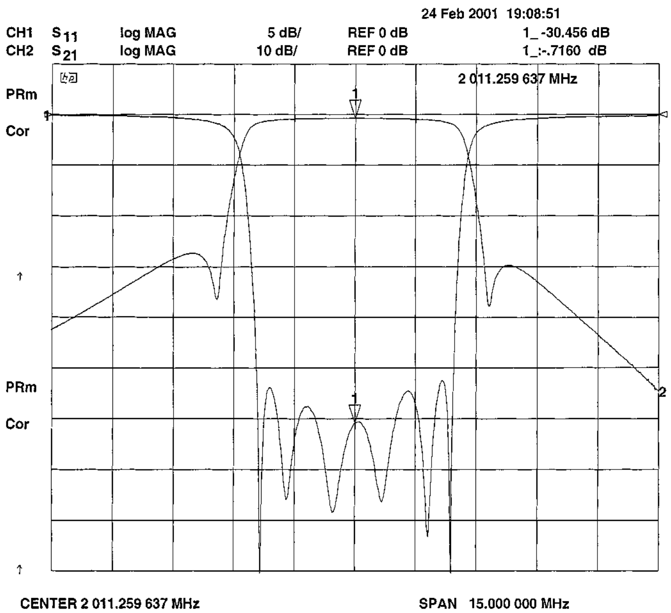

Fig. 7. Response of the 2–5 cross-coupled filter with 1–6 coupling canceled.

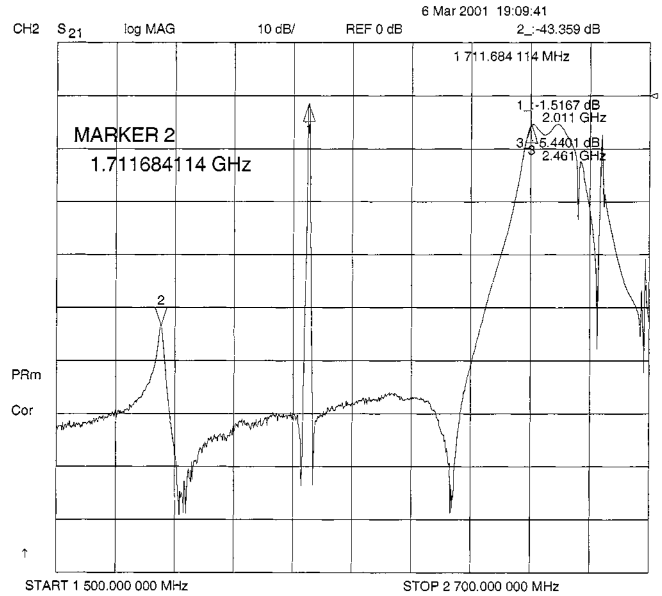

Fig. 8. Wide-band response of the 2–5 cross-coupled filter with 1–6 coupling canceled.

response of the filter, with the first spurious mode resonating at 2.51 GHz.

Two extra transmission zeros exist which are the result of some spurious 1–6 coupling occurring through both irises. Proper control of this coupling is necessary in order to realize most transfer functions. However, it cannot be tuned through the two existing irises directly, because of the difference in strength between main and spurious couplings in an iris (about 50 to 1 MHz). Instead, a second coupling path consisting of a capacitively coupled transmission line was created. The capacitive coupling was realized with probes. As an example, the 1–6 spurious coupling of the previous filter was canceled. Its measured frequency response is shown in Fig. 7. The resonance below the passband in Fig. 8 is due to the 1–6 cross-coupling transmission line resonating.

V. Conclusion

The design of cross-coupled triple mode $TE_{01\delta}$ filters using cubic resonators has been presented. Metal discs and chamfers were used to provide independent frequency and intra-cavity coupling tuning. A method for tuning all three inter-cavity couplings was investigated. This work demonstrates that filter responses with high rejection levels can be realized in a structure that presents a 2 : 1 volume reduction over conventional $TE_{01\delta}$ filters.

References

[1] J.-F. Liang and W. D. Blair, "High Q $TE_{01\delta}$ mode DR filters for PCS wireless base stations," *IEEE Trans. Microwave Theory Tech.*, vol. 46, pp. 2493–2500, Dec. 1998.
[2] S. J. Fiedziuszko, "Dual-mode dielectric resonator loaded cavity filters," *IEEE Trans. Microwave Theory Tech.*, vol. 30, pp. 1311–1316, Sept. 1982.
[3] W. C. Tang, J. Sferrazza, B. Beggs, and D. Siu, "Dielectric resonator output multiplexer for C-band satellite applications," in *IEEE MTT-S Dig.*, June 1985, pp. 343–345.
[4] K. Wakino, T. Nishikawa, and Y. Ishikawa, "Miniaturization technologies of dielectric resonator filters for mobile communications," *IEEE Trans. Microwave Theory Tech.*, vol. 42, pp. 1295–1300, July 1994.
[5] I. C. Hunter, J. D. Rhodes, and V. Dassonville, "Triple mode dielectric resonator hybrid reflection filters," *IEE Proc.-Microw. Antennas Propagat.*, vol. 145, pp. 337–343, Aug. 1998.
[6] J.-F. Liang, K. A. Zaki, and R. Levy, "Dual-mode dielectric-loaded resonators with cross-coupling flats," in *IEEE MTT-S Dig.*, May 1995, pp. 509–512.
[7] R. J. Cameron, "General prototype network synthesis methods for microwave filters," *ESA J.*, vol. 6, pp. 193–206, 1982.