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Miniaturized Triple-Mode Bandpass Filter using Dielectric Resonators

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***Abstract*— This paper presents a compact triple-mode dielectric resonator bandpass filter based on a single waveguide cavity. Two barium titanate pucks are used in the design, placed in the middle of the metallic cavity to reduce the size of the filter. A third-order simplified Chebyshev bandpass filter is selected to verify the technique and simulated using HFSS software. The input and output coaxial probes are used to excite the degenerate EH_{11} modes, while the TM_{01} mode is excited using a vertical hole etched in the top of the barium titanate pucks. The resonator offers a size reduction ratio of about 15.6% compared with equivalent air-filled coaxial filters. The filter has finite transmission zeros on the high or low side of the passband.**

Keywords—triple-mode dielectric resonator, bandpass filter, transmission zeros

I. Introduction

Dielectric resonator filters provide a reduction in size when compared with conventional metal resonators. The high relative permittivity helps to reduce the guided wavelength when compared with a hollow cavity. Additionally, further size reduction can be achieved by using multiple degenerate modes: this increases the efficiency of volume per resonance for a given Q-factor. An advantage of multiple mode resonators is the ability to realize real-frequency transmission zeros in in-line or cascaded configuration without the need to introduce physical cross-coupling structures [1]–[4]. However, to generate transmission zeros in the dielectric resonator filter technique, the design is complex and challenging.

To generate the triply-degenerate resonances (the triple-mode case), the structures have to be developed from shapes with symmetry in three dimensions, such as cubical and spherical structures [5]–[8]. However, there are many cases in which the triple-mode filter is based on an asymmetrical structure [9]– [11], where higher-order modes were utilized to obtain triply degenerate resonances in waveguide filters, yielding significant size reduction. The cavity structure in [3] was investigated and optimized to design triple-mode filters in dielectric-loaded cavities using the single TM_{01} mode and the degenerate pair of the TE_{11} mode. Conventionally, perturbation techniques are useful to provide good coupling between the degenerate modes. To create the desired filter response, the tuning screws or coupling elements are inserted into the cavity. Due to the lack of independent control of each resonant frequency and the spurious couplings between the multi-modes, it can degrade the resonator Q-factor and increase the design complexity. A parallel-coupled resonator approach [12] was chosen to design triple-mode dielectric resonator filters without inter-resonator couplings, resulting in simplifying the filter design complexity.

Multimode resonators offer the potential to produce an elliptic filter response with a minimum number of resonators [13]. Finite transmission zeros are generally generated by creating multiple paths in the structure, e.g., couplings between nonadjacent resonators. The limitations of this technique are the complexity, sensitivity, and poor temperature stability of the designs. For example, when finite transmission zeros are designed to perform close to the passband edge, the direct-coupling and cross-coupling values can be equivalent, which might not be realizable in practice. Another case is when the cross-coupling has a bit values compared to the direct couplings. This can take the lead to very sensitive and complicated designs. Otherwise, in [14], non-resonating nodes can be applied to perform finite transmission zeros in dual-mode and triple-mode cavities. Frequency tuning mechanisms with unbiased control of each resonance and all couplings are typically required in filter design. Owing to the appearance of some spurious couplings between resonances, the frequency tuning mechanisms can be a challenging task in multimode filters, thus increasing the design complexity and cost.

II. Triple-mode Dielectric Resonator Filter Design

Figure 1 shows the structure configuration of the triple-mode dielectric resonator. The proposed design consists of two dielectric pucks that are placed in the middle of a cylindrical cavity. The dielectric pucks are made of barium titanate with a relative permittivity of 43 and loss tangent of 4×10^{-5}. The metallic cylindrical cavity is formed of copper. A finite-element method em solver (HFSS) were used to calculate the resonant frequency and unloaded Q-factors (Q_u). The triple-mode operation was achieved by intersecting the resonant frequencies of the TE_{01} mode with the degenerate EH_{11} mode at a resonant frequency of 1.96 GHz. The diameter of cavity, D_{cavity}, is 36 mm. The length of the cavity, L_{cavity}, is 25 mm. The diameter of resonator, D_{puck}, and the length of resonator, L_{puck}, are 32 mm and 10 mm, respectively. The gap between the dielectric pucks and the metallic cavity side walls, g_{SW}, is set to 2 mm. The gap between top and the bottom surfaces of the dielectric pucks and the cavity walls, g_{TB}, is

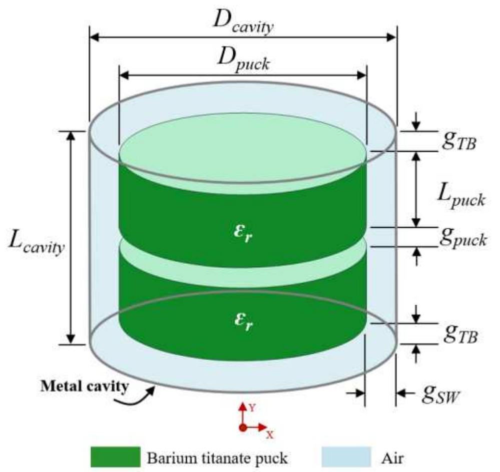

Figure 1. The geometry of triple-mode dielectric resonator without excitation port. The two barium titanate pucks are placed in the middle of the cylindrical metallic cavity.

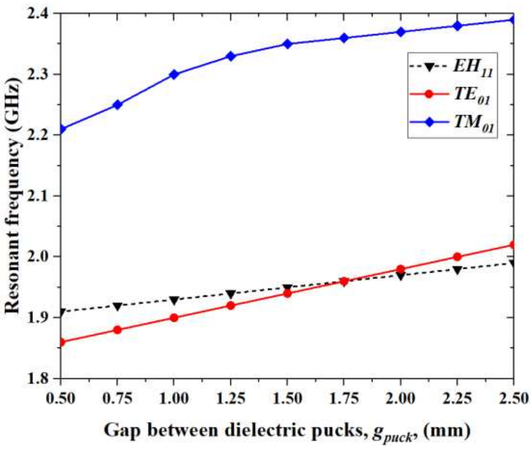

Figure 2. The resonant frequencies as a function of the gap between dielectric pucks, g_{puck}.

Table 1. The optimized parameters for exciting and coupling ports.

Parameter	Description	Length
D_{feed}	Diameter of the probe feed	2.0 mm
L_{feed}	Length of the probe feed	18 mm
W_{groove}	Width of the rectangular grooves	3.0 mm
L_{groove}	Length of the rectangular grooves	3.0 mm
D_{ver}	Diameter of the vertical screw	4.0 mm
D_{hor}	Diameter of the horizontal screws	1.5 mm
D_{hole}	Diameter of through hole	5.0 mm
L_{hor}	Length of the horizontal screws	4.0 mm
L_{offset}	Offset of hole	5.0 mm

1.5 mm. To investigate the effect of the gap between the pucks, g_{puck}, on the resonance, figure 2 shows the resonant frequencies as a function of g_{puck}. The intersection frequency between the dominant TE_{01} mode and the degenerate EH_{11} mode occurs at g_{puck} = 1.75 mm, which the triple-mode operation was achieved when the g_{puck} of 1.75 mm. Moreover, at g_{puck} = 1.75 mm, the spurious-free window is ~400 MHz, which provides good suppression in multi-mode dielectric filters.

Due to the small gap between the dielectric pucks and the cavity wall, it is difficult to excite the proposed resonator from the side wall. The best way to couple the triple-mode dielectric resonator is by inserting the excitation probe from the top of the cavity. Figure 3 shows the feeding configuration of the third-order triple-mode dielectric bandpass filter. Table 1 shows the optimized key parameters that affect the coupling section. The effects of the length of the input/output coupling probes, L_{feed}, were investigated and the results are shown in figure 4 and figure 5. Figure 4 shows the external Q-factor, Q_e, as a function of the length of the probe feed, L_{feed}, where the diameter of the copper probe, D_{feed}, is equal to 2 mm. The graph shows that the Q_e is dramatically decreased when L_{feed} increases varying between 5 mm and 15 mm. However, the Q_e steadily decreased for L_{feed} more than 15 mm. Figure 5 shows the resonant frequency as a function of L_{feed}. When the L_{feed} increasing, the frequency of the EH_{11} dual-mode, e.g., EH^{-}_{11} and EH^{+}_{11}, decreases while the TE_{01} frequency remains constant. From 8 mm onwards, the EH_{11} dual-mode starts to split into EH^{-}_{11} and EH^{+}_{11}, with coupling between them.

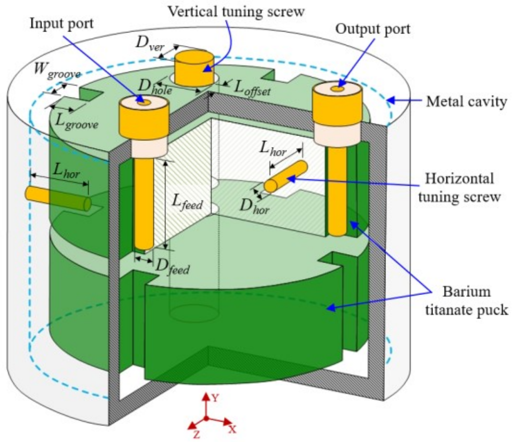

Figure 3. The 3D geometry of triple-mode third-order filter.

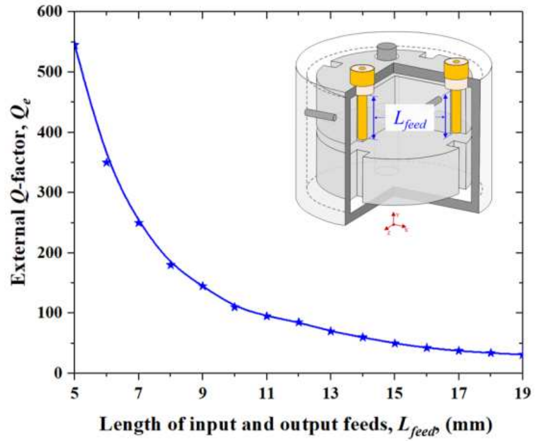

Figure 4. External Q-factor as a function of the length of input and output coupling probes.

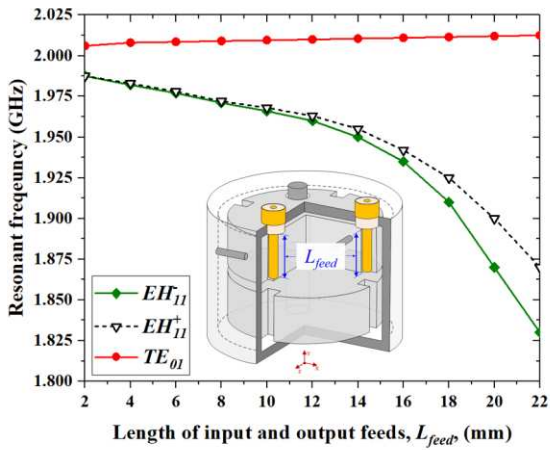

Figure 5. Resonant frequencies as a function of the length of input and output coupling probes.

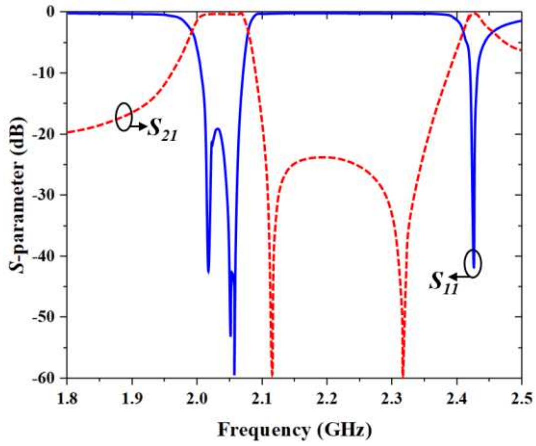

Figure 6. Frequency response of triple-mode filter without tuning screws.

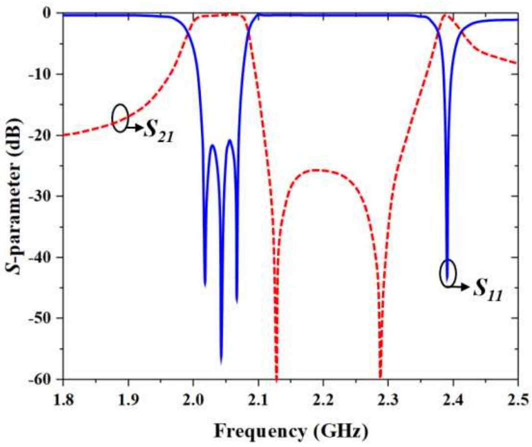

Figure 7. Frequency response of triple-mode filter with tuning screws.

III. Simulation Results

Figure 6 and figure 7 show the simulated *S*-parameter response for a third-order triple-mode dielectric resonator filter without and with any tuning screws, respectively. In the figure 6, the reflection coefficients in-band region are less than 19 dB. The resonant frequency is 2.04 GHz with the fractional bandwidth of 56 MHz. The maximum insertion loss is ~0.1 dB. The overall suppression window is 386 MHz, which is calculated from the different frequency between the first spurious freque ncy and the resonant frequency. The pair of finite transmission zeroes is performed by the topology of the triple-mode filter at the resonance frequency, while the final one comes from the spurious band coupling topology. Three finite transmission zeroes can be found in the response as follow: a pair of finite transmission zeroes occurred at 2.12 GHz and the other is located at 2.31 GHz. Figure 7 shows the simulated *S*-parameters response of the third-order filter triple-mode dielectric resonator with three tuning screws, e.g., one tunning screw at the top of the cavity and two tuning screws at side wall cavity. The reflection coefficients are less than 22 dB. The first spurious-free frequency and the second finite transmission zero were shifted backward by about 28 MHz and 36 MHz, respectively. When calculating the insertion loss and group delay, the extracted *Q*-factor is approximately 8500.

IV. Conclusion

A triple-mode dielectric resonator filter has been simulated and reported with finite transmission zeroes on the high or low sides. The extracted *Q*-factor from the insertion loss and group delay was approximately 8500. The dielectric resonator filter is achieved thevolume reduction ratio of ~15.6% when compared with a conventional air-coaxial filter. The gap between the barium titanate ceramic pucks is investigated. The results show that the gap has a significant effect on the resonant frequency. The proposed filter was designed and potentially applied for a typical cellar base station specification.

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References

[1] D. R. Hendry and A. M. Abbosh, "Analysis of Compact Triple-Mode Ceramic Cavity Filters Using Parallel-Coupled Resonators Approach," in *IEEE Transactions on Microwave Theory and Techniques*, vol. 64, no. 8, pp. 2529-2537, Aug. 2016, doi: 10.1109/TMTT.2016.2577579.

[2] S. Amari and U. Rosenberg, "A Circular Triple-Mode Cavity Filter With Two Independently Controlled Transmission Zeros," *2006 European Microwave Conference*, 2006, pp. 1091-1094, doi: 10.1109/EUMC.2006.281124.

[3] M. S. Bakr, F. Gentili and W. Bosch, "Triple mode dielectric-loaded cavity band pass filter," *2016 16th Mediterranean Microwave Symposium (MMS)*, 2016, pp. 1-3, doi: 10.1109/MMS.2016.7803797.

[4] S. Amari and U. Rosenberg, "New in-line dual- and triple-mode cavity filters with nonresonating nodes," in *IEEE Transactions on Microwave Theory and Techniques*, vol. 53, no. 4, pp. 1272-1279, April 2005, doi: 10.1109/TMTT.2005.845777.

[5] V. Walker and I. C. Hunter, "Design of triple mode TE01spl delta// resonator transmission filters," in *IEEE Microwave and Wireless Components Letters*, vol. 12, no. 6, pp. 215-217, June 2002, doi: 10.1109/LMWC.2002.1009999.

[6] I. C. Hunter, J. D. Rhodes and V. Dassonville, "Triple mode dielectric resonator hybrid reflection filters", *I EE Proceedings-Microwaves, Antennas and Propagation*, vol. 145, no. 4, pp. 337-343, Aug. 1998.

[7] L. H. Chua and D. Mirshekar-Syahkal, "Analysis of dielectric loaded cubical cavity for triple-mode filter design", *IEE Proceedings-Microwaves, Antennas and Propagation*, vol. 151, no. 1, pp. 61-66, Feb. 2004.

[8] N.-S. Park et al., "Compact triple-mode bandpass filter using spherical dielectric resonator", Proc. Eur. Microw. Conf., pp. 810-813, Oct. 2013.

[9] U. Rosenberg and D. Wolk, "Filter design usin g in-line triple-mode cavities and novel iris couplings," in *IEEE Transactions on Microwave Theory and Techniques*, vol. 37, no. 12, pp. 2011-2019, Dec. 1989, doi: 10.1109/22.44115.

[10] M. Mohammad-Taheri, D. Mirshekar-Syahkal and S. Safavi-Naeini, "Sixth-order elliptic function filter using triple-mode dielectric-loaded cylindrical cavities", in *IEE Proceedings-Microwaves, Antennas and Propagation*, vol. 149, no. 56, pp. 237-242, Oct. 2002.

[11] S. Wong, Z. Zhang, S. Feng, F. Chen, L. Zhu and Q. Chu, "Triple-Mode Dielectric Resonator Diplexer for Base-Station Applications," *in IEEE Transactions on Microwave Theory and Techniques*, vol. 63, no. 12, pp. 3947-3953, Dec. 2015, doi: 10.1109/TMTT.2015.2488658.

[12] D. R. Hendry and A. M. Abbosh, "Analysis of Compact Triple-Mode Ceramic Cavity Filters Using Parallel-Coupled Resonators Approach," in *IEEE Transactions on Microwave Theory and Techniques*, vol. 64, no. 8, pp. 2529-2537, Aug. 2016, doi: 10.1109/TMTT.2016.2577579.

[13] Wai-Cheung Tang and S. K. Chaudhuri, "A True Elliptic-Function Filter Using Triple-Mode Degenerate Cavities," in *IEEE Transactions on Microwave Theory and Techniques*, vol. 32, no. 11, pp. 1449-1454, Nov. 1984, doi: 10.1109/TMTT.1984.1132870.

[14] S. Amari and U. Rosenberg, "New in-line dual- and triple-mode cavity filters with nonresonating nodes," in *IEEE Transactions on Microwave Theory and Techniques*, vol. 53, no. 4, pp. 1272-1279, April 2005, doi: 10.1109/TMTT.2005.845777.