A Compact Quasi-Elliptic Dual-Mode Cavity Filter Using LTCC Technology for V-band WLAN Gigabit Wireless Systems

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Abstract — **In this paper, the development of highly integrated dual-mode filter solutions is presented for V-band compact, low-cost wireless front-end modules utilizing multilayer low temperature cofired ceramic (LTCC) technologies. A dual-mode cavity filter experimentally demonstrates a quasi-elliptic response and excellent performance in terms of low insertion loss (<2.76 dB) and high rejection. The rectangular shaped cavity resonator is first designed to generate two resonant modes (TE_{102} and TE_{201}) that are orthogonal each other. Then, the location of the feeding structures and the size of the external slots are optimized to generate the quasi-elliptic dual-mode response. The filter has been implemented by employing rows of vias as sidewalls represent a new class of devices that enable the three dimensional (3D) integration for V-band WLAN gigabit wireless systems.**

Index Terms — **dual-mode filter, V-band, gigabit wireless systems, cavity filter, LTCC.**

I. INTRODUCTION

The rapid expansion of wireless communications and personal communication networks has led to tremendous demands of miniaturization, portability, low-manufacturing cost and high performance in RF and millimeter-wave (mmW) wireless systems [1]. Especially, the appeal for transmitting multimedia information using high-speed digital data and wide-band image signals has motivated the development of 60 GHz wireless communication systems because of their high potential for actualizing compactness and wide bandwidth [2]. The 60 GHz front-end module is the foundation of these systems and requires the high performance filters that can be easily integrated into the modules.

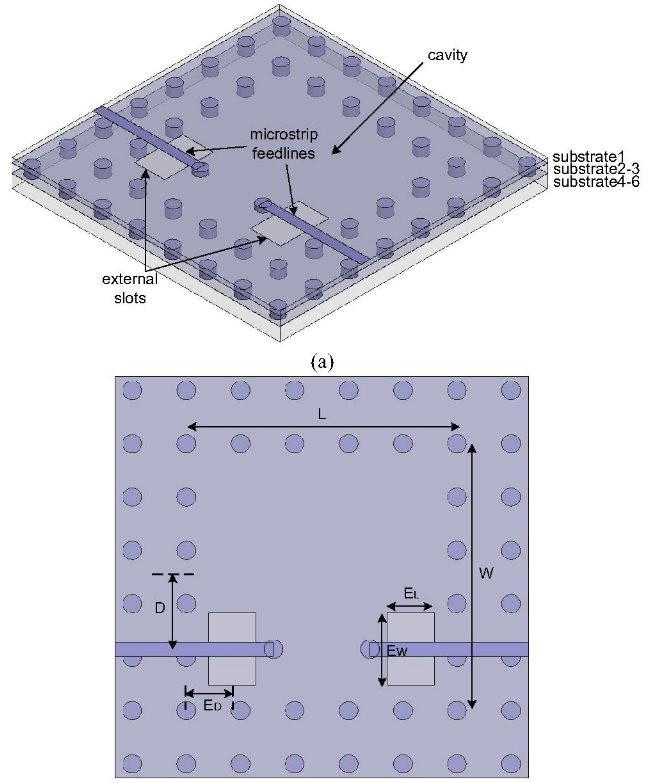
This paper focuses on the development of 61.6 GHz quasi-elliptic dual-mode cavity filters enabling low loss filter solution for RF Front-end module of V-band WLAN gigabit wireless systems. The rectangular shaped cavity resonator is first designed to generate two resonant modes (TE_{102} and TE_{201}) that are orthogonal each other. Then, the external coupling to resonant modes is employed to provide transmissions zeros that achieves the high selectivity. The multilayer LTCC process is utilized for the fabrication because of its mature packaging capability of integrating embedded functions. The performance of the proposed structure is experimentally validated for the first time at these high frequency ranges.

II. SINGLE DUAL-MODE CAVITY BAND PASS FILTER (BPF)

As the demand for compact and low loss band pass filters increases in V-band multi-gigabit-per-second wireless communication systems, integrating on-package cavity filters in LTCC multilayer technology are a very attractive option due to their relatively high Q and power handling capability compared to planar filter structures and less interference from other circuits utilized in packaging [3]. A conventional circular or rectangular waveguide dual-mode filter makes use of the coupling of two orthogonal modes generated from tuning screws [4] or rectangular ridges [5]. However, these techniques not only impose the heavy numerical burden for the modal characterization of waveguides because of a large number of evanescent modes but also are not applicable to LTCC multilayer process. A microstrip-fed dual-mode filter based on the substrate integrated waveguide (SIW) technique [6] also has been proposed to be one of possible passive solutions for L-band millimeter-wave systems, developed with a relative thick substrate and a low dielectric constant compared to LTCC tape.

In this paper, we propose a 61.6 GHz (V-band) quasi-elliptic dual-mode filter utilizing two arrays of via fences as sidewalls that can be easily integrated into a wireless RF front-end module in LTCC. The very mature multilayer capability of LTCC (ε_r=7.1, tanδ=0.0019) has been used to fabricate the proposed structure. The cavity filter is embedded into the first three substrate layers (four metal layers) of the LTCC substrate and consists of one cavity resonator, two microstrip lines for input/output (I/O) feeding structures and two external coupling slots etched on the top ground planes of the cavity.

Figure 1 shows (a) the overview and (b) the top view of the proposed structure. The rectangular shaped cavity resonator is first designed to generate two resonant modes (TE_{102} and TE_{201}) that are orthogonal each other, realizing dual-mode operation. The effective length, width (L, W in Fig. 1 (b), respectively) of the cavity resonator based on TE_{102} and TE_{201} modes can be determined by constraining both modes to resonate at the same frequency in the resonant frequency equation of the rectangular waveguide cavity [7]. The height of the cavity is determined to be 0.106 mm to satisfy the



(a)

(b)

Figure 1. (a) The overview (b) The top view of the quasi-elliptic dual-mode cavity filter.

compactness requirement. However, the height can be adjusted to obtain the desired quality factor (Q). The dual-mode cavity resonator is built using conducting planes as horizontal walls and via fences as vertical walls [3] based on the dimensions calculated, and the final dimensions are optimized with the aid of the full-wave simulator HFSS. Two external slots (Fig. 1 (a)) on the top ground plane of the cavity are dedicated to magnetically couple the energy from the I/O microstrip lines into the cavity resonators. The microstrip lines are terminated with shorting vias to avoid the interference coupling between the feeding structures [8]. The offset distance (D in Fig. 1 (b)) of the feeding structures is the critical design parameter to excite two resonant modes (TE_{102} and TE_{201}) and to generate the transmission zeros for the high selectivity. The transmission zeros that realize the quasi-elliptic response are provided by two factors: 1) the external coupling to two resonant modes that have the same amplitude but anti-phase at the I/O apertures 2) the parasitic coupling from the external coupling slots. Also, the position of feeding structures affects the coupling level to the modes, thus influencing the bandwidth. The size of the external coupling slots ($E_L \times E_W$ in Fig. 1 (b)) is another important design parameter to control the coupling between the feeding network and the cavity and the positions of the transmission zeros that determine the rejection level. All the layout dimensions are optimized in the HFSS full-wave simulator and summarized in Table I.

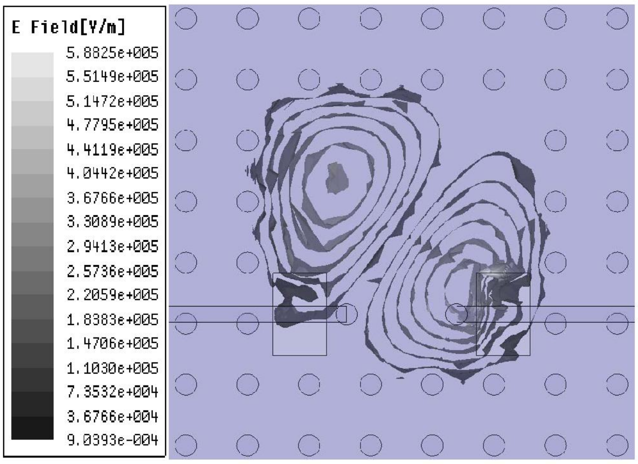


Figure 2. Magnitude of electric field distribution (TE_{102}) on horizontal plane inside the dual-mode cavity at the resonant frequency (=61.6 GHz).

TABLE I

3-POLE CAVITY BPF DIMENSIONS

Design Parameters	**Dimensions (mm)**
cavity length (L)	2.075
cavity width (W)	2.105
cavity height (H)	0.106
external slot length (EL)	0.360
external slot width (EW)	0.572
external slot position(ED)	0.352
Offset distance of the feedlines (D)	0.568

Figure 2 shows the electric field distribution of TE_{102} mode at 6.16 GHz that is bisected along the diagonal line. The electric fields in two sections represent the same magnitude but with 180° phase differences. Figure 3 shows the comparison between the simulated and the measured S-parameters of the dual-mode cavity filter. All fabricated resonators were measured using the Agilent 8510C Network Analyzer and Cascade Microtech probe station with 250 μm pitch air coplanar probes. A TRL method was employed for calibration. The filter exhibits an insertion loss <2.76 dB, which is slightly higher than the simulated (2.22 dB). The main source of this discrepancy might be caused by skin and edge effect of metal traces since the simulations assume a perfect definition of metal strips. The center frequency is measured to be 61.6 GHz that exactly matches the simulated result. The transmission zero is observed within < 3.5 GHz away from the center frequency at the right-hand side of the passband and < 6.75 GHz at the left-hand side. The discrepancy of the zero positions between the measurement and the simulation can be attributed to the fabrication tolerance. The tolerance of XY shrinkage of the LTCC process is expected to be - 3 % and that of metal dimensional accuracy ±0.1%. The fabrication tolerance also results in the

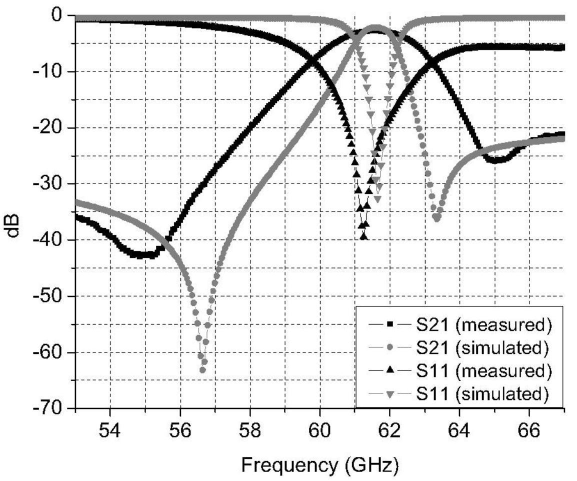


Figure. 3. Measured and simulated S-parameters of the dual-mode cavity BPF.

bandwidth differences that the filter exhibits a 3 dB bandwidth about 4.13 % (• 2.5 GHz) comparable to the simulated 2 % (• 1.25 GHz).

III. CONCLUSION

We have presented the development of compact quasi-elliptic dual-mode cavity filters that can be highly integrated into LTCC RF front-end modules for V-band WLAN gigabit wireless systems. For the first time at these high frequency ranges, this type of filters has experimentally demonstrated an excellent performance in terms of low insertion loss and high rejection. The quasi-elliptic dual-mode response of the cavity filter has been realized by adjusting the cavity dimensions and slots positions and can be improved by cascading or stacking the dual-mode cavities with inter-coupling structures.

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REFERENCES

[1] H.H.Meinel, “Commercial Applications of Millimeterwaves History, Present Status, and Future Trends,” *IEEE Trans. on Microwave Theory and Tech.*, Vol. 43, NO. 7, pp. 1639-1653, July 1995.

[2] K.Ohata et al., “Sixty-GHz-Band Ultra-Miniature Monolithic T/R Modules for Multimedia Wireless Communication Systems,” *IEEE Trans. on Microwave Theory and Tech.*, vol.44, no. 12, pp. 2354-2360, Dec. 1996.

[3] J.-H.Lee et al., “Low Loss LTCC Cavity Filters Using System-on-Package Technology at 60 GHz,” *IEEE Trans. on Microwave Theory and Tech.*, vol. 53, no. 12, pp. 231-244, Dec. 2005.

[4] A.E.Atia and A.E.Williams, “Narrow-Bandpass Waveguide Filters,” *IEEE Trans. Microwave Theory and Tech.*, vol. MTT-20, pp. 258-265, Apr. 1972.

[5] X.Liang, K.A.Zaki, and A.I.Atia, “Dual-Mode Coupling by Square Corner Cut in Resonators and Filters,” *IEEE Microwave Guided Lett.*, vol. 40, pp. 2294-2302, Dec. 1992.

[6] D.Deslandes and K.Wu, “Substrate Integrated Waveguide Dual-Mode Filters for Broadband Wireless Systems,” in *2003 Radio and Wireless Conf.*, Boston, MA, Aug. 2003, pp. 385-388.

[7] D.M.Pozar, Microwave Engineering, 2nd ed. New York:Wiley, 1998.

[8] J.-H.Lee et al., “Comparative Study of Feeding Techniques for 3D Cavity Resonators,” accepted for publication at the *IEEE Trans. on Advanced Packaging.*