A Ka-Band Narrow Bandpass Filter Using LTCC Technology

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***Abstract*—A Ka-band low-temperature co-fired ceramic (LTCC) narrow bandpass filter (BPF) is presented first. This BPF shows very narrow 3 dB fractional bandwidth of 4.5% centered at 28.7 GHz. The advantages of multilayered LTCC technology such as high integration and vertical stacking capabilities were employed to design three-dimensional interdigital end-coupled embedded microstrip narrow BPF. The difficulties in controlling the precise distance between two adjacent resonators in LTCC end-coupled BPF were overcome by locating the resonators on different layers. The measured insertion loss is 3 dB at 28.7 GHz**

***Index Terms*—End-coupled BPF, Ka-band, low-temperature co-fired ceramic (LTCC), narrow bandpass filter.**

I. Introduction

In recent years, low-temperature co-fired ceramic (LTCC) technologies are widely attracting microwave and millimeter-wave engineers' attentions for their superior advantages over other substrate technologies. Three-dimensional (3-D) integration capabilities can make size-reduction and low-cost design, and at the same time the small value of dielectric loss tangent reveals its excellent high frequency characteristics [1]. Microwave BPFs have been realized by employing the advantages of the LTCC technologies under 10 GHz [2], [3].

In this paper, we firstly present an end-coupled Ka-band pass filter by using 3-D multilayered LTCC technology. Although the end-coupled BPF has a narrow bandwidth characteristic compared to other filter structures, the shrinkage after co-firing and restricted resolution of the LTCC process make it difficult to control the precise distance between two adjacent resonators close enough for coupling on the same planar substrate. The minimum spacing between adjacent conductors is generally 150 μm with screen-printing LTCC process, which is too large to make the wanted series capacitive coupling between adjacent resonators. Locating microstrip resonators on different layers in the multilayered structure can clear those process limitations by vertically separating the adjacent resonators with an intermediate LTCC tape. Further more, by overlapping two adjacent ends of resonators we can control the filter characteristics such as bandwidth, sharpness, and minimum insertion loss in pass band [4].

II. Filter Design

This paper presents an embedded interdigital end-gap coupled BPF using multilayered LTCC technology for Ka-band application. The third-order gap-coupled BPF was designed according to Matthaei, Young, and Jones' synthesis method [5].

A prototype low-pass filter was designed and mapped to the corresponding BPF. Fig. 1 shows the gap-coupled BPF and its ideal electrical model. Three resonators were used to guarantee sufficient out-of-band rejection. The calculated capacitance between transmission lines and resonators (C_{01} and C_{34}) is 12.6 fF, and the capacitance between adjacent two resonators (C_{12} and C_{23}) is 2 fF. In this ideal planar gap-coupled BPF, resonators should be much closer than the limit of LTCC process design rule. In order to make the relatively high values of the capacitance, the first and the third resonator were placed one layer beneath the transmission lines and the second resonator, and the ends of the adjacent resonators were overlapped to fit the calculated capacitance values. The exact structure of the filter has been designed using a method of moment simulation, and the layout of embedded microstrip gap-coupled BPF and its side view are shown in Fig. 2.

The first and the third resonators on the second layer are not straightly arrayed with the other resonator and transmission lines on the third layer in order to optimize the capacitance values for a trade-off between an insertion/return loss and narrow bandwidth characteristic. A four-layer LTCC substrate was built on bottom ground plane. The measured dielectric constant of the LTCC tape is 7.4, and the thickness of each layer is about 106 μm after co-firing. Silver was used for both strip conductor and via conductor. Resonators were located two layers or three layers above the ground plane. Each length of the resonators was designed to be a half of the wavelength at 29.5 GHz.

III. Results of the Filter

Fig. 3 shows the fabricated LTCC Ka-band BPF of which size is $9.7 \times 2.2 \times 0.42$ mm^3. Openings were made to probe the CPW pads on the third layer for direct measurement without any additional vertically connected vias. Because the LTCC sheet shrinks about 10% in X/Y-direction after co-firing process, all conductors including transmission lines and resonators were designed considering the shrinkage.

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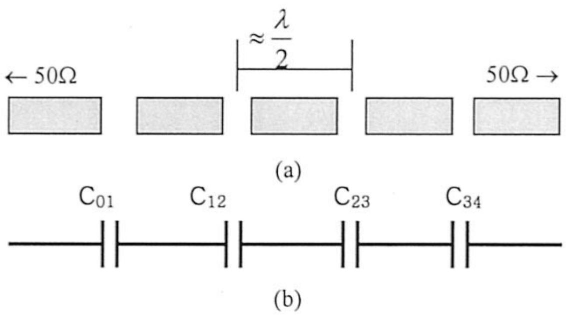

Fig. 1. (a) Gap-coupled BPF and (b) its ideal electrical model.

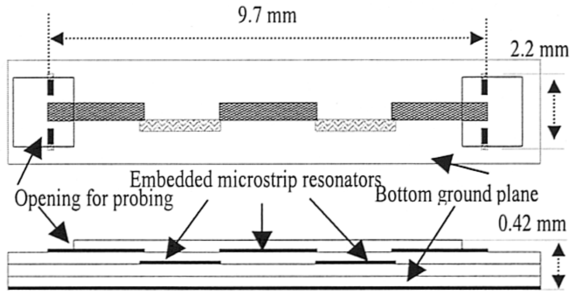

Fig. 2. Layout of embedded microstrip bandpass filter and its side view.

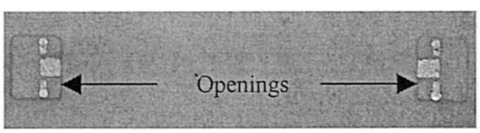

Fig. 3. Top view of the fabricated BPF.

The s-parameters of the BPF are measured and the insertion loss and the return loss are plotted in Fig. 4 with the EM simulation results. The measured data include the effect of microstrip feedthroughs. The minimum insertion loss of the BPF is 3 dB at 28.7 GHz, and the fractional bandwidth is 4.5%. The measured insertion loss is about 1.8 dB higher than that of simulated value, and the center frequency is also shifted from 29.2 GHz to 28.7 GHz. We suppose that the shift of the center frequency is mainly due to the shrink and the variation of dielectric constant after co-firing. The measured return loss is also negatively shifted about 0.7 GHz. There is an unwanted peak at 25 GHz in the EM simulation and at 24 GHz in the measurement which was not expected in the first trial ideal series capacitor model. The first trial circuit was optimized in the final layout to an electromagnetic structure of which coupling capacitances between the resonators are equivalent to 63 fF for C_{01} and C_{34}, and 10 fF for C_{12} and C_{23} in the circuit model, and which accounts the peaking in both EM simulation and measurement.

The summary of the end-gap coupled multilayered LTCC BPF characteristics is listed in Table I.

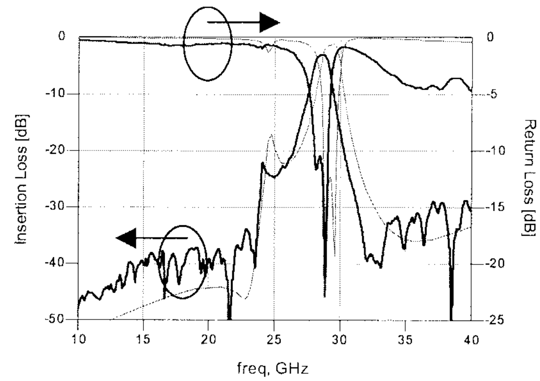

Fig. 4. Insertion and return losses from measurement (▬), and those from EM simulation (—).

TABLE I
SUMMARY OF BPF

Parameters	Measured	Simulated
Center frequency (f_0)	28.7 GHz	29.2 GHz
Lower band edge (f_L)	27.9 GHz	28.6 GHz
Upper band edge (f_H)	29.2 GHz	29.9 GHz
Fractional bandwidth (w)	4.5 %	4.5 %
Minimum insertion loss	3 dB	1.2 dB

IV. CONCLUSION

This paper presents a very narrow band LTCC BPF of which fractional bandwidth is 4.5% at the center frequency of 28.7 GHz. The BPF with 3-D end-coupled microstrip resonators has been implemented with a multilayered LTCC technology in order to achieve such a narrow bandwidth characteristic. The interdigital arrangement of the resonators in the filter was possible due to the advantages of multilayered LTCC technology. This narrow BPF can be used for a high selective or image rejection Ka-band BPF.

REFERENCES

[1] C. Q. Scrantom, “Where we are and where we’re going-II,” in *IEEE MTT-S IMS Dig.*, 1999, pp. 193–200.
[2] S. Pinel, S. Shakraborty, M. Roellig, R. Kunze, S. Mandal, H. Liang, C-H. Lee, R. Li, K. Lim, G. White, M. Tentzeris, and J. Laskar, “3D integrated LTCC module using μ BGA technology for compact C-band RF front-end module,” in *IEEE MTT-S IMS Dig.*, 2002, pp. 1553–1556.
[3] C.-H. Lee, S. Chakraborty, S. Yoo, D. Heo, and L. Laskar, “Broadband highly integrated LTCC front-end module for IEEE 802.11a WLAN applications,” in *IEEE MTT-S IMS Dig.*, 2002, pp. 1045–1048.
[4] C.-K. C. Tzuang, Y.-C. Chiang, and S. Su, “Design of a quasiplanar broadside end-coupled bandpass filter,” in *IEEE MTT-S IMS Dig.*, 1990, pp. 407–410.
[5] G. L. Matthaei, L. Young, and E. M. T. Jones, *Microwave Filters, Impedance-Matching Networks, and Coupling Structures*. New York: McGraw-Hill, 1964.