A Low-Loss Patch LTCC 60 GHz BPF Using Double Patch Resonators

Young Chul Lee
Mokpo National Maritime University (MMU)
E-mail : leeyc@mmu.ac.kr

ABSTRACT

In this paper, a three-dimensional (3-D) low-loss and wide-band BPF based on low-temperature co-fired ceramic (LTCC) has been presented for mm-wave wireless communication applications. The proposed BPF is designed in a 6-layer LTCC substrate. The double patch resonators are fully integrated into the LTCC dielectrics and vertical via and planar CPW transitions are designed for interconnection between embedded resonators and in/output ports and MMICs, respectively. The designed BPF was fabricated in a 6-layer LTCC dielectric. The fabricated BPF shows a centre frequency (fc) of 53.23 GHz and a 3dB bandwidth of 14.01 % from 49.5 to 56.9 GHz (7.46 GHz). An insertion loss of -1.56 dB at fc and return losses below -10 dB are achieved. Its whole size is 4.7 x 1.7 x 0.684 mm^3.

Keyword
LTCC, BPF, Patch resonator, mm-wave

Ⅰ. Introduction

Because of their unlicensed wide bands, frequency re-use, low interference, and implementation of small-sized devices [1-4], various high-data-rate 60 GHz wireless communications systems have been developed. These mm-wave systems require more than ever small-size and low-cost manufacturing technology and high-electric performance in mm-wave frequencies. A system-on-package (SoP) technology [1-4] based on low temperature co-fired ceramic (LTCC) is one of the good solutions because of its low loss, integration capability, and cost effectiveness. 3-D LTCC BPFs are very useful to integrate in radio SoP modules considering their size, integration capability, and performance.

Several structures of BPFs [5-10] have been investigated for low-loss and 3-D integration in RF SoP modules. Particularly, a dual-mode stripline BPF [5] using the novel vertical via transition [11] was integrated into the 60 GHz transmitter LTCC SoP module [2]. LTCC dual-mode cavity and vertically stacked multi-pole filters have been demonstrated at 60 GHz [6]. Also, LTCC BPFs [7, 8] using dielectric waveguide structures have been presented. In ref. [7], for the side wall ground (GND) of the waveguide two series zigzagged via fences were utilized. And also, for size reduction a vertically stacked waveguide was proposed [8]. In recent, using liquid-crystal polymer (LCP) for RF SoP, filters have been developed [9]. However, due to lower dielectric constant (εr=2.9~3.0) of the LCP materials LCP-based passive devices will be more bulky than LTCC-based devices. In addition, it's more lossy, while a little, than LTCC materials in mm-wave band.

In this paper, a low-loss and wide-band LTCC BPF has been presented for mm-wave wireless radio applications. For a low-loss and wide-band a double-patches resonator is designed. This filter is fully embedded in six LTCC dielectric layers.

II. Design and Fabrication of the LTCC BPF

Fig. 1 shows structures of a proposed compact and wideband LTCC BPF integrated fully into LTCC dielectrics. The BPF is designed using 6-layer LTCC green-sheets with relative dielectric constant and a loss tangent of 6.6 and 0.001, respectively, at 60 GHz. The thickness between the metal layers is 114 μm. The internal and external conductor materials are Ag and Au paste, respectively.

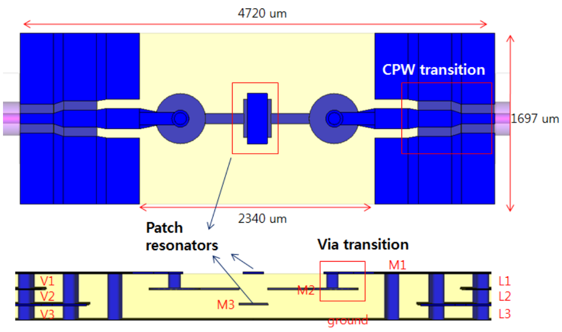

Fig. 1. Structures of a proposed LTCC BPF.

The proposed BPF consists of a double-patches resonator, feed lines, vertical via and planar CPW transitions. Fig. 1 shows the planar and vertical structure of the proposed BPF. A basic half-wavelength square patch resonator, which is commonly used for a microstrip patch antenna [14], is designed on the 1st (L1) and 3rd layer (L3). Basically, the patch resonators is in type of an embedded microstrip. The patch size can control the centre frequency and bandwidth of the filter. The size of the patch resonator on the L1 and L3 is 280 x 380 μm^2 and 200 x 500 μm^2, respectively. Because of LTCC design rule limitations about minimum spacing (~90μm) between lines, the feed lines are placed on a different layer (L2, the second layer) and its length is optimized in order to maximize the capacitive coupling strength, while minimizing the effects of the LTCC process. The width of the feed lines is 200 μm. Moreover, the minimum number of green sheets required in the LTCC design rule of the foundry company [13] is six. Therefore, the proposed BPF is designed in the six-layer LTCC substrate, while the three-LTCC layers are required as shown in Fig. 1. Additional three layers are just used as GND planes which are interconnected using GND vias and internal GND planes. For feeding of the patch resonator from an input and output port, vertical via and CPW planar transitions are required as shown in Fig. 1. This vertical via transition has lower and upper via pads. The diameter (D) of the via pad is 1.5 times larger than D of vias or D + 50 μm at the design rule. In this work, D of all upper via pads is 170 μm and lower via pads are 500 μm wide. For integrating the BPF into LTCC SoP modules, a CPW-to-CPW planar transition should be also designed for reduction of ground plane discontinuity which results from the difference in height of GND planes between the BPF and the active device mounted in the SoP cavities. The BPF using three layers has a ground height of 342 μm. In contrast, that of a RFIC mounted in a cavity is 114 μm. This steep difference of ground plane height can cause radiation problems. The transition is designed using three different CPW lines. Their gaps of 90 μm keep constant. For maintaining their characteristic impedance of 50 Ω, the line widths are designed according to its height. Each line and transition length is 330 and 100 μm, respectively. The detail design method was reported in detail [5]. The filter responses are analyzed as a function of the patch size, length of the feed lines, and diameter of the lower-via pads.

III. Fabrication and Measured Results

The designed filter was fabricated using six-LTCC dielectrics. The Ag and Au conductors were screen-printed on the unfired layers for internal and external conductors, respectively. Fig. 2 shows the fabricated BPF and its total size including whole transitions was 4.72 x 1.7 x 0.68 mm^3.

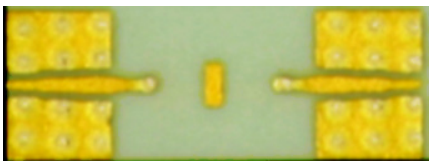

Fig. 2 The fabricated LTCC patch BPF.

The fabricated BPF was measured using probing method on the probe-station. The measured performance is shown in Fig. 3. Its centre frequency and insertion loss are 61.46 GHz and −2.88 dB, respectively. In addition, the

3-dB measured BW is 6.47 GHz (10.5 %) from 58.225 to 64.695 GHz. The downward shifting of the centre frequency and narrowing the BW, compared to the designed results, result from un-balance of coupling between feed lines and the patch due to misalignment at the lamination process of the LTCC fabrication.

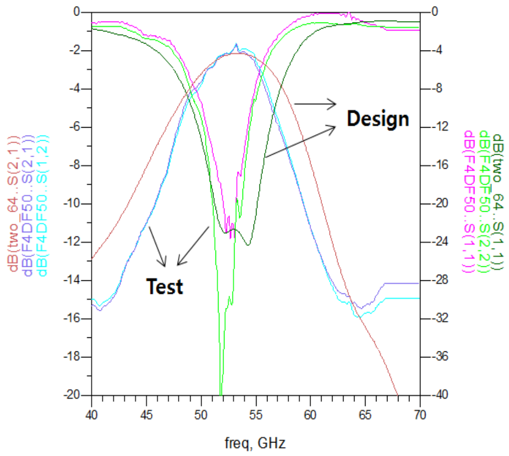

Fig. 3 Measured and simulated insertion loss (IL) and return one (RL) of the proposed LTCC BPF.

IV. Conclusion

In this paper, we present a 60 GHz low-loss and wideband LTCC patch BPF using a single-mode patch resonator for mm-wave SoP applications. The two-pole filter using the single-mode patch resonator and via pads as additional resonators is designed. The proposed BPF was fabricated in the 6-layer LTCC substrate. The overall size of the filter is 4.72 x 1.7 x 0.68 mm^3. The fabricated LTCC BPF showed a centre frequency of 61.46GHz, 3dB bandwidth of 10.5% (=6.47GHz) and insertion loss of -2.88dB at centre frequency.

References

[1] Young Chul Lee, Won-il Chang, Yun Hee Cho, and Chul Soon Park, "A Very Compact 60GHz Transmitter Integrating GaAs MMICs on LTCC Passive Circuits for Wireless Terminal Applications", *IEEE Compound Semiconductor Integrated Circuit Symposium Technical Digest*, 313-316, October 2004.

[2] Young Chul Lee, Won-il Chang, and Chul Soon Park, "Monolithic LTCC SiP Transmitter for 60 GHZ Wireless Communication Terminals", *IEEE MTT-S Int. Microwave Symposium Digest*, June 2005.

[3] Dong Yun Jung, Won-il Chang, Ki Chan Eun, Chul Soon Park, "60-GHz System-on-Package Transmitter Integrating Sub-Harmonic frequency Amplitude Shift-Keying Modulator" *IEEE Transactions on Microwave Theory and Techniques*, Vol. 55, No.8, 1,786-1,793, 2007.

[4] Tomohiro Seki, Kenjiro Nishikawa, Yasuo Suzuki, Ichihiko Toyoda, and Kouichi Tsunekawa, "60GHz Monolithic LTCC Module for wireless Communication Systems" *European Microwave Conference (EuMC)*, 1,671-1,674, 2006.

[5] Young Chul Lee and Chul Soon Park, "A Fully Embedded 60-GHz Novel BPF for LTCC System-in-Package Applications" *IEEE Transactions on Advanced Packaging*, Vol. 29, No. 4, 804-809, 2006.

[6] Jong-Hoon Lee, Pinel, S., Laskar, J., and Tentzeris, M.M., "Design and Development of Advanced Cavity-Based Dual-Mode Filters Using Low-Temperature Co-Fired Ceramic Technology for V-Band Gigabit Wireless Systems" *IEEE Transactions on Microwave Theory and Techniques*, Vol. 55, No.9, 1,869-1,879, 2007.

[7] Dong Yun Jung, Won Il Chang, Ji Hoon Kim, and Chul Soon Park, "A Low Loss Multi-Layer Dielectric Waveguide Filter for 60-GHz System-on-Package Applications" *IEICE Trans. Fundamentals*, Vol. E89-A, No.6, 1,690-1,691, 2006.

[8] Tze-Min Shen, Chi-Feng Chen, Ting-Yi Huang, and Ruey-Beei Wu, "Design of Vertically Stacked Waveguide Filters in LTCC", *IEEE Transactions on Microwave Theory and Techniques*, Vol. 55, No.8, 1,771-1,779, 2007.

[9] Ki Seok Yang, Stephane Pinel, Il Kwon Kim, Joy Laskar, "Low-Loss Integrated PassiveCircuits Using Liquid-Crystal Polymer System-on-Package (SOP) Technology for Millimeter-Wave Applications", *IEEE Transactions on Microwave Theory and Techniques*, Vol. 54, No.12, 4,572-4,579, 2006.

[10] Lung-Kai Yeh, Cheng-Ying Hsu, Chu-Yu Chen, and Huey-Ru Chuang, "A 24-/60-GHz CMOS On-Chip Dual-Band Bandpass Filter Using Trisection Dual-Behavior Resonators", *IEEE Electron Device Letters*, Vol. 29, No. 12, 1,373-1,375, 2008.

[11] Y. C. Lee, "CPW-to-Stripline Vertical Via Transitions for 60GHz LTCC SoP Applications", *Progress In Electromagnetics Research Letters*, Vol. 2, 37-44, 2008.

[12] CST MICROWAVE STUDIO, CST Inc., [Online] Available: http://www.cst.com.

[13] RN2 Technologies, [Online] Available: http://www.RN2LTCC.com.

[14] D.M. Pozar, "Microstrip antennas", *IEEE Proc.*, Vol.80, 79-91, 1992.