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A LOW-LOSS PATCH LTCC BPF FOR 60 GHz SYSTEM-ON-PACKAGE (SOP) APPLICATIONS

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Abstract—In this paper, a three-dimensional (3-D) low-loss and wideband BPF based on lowtemperature co-fired ceramic (LTCC) has been presented for 60 GHz wireless communication applications. Via pads in the vertical via transitions are designed as an additional resonator for lowloss and wide-bandwidth of the BPF. The proposed BPF has been designed by investigating its characteristics as a function of dimensions of the resonators such as a single-mode patch and via pads and also a length of feed lines are optimized for effective coupling. The designed BPF was fabricated in a 6-layer LTCC dielectric. The fabricated BPF shows a centre frequency (fc) of 61.46 GHz and a 3 dB bandwidth of 10.5% from 58.2 to 64.7 GHz (6.47 GHz). An insertion loss of -2.88 dB at fc and return losses below -10 dB are achieved. Its whole size is $4.72 \times 1.7 \times 0.684\,\mathrm{mm}^3$.

1. INTRODUCTION

Recently, several high-data-rate wireless services such as millimeter-wave (mm-wave) video transmission, wireless-PAN (personal area network), and point-to-point wireless communications have been developed using 60 GHz bands, because of their unlicensed wide bands, frequency re-use, low interference, and implementation of small-sized devices [1–4]. 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 cofired 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 [1–4] considering their size, integration capability, and performance.

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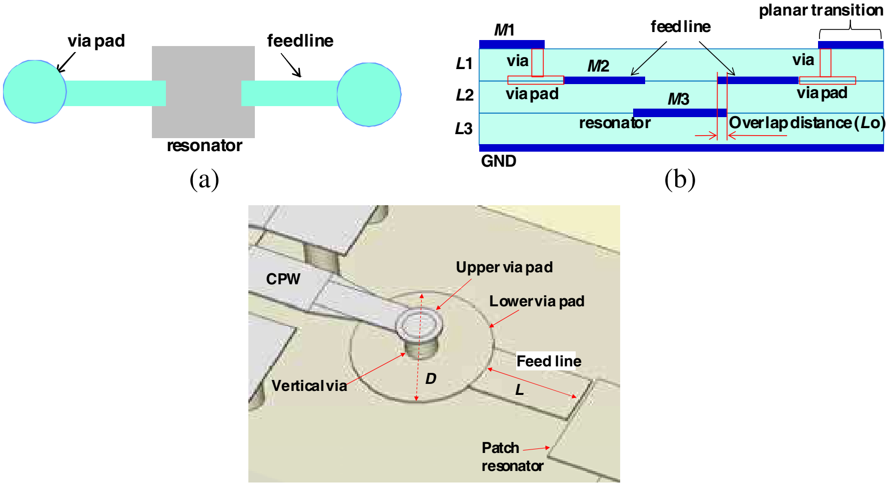
Several types of BPFs [5–10] using various structures and technologies have been developed for low-loss and 3-D integration in RF SoP modules. Particularly, a dual-mode stripline BPF [5] using the novel vertical via transition [11] was integrated into the 60 GHz transmitter LTCC SoP module [2]. LTCC dual-mode cavity and vertically stacked multi-pole filters have been demonstrated at 60 GHz [6]. In this work, by controlling the locations of transmission zeros, a variety of quasi-elliptic responses were implemented [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 ($\varepsilon_r = 2.9 \sim 3.0$) 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 mmwave band.

In this paper, a low-loss and wideband 60-GHz BPF based on LTCC SoP technology has been presented for 60 GHz wireless radio applications. For a low-loss and wideband BPF using a singlemode patch resonator, lower via pads in the vertical transitions are designed as an additional resonator. This filter is embedded in six LTCC dielectric layers. The compact, low-loss, and wideband LTCC BPF with a two-pole response is designed by optimizing the patch size, length of the feed lines, and diameter of via pads. A 3-D finite integration technique (FIT) simulator [12] has been used for the filter design. The designed BPF was fabricated in the commercial LTCC foundry (RN2 Technologies) [13] and characterized using probing method on the probe-station.

2. DESIGN OF A FULLY EMBEDDED STRIPLINE BPF

Figure 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.

The proposed BPF consists of a single-mode patch resonator, feed lines, and vertical via transitions. Fig. 1(a) shows the resonators of the single-mode patch and via pads the feed lines for coupling. A basic half-wavelength square patch resonator, which is commonly used for a microstrip patch antenna [14], is designed on the 3rd layer (L_3).



(a) (b) (c)

Figure 1. Structures of a proposed LTCC BPF. (a) Top view of a square patch, feed lines, and via pads. (b) Side view of a 60 GHz resonant structure. (c) Perspective view of resonant structures.

Basically, the patch resonator is in type of an embedded microstrip. The patch size can control the centre frequency of the filter. Because of LTCC design rule limitations about minimum spacing ($\sim 90\,\mu$m) between lines, the feed lines are placed on a different layer (L_2, 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(b). 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 transitions are required as shown in Figs. 1(b) and (C). This vertical via transition has lower and upper via pads. For broadband and two-pole characteristics of the BPF, the lower via pads on the L_2 are designed as an additional resonator. In general, the diameter (D) of the via pad is 1.5 times larger than D of vias or $D + 50\,\mu$m at the design rule. In this work, D of all upper via pads is 170 µm and lower via pads are optimized for additional resonator. For integrating the BPF into LTCC SoP modules, a CPW-to-CPW planar transition should be also designed, as shown in Fig. 1(b), 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.

Figure 2 explains the simulated response for an insertion (S_{21}) and return (S_{11}) loss as the patch size decrease while other dimensions of feed lines and lower-via pads are fixed. It can be observed that as the size decreases a lower cut-off and pole frequency shifts upward while upper ones are nearly fixed. In spite of the single-mode patch resonator, the BPF has two poles, because of other resonators (lower via pads). For 61.7 GHz operation, the patch size is determined as $336 \times 400\,\mu\text{m}^2$.

Figure 3 shows the filter response as a function of the length (L) of the feed lines. Shortening the length of the feed lines is the same meaning as decreasing overlap distance (L_o) between the patch and feed line. As the L is shortened, each centre frequency and bandwidth (BW) increases and gets narrow, respectively, due to a weaker coupling effect. The L is determined to be 378 μm that is the same Lo as 38 μm, because these dimensions correspond to the centre frequency of 61.7 GHz.

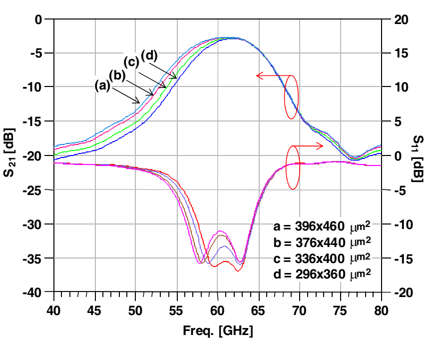


Figure 2. Simulated responses as a function of a patch size.

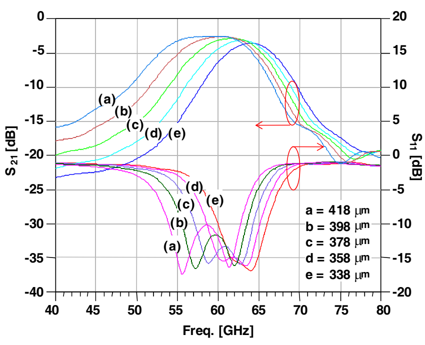


Figure 3. Simulated responses as a function of a length of feed lines.

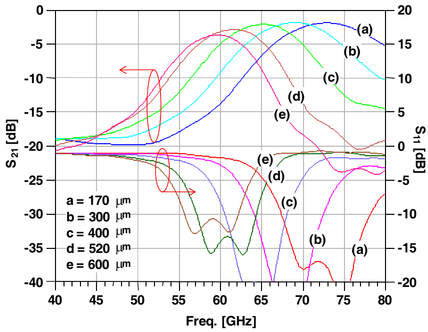


Figure 4. Simulated responses as a function of a diameter of via pads.

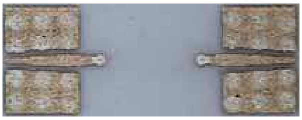


Figure 5. The fabricated LTCC patch BPF (Size: $4.72 \times 1.7 \times 0.68\,\text{mm}^3$).

Figure 4 presents the simulated results of the filter as the diameter (D) of lower via pads in the vertical transitions increases from 170 to 600 µm while other physical parameters such as the patch and feed lines are fixed in previous simulations (Figs. 2 and 3). As the D increases the centre and two-pole frequencies shifts further downward and also 3-dB BW decreases but an insertion loss (IL) is degraded. In this simulation, it is revealed that the wider pads lead to higher parasitic capacitance with the GND plane and it results in weaker coupling in the feeding parts. Therefore, the 3-dB BW decreased and the IL degraded. In addition, the lower-via pads operate as the additional resonators of the BPF, judging from characteristics of the centre and two-pole frequency. Considering the performance of the BPF, the D is determined to be 520 µm. The centre frequency and 3-dB BW of the designed LTCC BPF are 61.7 and 9.37 GHz, respectively.

3. 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. 5 shows the fabricated BPF and its total size including whole transitions was $4.72 \times 1.7 \times 0.68\,\text{mm}^3$.

The fabricated BPF was measured using probing method on the probe-station. The measured performance is shown in Fig. 6. 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,

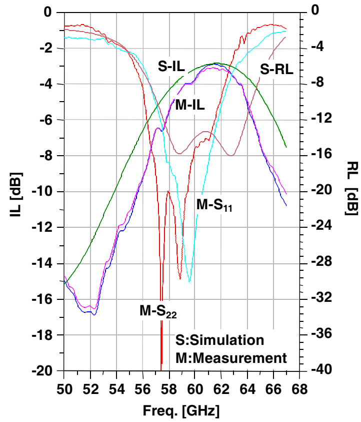


Figure 6. Measured and simulated insertion loss (IL) and return one (RL) of the 60-GHz LTCC BPF.

result from un-balance of coupling between feed lines and the patch due to misalignment at the lamination process of the LTCC fabrication.

4. 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 $4.72 \times 1.7 \times 0.68\,\text{mm}^3$. The fabricated LTCC BPF showed a centre frequency of 61.46 GHz, 3 dB bandwidth of 10.5% (= 6.47 GHz) and insertion loss of −2.88 dB at centre frequency.

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