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A Compact 60 GHz LTCC Microstrip Bandpass Filter With Controllable Transmission Zeros

Fanyi Meng, Kaixue Ma, Kiat Seng Yeo, Shanshan Xu, Mahalingam Nagarajan

Division of Circuit and Systems, Nanyang Technological University, Singapore 639798.

Abstract — **This paper presents a compact microstrip bandpass filter (BPF) with separate electric and magnetic coupling paths (SEMCPs) for 60 GHz applications. Either electric or magnetic coupling can be dominant in the total electromagnetic coupling, while the location of transmission zeros differs. The proposed fourth-order BPF is designed based on two metal layers of a 85 µm LTCC substrate. Without any via connections, the design configuration is very simple which facilitates the crafts of fabrications. The filter achieves a center frequency of 60.275 GHz, a 3-dB bandwidth of 3.15 GHz (5.22%), and a compact size of only 1.3 × 0.74 mm^2. The minimum insertion loss of the filter is 2.7 dB and the return loss is better than 17 dB in the passband.**

Index Terms — **LTCC, bandpass filters, 60 GHz, V-band, SEMCPs.**

I. Introduction

THE rapid demand of wireless personal area network (WPAN) applications has led to immense research efforts in 60 GHz circuits design over the past years. The three-dimensional (3D) system-on-package approach using multilayer low-temperature co-fired ceramic (LTCC) technologies has emerged as an attractive solution for V-band systems, due to its compactness and less interference from other circuits integrated in the package [1].

Two controllable separate electric and magnetic coupling paths (SEMCPs) are firstly proposed for planar filter application by Dr. Ma [2]. The coexistence of electric and magnetic coupling creates transmission zeros at both sides of stopband.

In this paper, a novel microstrip bandpass filter based on LTCC technology operating at 60 GHz is presented, which enables separate control of transmission zeros at both lower and upper sides of passband. Compared with filter in [2], the via ground structure is removed to facilitate the arts and crafts of fabrication. Consequently, it provides more options in the resonators alignment. Advantages such as high rejection level and asymmetrical response are achieved comparing to conventional cascaded filters [3]. Furthermore, the location of transmission zeros can be accurately controlled by tuning the physical coupling parameters which will be illustrated in Section II.

II. Second-order Filter Realization

The commercial EM software Ansoft HFSS is used in the following design and analysis. In the project, the microstrip structure consists of two metal layers on 0.85 mm thick LTCC substrate (ε_r = 7.1).

Fig. 1 shows the configuration of the electric (*E*) dominant filter (ground layer not shown). The portion of the microstrip with length of L_d is 45° with respect to vertical axis. It is clear that the space between open ends is much smaller than that between the middle of the resonators. Consequently, the electric coupling is stronger than the magnetic coupling so that the *E* dominant filter prototype is developed. By fine tuning of the physical parameters, the configuration is finalized as below. In Fig. 2, the second-order *E* dominant filter shows a dual-mode response with a transmission zero at upper side of the passband. The transmission zero is located at 70 GHz which enhances the roll-off of the BPF at higher frequency of passband. The minimum insertion loss at passband is 0.77 dB.

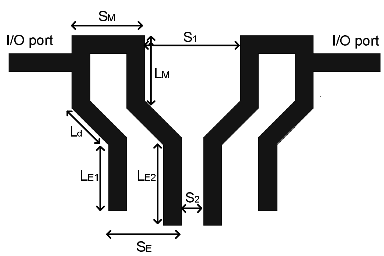

Fig. 1. Configuration of the second-order *E* dominant SEMCP filter. L_M = 0.2 mm, L_{E1} = 0.18 mm, L_{E2} = 0.22 mm, L_d = 0.14 mm, S_1 = 0.26 mm, S_2 = 0.06 mm, S_M = 0.2 mm, S_E = 0.2 mm.

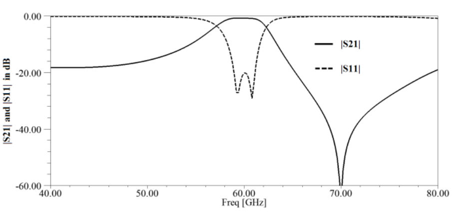

Fig. 2. Frequency response of the second-order *E* dominant SEMCP filter.

Fig. 3 shows the configuration of the magnetic (*M*) dominant filter. The smaller space between magnetic coupling comparing to electric coupling ensures that the magnetic coupling dominates in the total electromagnetic coupling In Fig. 4, the second-order *M* dominant filter shows a dual-mode response with two transmission zeros at lower side of the passband due to the harmonic effects. The transmission zeros are located at 45.2 GHz and 55.6 GHz respectively.

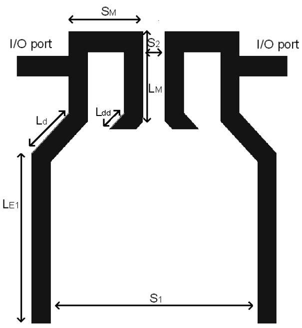

Fig. 3. Configuration of the second-order *M* dominant SEMCP filter. L_M = 0.2 mm, L_{E1} = 0.42 mm, L_d = 0.14 mm, L_{dd} = 0.06 mm, S_1 = 0.56 mm, S_2 = 0.06 mm, S_M = 0.2 mm.

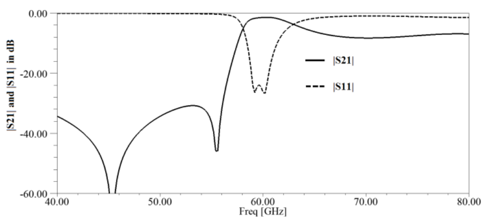

Fig. 4. Frequency response of the second-order *M* dominant SEMCP filter.

III. Fourth-order Filter Realization

The fourth-order filter is realized by cascading the second-order *E* dominant and *M* dominant filters with capacitive loading. As shown in Fig. 5(a), the space between the two second-order filters S_{EM} is 0.06 mm. All other physical parameters are the same as in Section II.

Fig. 6 shows the simulated performance of fourth-order SEMCP filter. The filter has minimum insertion loss of 2.7 dB at passband, and the locations of the transmission zeros are at 55.6 GHz and 70 GHz which coincides with the second-order *E* dominant and *M* dominant filters. Therefore, the location of the transmission zeros can be separately controlled. The centre frequency is 60.275 GHz with 3-dB bandwidth of 3.15 GHz (FBW = 5.22%). The return loss is better than 17 dB at passband. Besides, the filter has a size of only 1.3 × 0.74 mm^2 without considering the I/O feed lines.

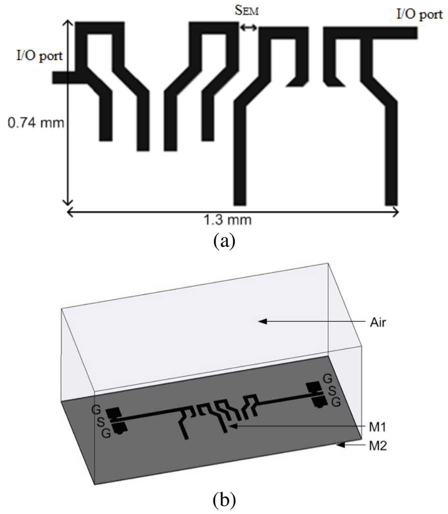

Fig. 5. Configuration of the four-order SEMCP filter. (a) Top view. (b) Three-dimensional view with GSG pads.

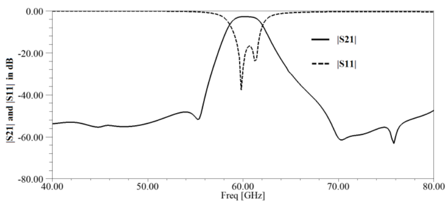

Fig. 6. Frequency response of the fourth-order SEMCP filter.

IV. Conclusion

In this paper, a novel microstrip bandpass filter configuration for 60 GHz applications has been proposed. The advantages such as compact size, sharp roll-off, and low insertion loss have been demonstrated through simulation.

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