Novel Silicon-Based Microwave Bandstop Filters for Communication Systems

Yeong-Lin Lai and Pei-Yen Cheng

Department of Mechatronics Engineering,
National Changhua University of Education,
Changhua 500, Taiwan, R.O.C.
E-mail: yllai@cc.ncue.edu.tw

Abstract

This paper presents state-of-the-art silicon-based bandstop filters for the realization of microwave system-on-a-chip (SOC) communication systems. The characteristics of the bandstop filters are designed by the adjustment of the geometric dimensions of the filters in order to meet different system requirements. The filters exhibit compact circuit dimensions and outstanding stopband and passband characteristics at K and Ka bands.

Keywords: Bandstop, communication system, filter, K-band, Ka-band, microwave, silicon, silicon-on-a-chip.

1. Introduction

Monolithic microwave integrated circuits (MMICs) [1]-[4] based on GaAs technologies [5]-[8] have successfully applied to amplifiers, filters, mixers, and so on for communication systems. The GaAs-based MMIC technology has demonstrated outstanding performance because of the inherent GaAs semiconductor properties at microwave frequencies.

On the other hand, the silicon-based complementary metal-oxide semiconductor (CMOS) technology has long been the mainstream for very-large-scale integration (VLSI) system applications because it provides low power consumption and low substrate cost. With the advances in the scale-down CMOS technology, the CMOS redio-frequency integrated circuits (RFICs) were reported for microwave communication applications [9], [10]. The CMOS RFICs will continuously progress toward the realm of system-on-a-chip (SOC) [11], [12].

In this paper, we propose novel microwave silicon-based bandstop filters on the basis of the CMOS RFIC technology. The filters have coplanar waveguide (CPW) [13] structures. The characteristics of the CPW filters are determined by the proper design of geometric dimensions. The bandstop filters with different geometric design parameters are investigated.

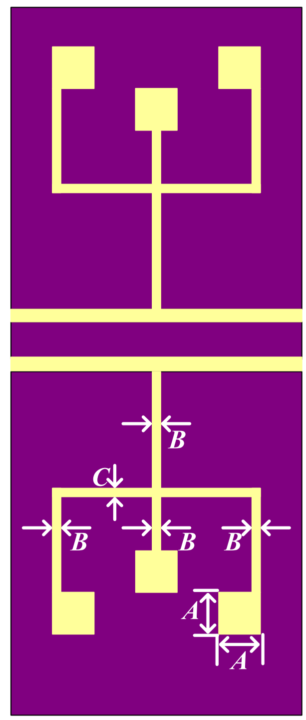

Fig. 1: Circuit structure of bandstop filter.

2. Circuits

The typical circuit structure of the microwave bandstop filter is shown in Fig. 1. A high-resistivity silicon semiconductor wafer is used for the substrate of the filter. A 0.5-μm-thick silicon dioxide film is grown on the top of the 675-μm-thick silicon substrate. The copper metal layer has a ground-signal-ground CPW configuration. The ground metal planes are etched to insert impedances in the CPW transmission line. There

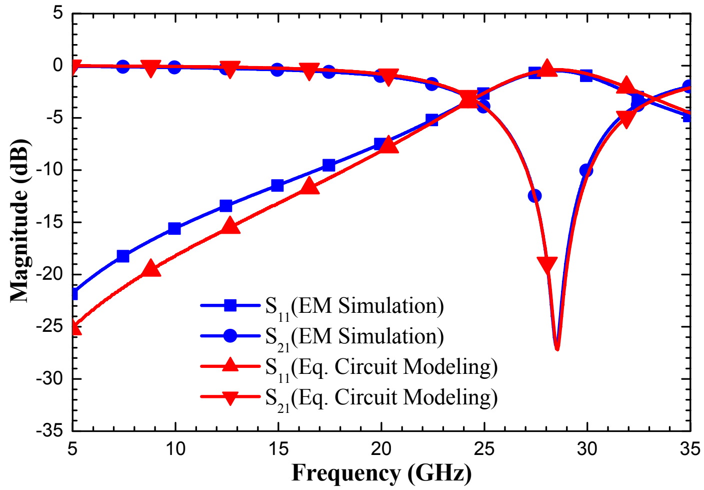

Fig. 2: EM simulation and equivalent circuit modeling characteristics of bandstop filter with A = 45 μm, B = 10 μm, and C = 10 μm.

are three geometric design parameters, *A*, *B*, and *C*. The parameter *A* represents the width of the square etched holes. The parameter *B* indicates the width of the vertical etched branches and the parameter *C* symbolizes the width of the horizontal etched branches.

The full-wave electromagnetic (EM) design of the circuit is conducted by the commercial simulator Zeland IE3D. The geometric design parameters, *A*, *B*, and *C* determine the microwave characteristics of the filters. On the basis of the physical circuit structure of the filter, the equivalent circuit of the bandstop filter is modeled by an inductor-capacitor-resistor parallel circuit. The inductor and capacitor components contribute the bandstop characteristics. The deepness of the frequency response at the resonant frequency is described by the resistor component. The EM simulation and equivalent circuit modeling characteristics of the bandstop filter with A = 45 μm, B = 10 μm, and C = 10 μm are shown in Fig. 2. The filter exhibits low insertion loss in the pass band and high attenuation in the stop band. According to the EM simulation, the resonant frequency (f_o) is 28.5 GHz and the deepness of the frequency response at f_o is –26.9 dB. The –3-dB frequency ($f_{-3\text{-dB}}$) is 24.25 GHz. The lower –10-dB frequency and upper –10-dB frequency are 27.05 GHz and 29.95 GHz, respectively. The results of the equivalent circuit modeling are in consistent with those of the EM simulation.

In order to investigate the optimum design of the filters for different system requirements, the geometric design parameters, *A*, *B*, and *C*, are varied as Table I. Fig. 3 shows the microwave characteristics of the bandstop filters with B = 10 μm and C = 10 μm with respect to the different values of the parameter *A*. The resonant frequencies for the *A* values of 100, 50, and 25 μm are 24.30, 27.30, and 29.30 GHz, respectively. The

TABLE I
DIMENSIONS OF FILTERS

Case	*A* (μm)	*B* (μm)	*C* (μm)
A1	100	10	10
A2	50	10	10
A3	25	10	10
B1	100	10	10
B2	100	20	10
B3	100	40	10
C1	100	10	10
C2	100	10	20
C3	100	10	40

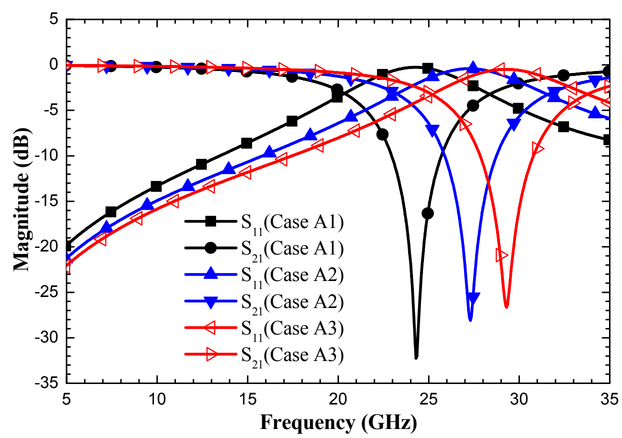

Fig. 3: Microwave characteristics of bandstop filters with B = 10 μm and C = 10 μm with respect to different values of parameter *A*.

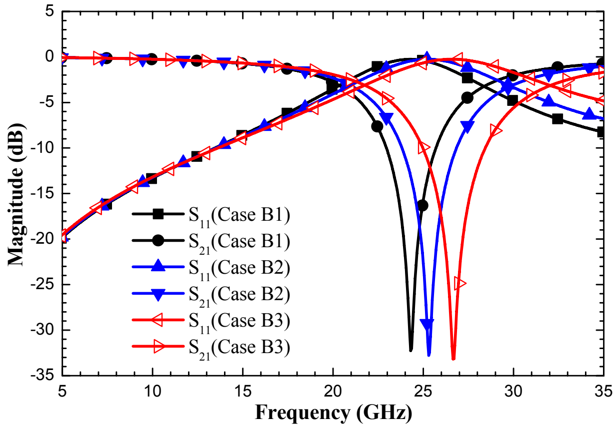

Fig. 4: Microwave characteristics of bandstop filters with A = 100 μm and C = 10 μm with respect to different values of parameter B.

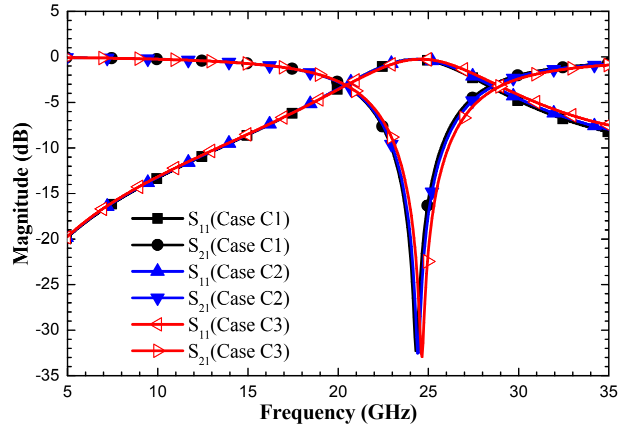

Fig. 5: Microwave characteristics of bandstop filters with A = 100 μm and B = 10 μm with respect to different values of parameter C.

results can be explained through the equivalent circuit modeling of the filters. The equivalent inductance is changed from 0.234 to 0.167 nH when the parameter A is varied from 100 to 25 μm. The increase in the resonant frequency is due to the effective reduction in the equivalent inductance. The –3-dB frequency has the same trend as the resonant frequency with regard to the parameter A.

The microwave characteristics of the bandstop filters with A = 100 μm and C = 10 μm with respect to the different values of the parameter B is shown in Fig. 4. The resonant frequency is changed from 24.30 to 26.65 GHz and the –3-dB frequency is increased from 20.35 to 21.75 GHz when the parameter B is varied from 10 to 40 μm. After the conduction of the equivalent circuit modeling, it is found that the change in the resonant frequency is mainly caused by the reduction in the equivalent capacitance.

Fig. 5 shows the microwave characteristics of the bandstop filters with A = 100 μm and B = 10 μm with respect to the different values of the parameter C. The frequency responses are almost the same for the different C values. It is because that the width of the horizontal etched branches has small influence on the equivalent inductance and capacitance.

Table II summarizes the resonant frequency and the –3-dB frequency characteristics of the bandstop filters. The microwave characteristics of the filters are dominated by the geometric design parameters A and B. Therefore, we are able to easily design the bandstop filters by means of controlling the dimensions of the square etched holes and the vertical etched branches in the ground planes. In this work, we have demonstrated that the bandstop filters can be applied to K-/Ka-band communication systems.

TABLE II
CHARACTERISTICS OF FILTERS

Case	f_o (GHz)	$f_{-3\text{-dB}}$ (GHz)
A1	24.30	20.20
A2	27.30	23.05
A3	29.30	24.95
B1	24.30	20.20
B2	25.30	20.85
B3	26.65	21.65
C1	24.30	20.20
C2	24.40	20.25
C3	24.65	20.30

3. Conclusion

New microwave bandstop filters based on the silicon technology have been demonstrated for the applications of the communication systems at the K and Ka bands. The filters have the CPW defected ground structures. The microwave characteristics of the bandstop filters are determined by the geometric dimensions of the etched patterns in the ground planes. The equivalent circuit modeling of the filters is established. The results of the equivalent circuit modeling interpret the trend of the microwave characteristics of the filters.

Acknowledgment

This work was supported in part by the National

Science Council of the Republic of China under Contract NSC 94-2215-E-018-006.

References

[1] Y.-L. Lai, T.-L. Li , and C.-Y. Chang, "Power amplifier MMICs with improved matching circuit design," in *Proc. Progress in Electromagnetics Research Symp.*, Singapore, Jan. 2003, p. 114.

[2] D. Drolet, A. Panther, C. J. Verver, K. Kautio, and Y.-L. Lai, "Ka-band direct transmitter modules for baseband pre-compensation," in *Proc. 35th European Microwave Conf.*, Paris, France, Oct. 2005, pp. 673–676.

[3] Y.-L. Lai, E. Y. Chang, A. A. Ezzeddine, A. Darwish, and H. C. Huang, "Fully-matched GaAs power amplifier MMICs for L-band wireless communications," in *Proc. Int. Symp. on Signals, Systems, and Electronics*, Tokyo, Japan, July 2001, pp. 335–338.

[4] Y. Yun, "A novel microstrip-line structure employing a periodically perforated ground metal and its application to highly miniaturized and low-impedance passive components fabricated on GaAs MMIC," *IEEE Trans. Microwave Theory Tech.*, vol. 53, no. 6, pp. 1951–1959, Jun. 2005.

[5] C. E. Chang, P. F. Chen, P. M. Asbeck, L. T. Tran, D. C. Streit, and A. K. Oki, "Lightly doped emitter HBT for low-power circuits," *IEEE Microwave and Guided Wave Lett.*, vol. 7, no. 11, pp. 377–379, Nov. 1997.

[6] Y.-L. Lai, E. Y. Chang, C.-Y. Chang, T. H. Liu, S. P. Wang, and H. T. Hsu, "2-V-operation δ-doped power HEMT's for personal handy-phone systems," *IEEE Microwave and Guided Wave Lett.*, vol. 7, no. 8, pp. 219–221, Aug. 1997.

[7] D. C. Streit, D. K. Umemoto, K. W. Kobayashi, and A. K. Oki, "Monolithic HEMT-HBT integration by selective MBE," *IEEE Trans. Electron Devices*, vol. 42, no. 4, pp. 618–623, Apr. 1995.

[8] Y.-L. Lai, E. Y. Chang, C. Y. Chang, T. K. Chen, T. H. Liu, S. P. Wang, T. H. Chen, and C. T. Lee, "5mm high-power-density dual-delta-doped power HEMT's for 3 V L-band applications," *IEEE Electron Device Lett.*, vol. 17, no. 5, pp. 229–231, May 1996.

[9] A. A. Abidi, "RF CMOS comes of age," *IEEE J. Solid-State Circuits*, vol. 39, no. 4, pp. 549–561, Apr. 2004.

[10] X. Guan and A. Hajimiri, "A 24-GHz CMOS front-end," *IEEE J. Solid-State Circuits*, vol. 39, no. 2, pp. 368–373, Feb. 2004.

[11] A. Matsuzawa, "RF-SoC–expectations and required conditions," *IEEE Trans. Microwave Theory Tech.*, vol. 50, no. 1, pp. 245–253, Jan. 2002.

[12] Y.-L. Lai and Y.-H. Chen, "Influence of membranes on RF microelectromechanical system switches," *J. Chinese Society of Mechanical Engineers, Trans. Chinese Institute of Engineers, Series C*, vol. 27, no. 2, pp. 255–260, Apr. 2006.

[13] C. P. Wen, "Coplanar waveguide: a surface strip transmission line suitable for nonreciprocal gyromagnetic device applications," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-17, no. 12, pp. 1087–1090, Dec. 1969.