CPW Filters with Defected Ground Structures for RF and Microwave Applications

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Abstract

New coplanar waveguide (CPW) filters with a fork-shaped defected ground structure (DGS) are proposed for radio-frequency (RF) and microwave applications. The miniature CPW DGS filters developed are based on the silicon technology. The filters are able to provide the bandstop characteristics with high attenuation in the stop band and low insertion loss in the pass band. A typical filter designed for Ka-band satellite communication systems exhibits an attenuation of 26.3 dB at a resonant frequency of 28.35 GHz.

Keywords: Coplanar waveguide, defected ground structure, filter, Ka-band satellite communication system, microwave, RF.

1. Introduction

The coplanar waveguide (CPW) technique has long been an attractive subject in the microwave field because of its unique structure advantages [1]-[3]. First, since that the signal line and the ground planes are on the same plane of the substrate, there is no via hole process is needed and the fabrication of the CPW is simpler than that of the microstrip line. Secondly, the CPW provides greater design flexibility because the widths of the slots and signal line of the CPW can be easily adjusted for the determination of the characteristic impedance as compared with the microstrip line.

Radio-frequency (RF) and microwave filters have been widely used in communication systems [2], [4]-[6]. In the Ka-band satellite communication systems [7]-[10], the bandstop filters are often needed in the frond-ends of the systems. The bandstop filter in the receiver of the earth station is required to pass the downlink signals from the antenna and eliminate the uplink signals from the transmitter.

In this paper, CPW bandstop filters are developed for the Ka-band satellite communication systems. The filters adopt the defected ground structure (DGS) which has the etched pattern in the ground plane of a transmission line [11]-[13]. The CPW filters with a fork-shaped DGS topology perform excellent bandstop characteristics. The equivalent circuit modeling of the filters is established and discussed in detail.

2. Structure

Fig. 1 shows the structure of the proposed CPW bandstop filter with the fork-shaped DGS. The

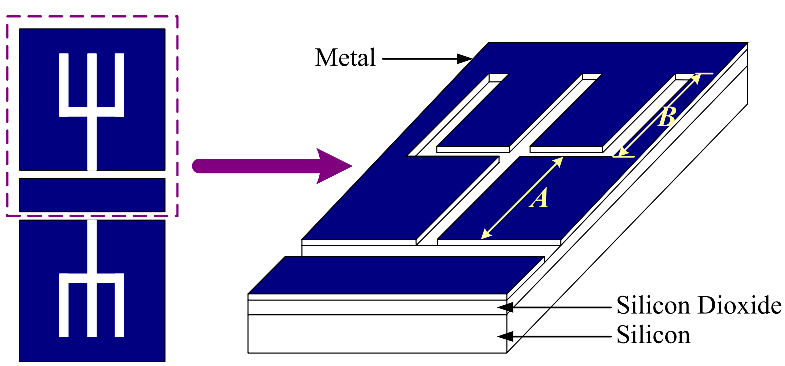

Fig. 1: Structure of CPW bandstop filter with fork-shaped DGS.

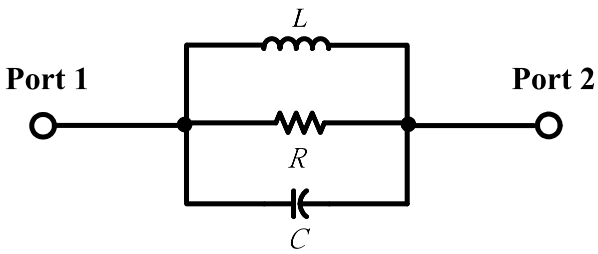

Fig. 2: Equivalent circuit model of proposed CPW bandstop filter.

substrate of the filter is the high-resistivity silicon semiconductor with a thickness of 675 μm. The dielectric constant of the silicon is 11.9. On the top of the silicon wafer, a layer of silicon dioxide with a thickness of 0.5 μm is grown. A 2-μm copper metal layer is deposited on the silicon dioxide. The CPW metal layer is patterned by lithography. The CPW filter has the fork-shaped defects in the metallic ground planes. The circuit size of the filter is 1 mm × 2 mm. The geometric parameters *A* and *B* are designed to comply with the frequency response requirements of the communication systems.

3. Design

The design of the filters is performed by the full-wave electromagnetic (EM) simulator Zeland IE3D. The microwave characteristics of the filters are associated with the geometric dimensions of the etched fork-shaped defects.

The equivalent circuit model of the CPW bandstop filter is constructed according to the physical structure of the filter. Fig. 2 shows the equivalent circuit model with an inductor *L*, a resistor *R*, and a capacitor *C*. The bandstop response is modeled by the *LC* resonator. The attenuation property at the resonant frequency is indicated by the resistor *R*.

Fig. 3 shows the microwave characteristics of the CPW DGS filter. Both the geometric parameters *A* and *B* of the filter are 300 μm. Not only the EM simulation results but also the equivalent circuit modeling characteristics are shown. The bandstop performance is realized by the fork-shaped DGS topology. The resonant frequency is 28.35 GHz. The attenuation at the resonant frequency is 26.3 dB. The –10-dB band ranges from 27.0 to 29.80 GHz and the corresponding –10-dB bandwidth is 2.8 GHz. The extracted inductance and capacitance of the equivalent circuit model are 0.1692 nH and 0.186 pF, respectively. The equivalent circuit modeling results agree with the EM simulation data. The filter exhibits enough attenuation at the transmission frequency band from 27.6 to 29.1 GHz for the Ka-band satellite communication systems. The low insertion loss is obtained by the filter at the receiving frequency band from 17.8 to 19.3 GHz.

The characteristics of the CPW filters are determined by the geometric dimensions of the fork-shaped DGS. The geometric parameters *A* and *B* are varied in order to study the effect of the geometric dimensions of the filters. At first, the geometric parameter *A* is increased from 300 to 600 μm with an increase step of 150 μm while the geometric parameter *B* is kept at 300 μm. Fig. 4 shows the microwave characteristics of the filters. The resonant frequencies for the *A* values of 450 and 600 μm are 23.45 and 19.00 GHz, respectively. The –10-dB bandwidths for the *A* values of 450 and 600 μm are 2.20 and 1.90 GHz, respectively. The increase in parameter *A* causes the reduction in both the resonant frequency and –10-dB bandwidth. The equivalent inductances and capacitances of the filters for the changes in the values

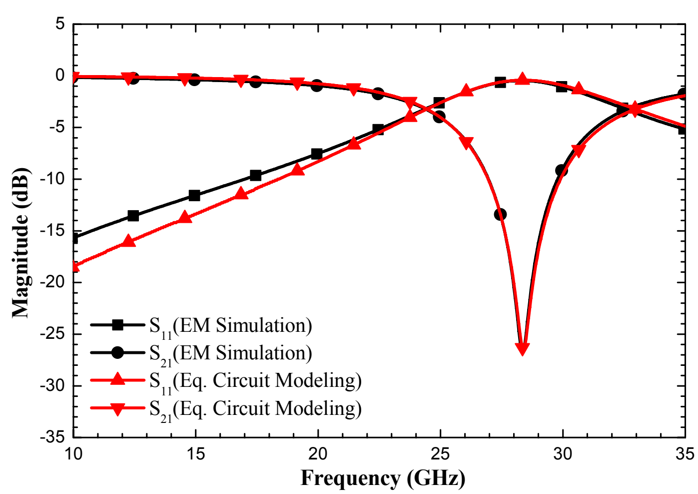

Fig. 3: Microwave characteristics of CPW bandstop filter with *A* = 300 μm and *B* = 300 μm.

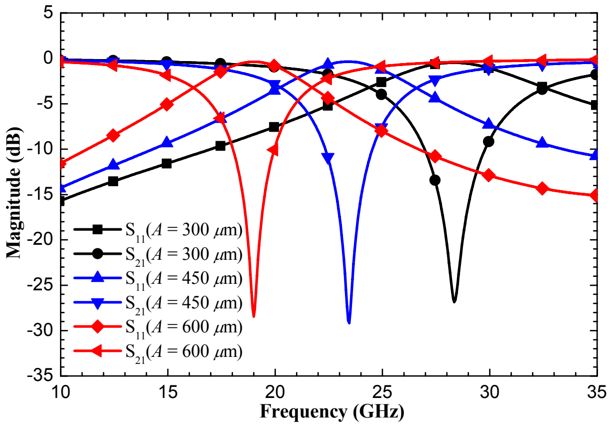

Fig. 4: Microwave characteristics of CPW bandstop filters with B = 300 μm for different values of parameter A.

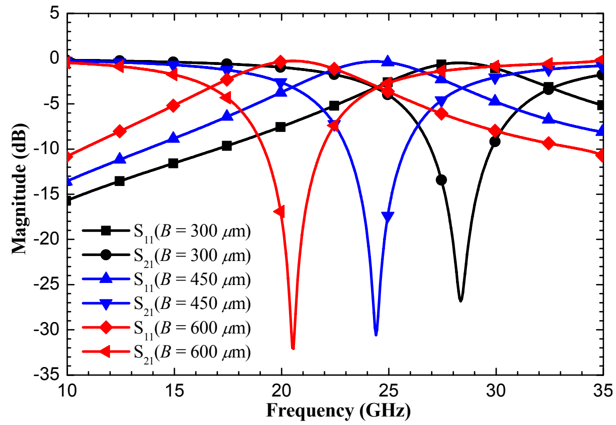

Fig. 6: Microwave characteristics of CPW bandstop filters with A = 300 μm for different values of parameter B.

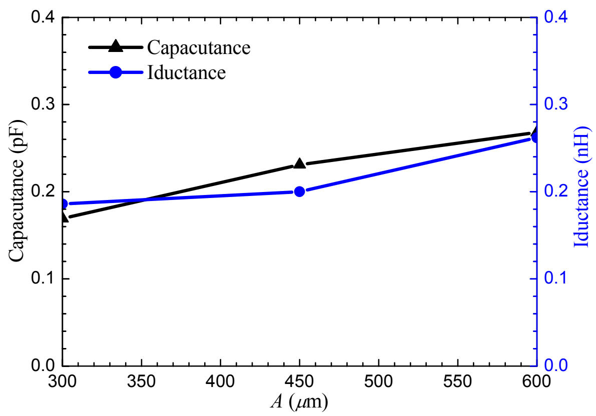

Fig. 5: Equivalent inductances and capacitances of CPW bandstop filters with B = 300 μm for different values of parameter A.

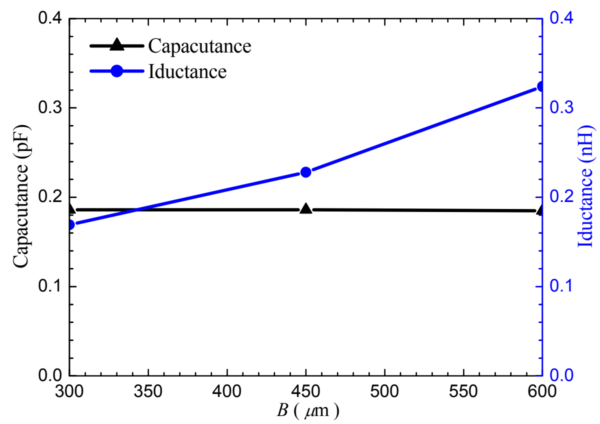

Fig. 7: Equivalent inductances and capacitances of CPW bandstop filters with A = 300 μm for different values of parameter B.

of the geometric parameter A are shown in Fig. 5. The increase in the parameter A effectively enlarges the equivalent inductances and capacitances of the filters.

After the study of the influence of the parameter A, the effect of the parameter B is also investigated. Fig. 6 depicts the microwave characteristics of the filters with A = 300 μm for the changes of the B values from 300 to 600 μm. It is observed that the resonant frequency changes from 28.35 to 20.55 GHz when the parameter A increases from 300 to 600 μm. Fig. 7 shows the equivalent inductances and capacitances of the filters for different values of the parameter B. The equivalent inductances increase with the increasing B values while the equivalent capacitances are kept almost the same.

The CPW filters with the fork-shaped DGS contribute the inductive and capacitive loads in the transmission line and display the slow wave effect which miniaturizes the circuit size. The developed filters can be applied to the Ka-band satellite communication systems. By adjusting the geometric dimensions of the CPW DGS structures, the filters can be employed for more RF and microwave applications in other frequency bands such as K, Ku, and X bands.

4. Conclusion

The novel CPW bandstop filters have been demonstrated by the silicon technology. The filters with the fork-shaped DGS have exhibited compact circuit dimensions and outstanding stopband and passband characteristics because of the slow-wave effect. The characteristics of the CPW DGS filter can be easily designed by the proper adjustment of the DGS geometric dimensions. The developed CPW DGS bandstop filters can be applied to the RF and microwave communication systems.

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References

[1] 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.

[2] Y.-L. Lai and C.-H. Chang, "Microwave filters with novel CPW periodic structures," in *Proc. Progress in Electromagnetics Research Symp.*, Aug. 2004.

[3] M. Nedil, T. A. Denidni, and L. Talbi, "Novel butler matrix using CPW multilayer technology," *IEEE Trans. Microwave Theory Tech.*, vol. 54, no. 1, pp. 499-507, Jan. 2006.

[4] D. Kaddour, E. Pistono, J.-M. Duchamp, J.-D. Arnould, H. Eusèbe, P. Ferrari, and R. G. Harrison, "A compact and selective low-pass filter with reduced spurious responses, based on CPW tapered periodic structures," *IEEE Trans. Microwave Theory Tech.*, vol. 54, no. 6, pp. 2367-2375, Jun. 2006.

[5] I. C. Hunter, L. Billonet, B. Jarry, and P. Guillon, "Microwave filters-applications and technology," *IEEE Trans. Microwave Theory Tech.*, vol. 50, no. 3, pp. 794-805, Mar. 2002.

[6] J. García-García, J. Bonache, I. Gil, F. Martín, M. d. C. Velázquez-Ahumada, and J. Martel, "Miniaturized microstrip and CPW filters using coupled metamaterial resonators," *IEEE Trans. Microwave Theory Tech.*, vol. 54, no. 6, pp. 2628-2635, Jun. 2006.

[7] P. Caudrillier, A. Takacs, O. Pascal, H. Aubert, P. Pons, and R. Plana, "Compact circularly polarized radiating element for Ka-band satellite communications," in *IEEE AP-S Int. Symp. Dig.*, Jun. 2002, pp. 18–21.

[8] 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.

[9] H. Vasseur, C. Amaya, and D. Vanhoenacker, "System implications of rain and ice depolarisation in Ka-band satellite communications," in *Proc. Tenth Int. Conf. on Antennas and Propagation*, vol. 2, Apr. 1997, pp. 115–118.

[10] A. Takacs, H. Aubert, P. Pons, R. Plana, T. Parra, J. Graffeuil, H. Baudrand, and J. L. Cazaux, "An original micromachined planar Ka band filter based on a resonant coupling irises topology," in *Proc. Int. Semiconductor Conf.*, Oct. 2001, pp. 147–150.

[11] J.-S. Lim, J.-S. Park, Y.-T. Lee, D. Ahn, and S. Nam, "Application of defected ground structure in reducing the size of amplifiers," *IEEE Microwave Wireless Comp. Lett.*, vol. 12, no. 7, pp. 261–263, Jul. 2002.

[12] S. M. Kang, J. H. Choi, S. W. Nam, and K. H. Koo, "A novel 5GHz and 2.4GHz dual band transmitter using microstrip defected ground structure," in *IEEE MTT-S Int. Microwave Symp.* Jun. 2005, pp. 2259–2262.

[13] J.-S. Lim, Y.-T. Lee, J.-H. Han, J.-S. Park, D. Ahn, and S. Nam, "A technique for reducing the size of amplifiers using defected ground structure," *in IEEE MTT-S Int. Microwave Symp.,* Jun. 2002, pp. 1153–1156.