Equivalent Circuit Model for Closely Spaced Patch Antenna and Microstrip Line with Loaded Defected Microstrip Structure

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***Abstract*—In this paper, a defected microstrip structure (DMS) is proposed and put on the transmission line to reduce the mutual coupling between closely spaced patch antenna and microstrip line. The equivalent circuit model of the considered structure with loading DMS are presented and extracted. The lumped elements of the equivalent circuit model are obtained from the antenna and DMS equivalent circuits by including the coupling between the patch antenna and the 50-Ω transmission line. The proposed structure is simulated by HFSS and the extracted circuit is verified by using ADS simulation. The accuracy of the circuit model agrees well with the full wave, which help to verify its effectiveness.**

Keywords—Defected microstrip structure (DMS); decoupling; equivalent circuits

I. INTRODUCTION

In modern compact communication devices, the mutual coupling intensively increases because of the closely spaced elements, such as antenna and transmission lines, which might affect the performance of the device. Hence, there is a need to suppress the mutual coupling between closely spaced elements in communication devices. A great number of methods have been proposed to suppress the mutual coupling between closely spaced antennas and coupled microstrip transmission lines [1-3]. However, there are few researches on reduction of mutual coupling between closely packed patch antenna and microstrip transmission lines. In addition, there is little analysis on the equivalent circuit model. Although various mutual coupling reduction techniques have been proposed, some of these methods are complex and difficult to implement. Defected microstrip structure (DMS) has received considerable interest and has been applied to filter and antenna designs because of its simple structure and unique characteristics [4-6].

In this paper, a DMS is used and integrated on a 50-Ω transmission line to provide an enhanced isolation of 12 dB between the patch antenna and the transmission line. Also, an equivalent circuit model is proposed to analyze the coupling of the proposed analysis structure. The performance is investigated by using the HFSS and ADS. The results show that a coupling is reduced between the antenna and the transmission line.

II. MODEL OF THE ANTENNA AND TRANSMISSION LINE

The proposed DMS and its dimensions are shown in Fig.1. The DMS is etched on a 50-Ω microstrip transmission line which is shown in Fig.1. The dimensions are: L= 18 mm, W = 26 mm, l1 = 15 mm, w1 = 11.3 mm, w2 = 3.13 mm, yf = 7.5 mm, xf = 2.43 mm, a1 = 5.7 mm, a2 = 4.2 mm, a3 = 5 mm, b1 = 2.5 mm, b2 = 1.3 mm, b3 = 2.2 mm, c1 = 0.9 mm, c2 = 0.4 mm. The distance *d* between the patch antenna and transmission line is 2 mm. The antenna and transmission line are printed on a FR4 substrate of thickness 1.6 mm, whose dielectric constant is 4.4.

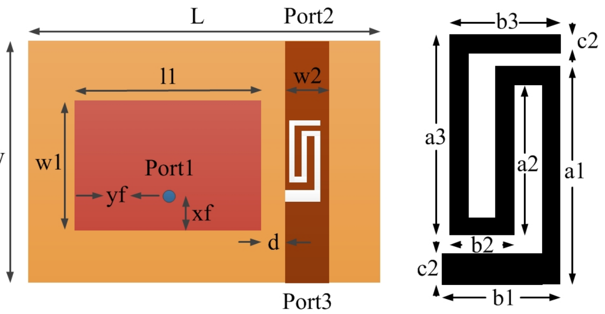

Fig. 1. Geometry of the structure loaded DMS

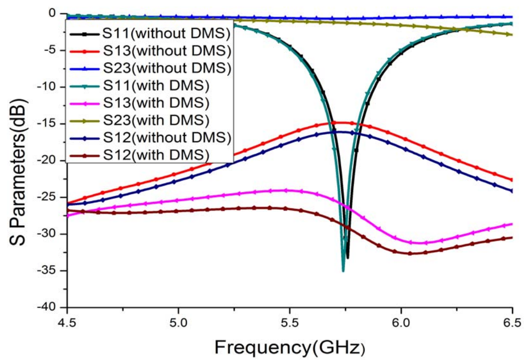

Fig. 2. The simulated results with/without DMS

Fig.2 shows the simulated results of the structure with /without DMS. The neighboring patch antenna gives a mutual coupling to microstrip transmission line, which might interfere with the transmission line. It is also worth noting that the coupling in near-end and far-end are not equal due to the asymmetry of the structure, which can be seen from S12 and S13. It is found from Fig. 2 that the crosstalk is reduced about 12 dB by means of the proposed DMS in the transmission line.

III. Equivalent Circuit Model

To investigate the equivalent circuit model of the decoupling structure proposed in Fig.1, equivalent circuit model of the patch antenna is extracted based on the S-parameters obtained from HFSS. Then, the circuit model of microstrip transmission line loaded with DMS is extracted. Also, we consider the equivalent circuits of the patch antenna and the DMS loaded transmission line to create the equivalent circuit of the proposed coupling structure, which is presented in Fig.3. In this equivalent circuit model, the coupling function is approximated to be coupling capacitors and mutual inductors.

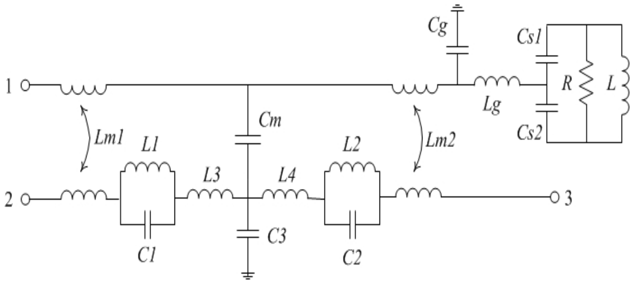

Fig. 3 Equivalent circuit model of the structure in Fig.1

In the equivalent circuit model, the resonance characteristic of the antenna is given by RLC resonance circuit, where the capacitance C is the combination of the two series capacitors ($Cs1$ and $Cs2$) which is to widen the frequency band. The coaxial probe and the feed port are equaled to be a capacitor (Cg) and an inductor (Lg) [7]. For the microstrip transmission line, the values of the elements can be predicted based on the formulas in [8]. Finally, the coupling capacitor Cm and mutual inductance Lm are obtained from the cure fitting in comparison with the full wave simulation results.

IV. The Results of Circuit Model

The equivalent circuit is modeled and simulated in ADS, where the key circuit parameters are extracted from the S parameters gotten by the full wave simulation. The optimized parameters are: $L1$ = 3.09 nH, $C1$ = 1 pF, $L2$ = 1 nH, $C2$ = 2.94 pF, $L3$ = 2.15 nH, $L4$ = 0.89 nH, $C3$ = 0.5 pF, L =0.5 nH, $Cs1$ = 2.74 pF, $Cs2$ = 3.71 pF, Cg = 0.13 pF, Lg = 0.76 nH, Cm = 0.04 pF, $Lm1$ = 7.3 pF, $Lm2$ = 0.047 pF, R = 257 Ohm. It can be seen that the coupling capacitor and mutual inductances are small, which means that the coupling is also reduced.

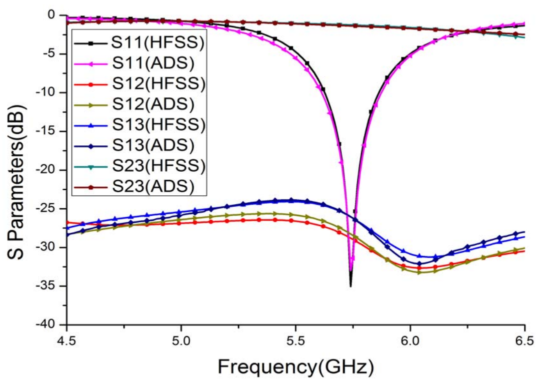

Fig.4. Comparison of EM and circuit model simulations

Figure 4 presents the comparison between the full wave simulated and equivalent circuit simulation on the basis of the S-parameters of the structure given in Fig. 1. It can be seen that the agreement of the circuit simulation and the EM simulation is acceptable, and the excellent agreement also validates the accuracy of the equivalent circuit model.

V. Conclusion

In this paper, a DMS is used to realize the crosstalk reduction between the closely spaced patch antenna and a 50-Ω microstrip transmission line. The equivalent circuit model of the proposed structure is extracted and is investigated by using the ADS. The performance of the decoupling is studied by using the HFSS and ADS to verify the effectiveness of the decoupling and to validate the correctness of the proposed equivalent circuit model.

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References

[1] T. Jiang, T. Jiao, Y. Li. “Array coupling reduction using L-Loading E-shaped electromagnrtic band gap structure”. International Journal of Antennas and Propagation, 2016.

[2] G. Yan, Z. Du, K. Hong, “Altered phase velocity lines for low crosstalk microstrip interconnection of high-speed digital circuits: design and experimental validation”. IEEE Transactions on Electromagnetic Compatibility, 2006, vol. 48, pp. 95-103.

[3] M. Kazerooni M, M. A. Salari, A. Cheldavi, “A novel method for crosstalk reduction in coupled pair microstrip lines”. International Journal of RF and Microwave Computer-Aided Engineering, 2012, vol.22, pp. 167–174.

[4] T. Jiang, Y. Wang, Y. Li, “Design and analysis of a triple stop-band filter using ratioed periodical defected microstrip structure”. Frequenz, 2017, vol.71, pp. 341-347.

[5] Y. Wang,T. Jiang, Y. Li, "Equivalent circuit model of a triple frequency rejection band UWB antenna." Applied Computational Electromagnetics Society Symposium - Italy IEEE, 2017.

[6] Y. Li, W. Li, Q. Ye, A reconfigurable triple notch band antenna integrated with defected microstrip structure band-stop filter for ultra-wideband cognitive radio applications, International Journal of Antennas and Propagation, vol.2013, Article ID: 472645, pp.1-13.

[6] K. Chang, “Microstrip Filters for RF/Microwave Applications”. John Wiley & Sons, Inc, 2001.

[7] Chaudhary, Girdhari, et al. "Analysis and circuit modeling method for defected microstrip structure in planar transmission lines." Microwave Conference Proceedings IEEE, 2012, pp. 999-1002.