Mutual Coupling Characterization of Ultra-Wideband U-Slot Microstrip Patch Array Antennas

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Abstract **─** Ultra-wideband (UWB) phased arrays are increasingly used in radar and medical applications. Mutual coupling reduction between the phased array elements is critical in achieving good scan bandwidth. This study investigates the mutual coupling of a UWB U-slot microstrip patch 2-element array to find the patch orientation and U-slot topology with the least mutual coupling. Electromagnetic (EM) simulation results indicate that, for $\varepsilon_r = 2.2$ substrate, diamond patch orientation with opposite U-slot topology has the least coupling between the array elements. Results also indicate that the current density distribution on the microstrip patch has an effect on mutual coupling between the array elements. Results show good agreement between MoM and FEM EM solvers.

Index Terms **─** Arrays, FEM, L-probe, microstrip, MoM, mutual coupling, U-slot, UWB.

I. INTRODUCTION

UWB scanning phased arrays are finding increasing use in wireless communication and medical applications [1, 2]. Scan blindness due to surface wave excitations could reduce the scan bandwidth range [3]. By reducing the mutual coupling between array elements, the scan blindness effects will be reduced [3]. In this study, the mutual coupling of a UWB U-slot microstrip patch 2-element array is investigated to find the patch orientation and U-slot topology with the least mutual coupling.

U-slot patch antennas are a class of UWB microstrip patch antennas. Several feeding structure designs for the U-slot patch antenna are proposed in the literature [4, 5]. The L-shaped probe feeding structure has led to further improved impedance bandwidth for the U-slot patch antenna [5]. Moreover, its simple structure and low material and production cost [5] make it an attractive feeding method for the U-slot microstrip patch antenna.

Previous work [6, 7] analyzed the mutual coupling between the U-slot microstrip array elements using the vertical probe feeding structure. The study in [8] aimed to characterize the mutual coupling of a U-slot microstrip 2-element array for the L-probe feeding structure compared to the vertical probe feeding structure using different U-slot topologies for $\varepsilon_r = 2.2$ substrate. This paper aims to extend this study by characterizing the mutual coupling of an L-probe-fed U-slot microstrip 2-element array using different patch orientations and U-slot topologies for $\varepsilon_r = 2.2$ substrate.

II. DESCRIPTION OF MODEL

The U-slot microstrip patch antenna array is simulated and analyzed using the Method of Moments (MoM) solver in the commercially available EM simulation package, FEKO. The FEKO MoM results are validated by another EM simulation package, HFSS, which is based on the Finite Element Method (FEM).

The simulated U-slot microstrip patch antenna geometry is shown in Fig. 1. The RT/Duroid 5880 substrate material with $\varepsilon_r = 2.2$ and $\tan(\delta) = 0.0009$ is used. The method of dimensional invariance described in [9] is used to realize the U-slot antenna patch dimensions, shown in Table 1, for a 2.4 GHz design frequency. Experimental validation of the method of dimensional invariance is reported in earlier work [7].

Several simulation optimization runs were performed to arrive at the substrate height and probe position which yield best bandwidth. In FEKO, infinite substrate and ground is assumed. In HFSS, the substrate and ground (W_g and L_g) dimensions are extended by $\lambda/2$, where λ corresponds to lower bandwidth frequency, from the edge of the patch to simulate an infinite substrate and ground. In HFSS, a radiation air box boundary which is $\lambda/2$, where λ corresponds to the lower bandwidth frequency, above the patch is used. A 50-ohm coaxial feed line is used to feed the L-probe. The different 2-element patch orientations and U-slot topologies simulated are shown in Fig. 2. The inter-element spacing between the patch edges is taken to be approximately $\lambda/4$. For the diamond patch orientations,

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the patches are rotated by 45°.

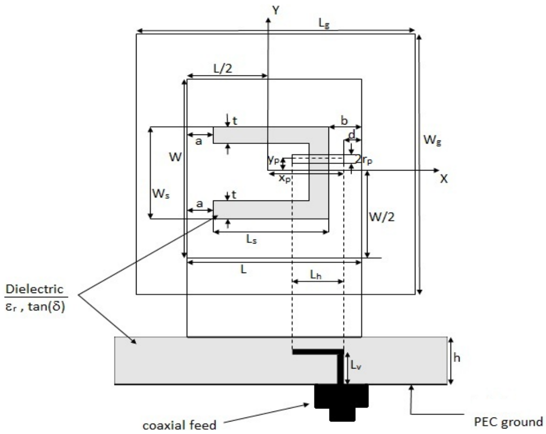
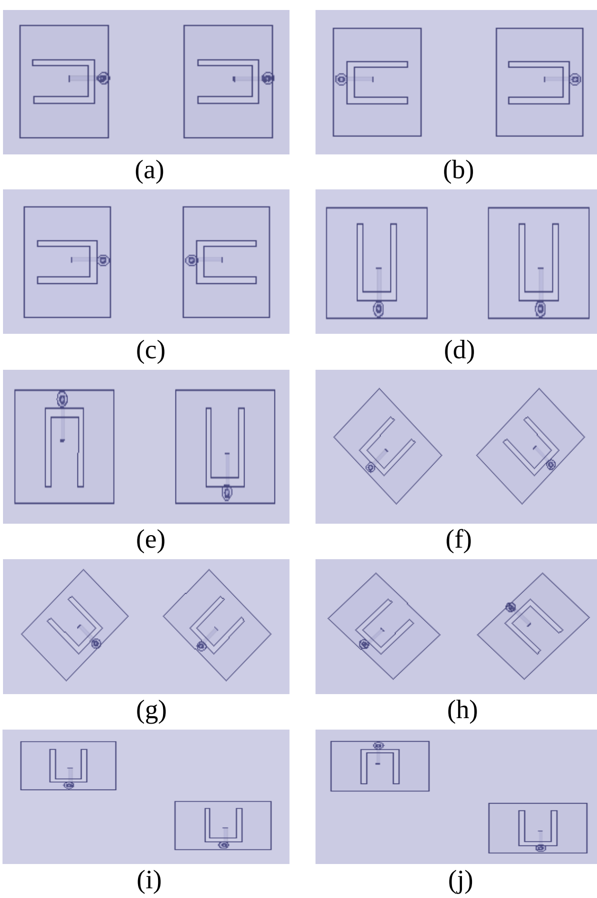
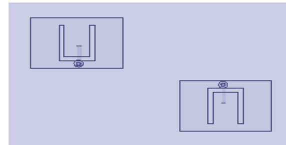


Fig. 1. Geometry of L-shaped, probe-fed, rectangular, U-slot, patch microstrip antenna.

Table 1: U-slot microstrip patch antenna dimensions

a	5.17 mm	W_s	18.09 mm	d	3 mm
b	5.17 mm	r_p	1 mm	h	14 mm
W	46.53 mm	x_p	13.8 mm	L_v	10 mm
L	33.6 mm	y_p	-1 mm	L_h	12 mm
t	2.6 mm				





(k)

Fig. 2. Variations of U-slot topologies and patch orientations in a 2-element array: (a-c) E-plane patch orientation, (d-e) H-plane patch orientation, (f-h) diamond patch orientation, and (i-k) Diagonal patch orientation.

III. RESULTS AND DISCUSSION

In [10], the bandwidth for a single-element L-probe-fed U-slot microstrip patch antenna with $\varepsilon_r = 2.2$ substrate was found to be between 1.8 GHz and 3 GHz. Figure 3 shows the E-plane coupling between two L-probe-fed U-slot patch elements for 3 different U-slot topologies over the 2-3 GHz bandwidth. HFSS and FEKO simulation results indicate that topology (a) has the lowest mutual coupling in the 20-27 dB range, and topology (c) has the highest mutual coupling. Figure 4 shows the H-plane coupling between two L-probe-fed U-slot patch elements for 2 different U-slot topologies. Results indicate that topology (e) has the lowest mutual coupling in the 20-25 dB range. Figure 5 shows the diamond patch orientation coupling between two L-probe-fed U-slot patch elements for 3 different U-slot topologies. Results indicate that the opposite U-slot topology (h) has the lowest mutual coupling in the 25-45 dB range, and topology (g) has the highest mutual coupling. Figure 6 shows the diagonal patch orientation coupling between two L-probe-fed U-slot patch elements for 3 different U-slot topologies. Results indicate that no particular topology has the highest or lowest mutual coupling throughout the entire bandwidth; however, topology (j) has the lowest mutual coupling in half of the bandwidth in the 20-40 dB range. In Figs. 3-6, HFSS and FEKO results show good agreement.

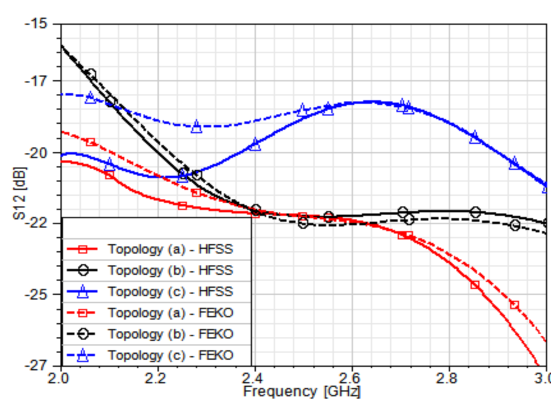


Fig. 3. E-plane patch orientation coupling for different U-slot topologies.

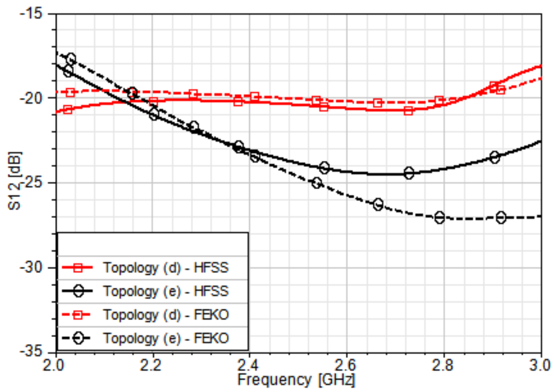


Fig. 4. H-plane patch orientation coupling for different U-slot topologies.

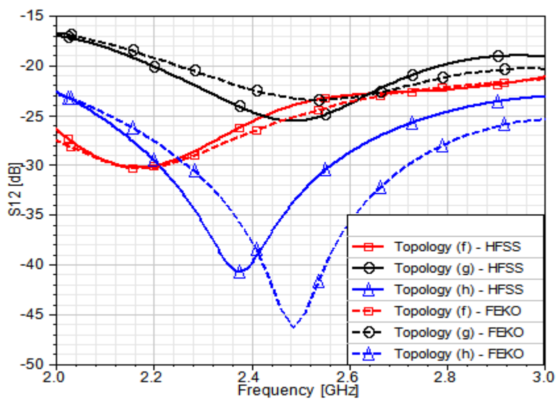


Fig. 5. Diamond patch orientation coupling for different U-slot topologies.

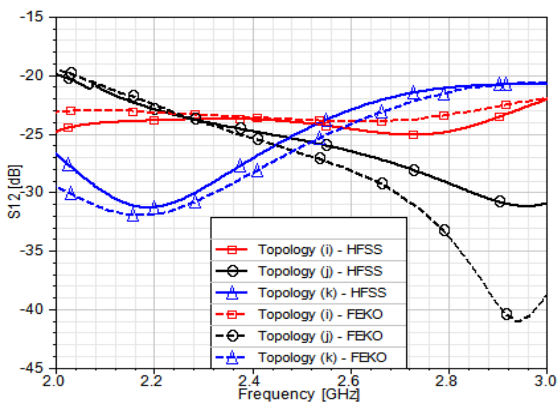


Fig. 6. Diagonal patch orientation coupling for different U-slot topologies.

Figures 7 and 8 show the current density distribution at 2.4 GHz for the U-slot topology, (h) with the least mutual coupling and the U-slot topology (c) with the highest mutual coupling, respectively. As seen in both figures more current density is concentrated around the base side of the U-slot, underneath which the L-probe feed is located. In Fig. 7, the two U-slot bases are farther apart from each other than in Fig. 8. This explains the lower mutual coupling in U-slot topology (h). Similarly, it is observed in the H-plane patch orientation that the U-slot topology (e) has less mutual coupling than U-slot topology (d) mainly because the U-slot base sides, where more current density is present, are farther apart in the case of U-slot topology (e). Also, in the diamond patch orientation, the U-slot topology (g) has the highest mutual coupling because the two U-slot base sides are closest to each other.

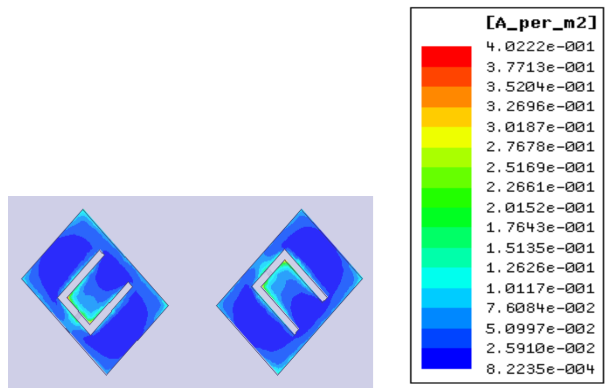


Fig. 7. Current density distribution in Diamond patch orientation for U-slot topology (h) at 2.4 GHz.

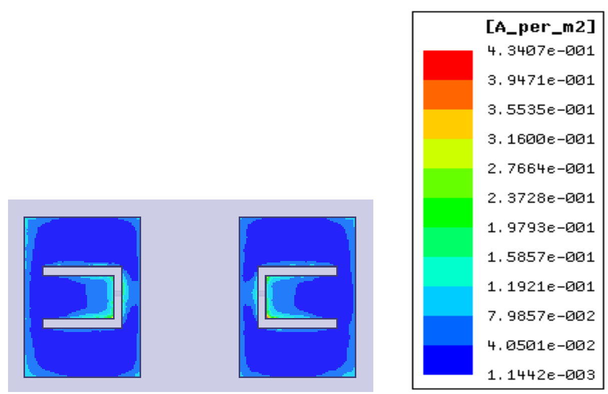


Fig. 8. Current density distribution in E-plane patch orientation for U-slot topology (c) at 2.4 GHz.

IV. CONCLUSION

In this paper, the evaluation of the mutual coupling of an L-probe-fed U-slot microstrip patch 2-element array using different patch orientations and U-slot topologies for $\varepsilon_r = 2.2$ substrate is presented. HFSS and FEKO simulation results show good agreement and indicate that the current density distribution on the microstrip patch has an effect on mutual coupling between the array elements. Results also indicate that the diamond patch orientation with opposite U-slot topology has the least coupling between the array elements. Future work will examine the scan bandwidth of such patch orientation and U-slot topology in a planar array. Also, the same study will be performed for higher substrate permittivities.

REFERENCES

[1] P. T. Nguyen, A. Abbosh, and S. Crozier, "Microwave hyperthermia for breast cancer treatment using electromagnetic and thermal focusing tested on realistic breast models and antenna arrays," *IEEE Transactions on Antennas and Propagation*, vol. 63, no. 10, pp. 4426-4434, October 2015.

[2] T. Lambard, O. Lafond, M. Himdi, H. Jeuland, S. Bolioli, and L. Le Coq, "Ka-band phased array antenna for high-data-rate SATCOM," *IEEE Antennas and Wireless Propagation Letters*, vol. 11, pp. 256-259, 2012.

[3] W. L. Stutzman and G. A. Thiele, *Antenna Theory and Design*, 3rd Edition, Wiley, New York, pp. 319, 2012.

[4] K. F. Lee, S. L. S. Yang, A. A. Kishk, and K. M. Luk, "The versatile U-slot patch antenna," *IEEE Antennas and Propagation Magazine*, vol. 52, no. 1, pp. 71-88, February 2010.

[5] K. M. Luk, K. F. Lee, and H. W. Lai, "Development of wideband L-Probe couple patch antenna," *Applied Computational Electromagnetics Society (ACES) Journal*, vol. 22, no. 1, pp. 88-96, March 2007.

[6] D. Chatterjee, "Numerical modeling of scan behavior of finite planar arrays of wideband U-slot and rectangular microstrip patch elements," *Proceedings of IEEE International Symposium on Phased Array Systems and Technology*, Boston, MA, pp. 323-328, October 14-17, 2003.

[7] R. D. Hofer, D. E. Oliver, and D. Chatterjee, "Analysis of U-slot, microstrip phased array radiator elements on electrically thick substrates," *IEEE Antennas and Propagation Society International Symposium*, Honolulu, HI, pp. 3648-3651, June 9-15, 2007.

[8] M. M. Elsewe, V. K. Dandu, and D. Chatterjee, "Assessment of computational fidelity of MoM and FEM solvers for characterizing a class of UWB microstrip antennas: 2-element case," *29th Annual Review of Progress in Applied Computational Electromagnetics*, Monterey, CA, pp. 399-404, March 24-28, 2013.

[9] V. Natarajan and D. Chatterjee, "An empirical approach for design of wideband, probe-fed, U-slot microstrip patch antennas on single-layer, infinite, grounded substrates," *Applied Computational Electromagnetics Society (ACES) Journal*, vol. 18, no. 3, pp. 191-201, November 2003.

[10] M. M. Elsewe, V. K. Dandu, and D. Chatterjee, "Ultra-wideband low profile, U-slot microstrip patch antennas: L-probe feed design guidelines," *Applied Computational Electromagnetics Society (ACES) Journal*, submitted October 2015.