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# Mutual Coupling Reduction Using F-Shaped Stubs in UWB-MIMO Antenna

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**ABSTRACT** A compact, high performance, and novel-shaped ultra-wideband (UWB) multiple-input multiple-output (MIMO) antenna with low mutual coupling is presented in this paper. The proposed antenna consists of two radiating elements with shared ground plane having an area of $50 \times 30$ mm$^2$. F-shaped stubs are introduced in the shared ground plane of the proposed antenna to produce high isolation between the MIMO antenna elements. The designed MIMO antenna has very low mutual coupling of ($S_{21} < -20$ dB), low envelop correlation coefficient (ECC $< 0.04$), high diversity gain (DG $> 7.4$ dB), high multiplexing efficiency ($\eta_{\text{Mux}} > -3.5$), and high peak gain over the entire UWB frequencies. The antenna performance is studied in terms of S-Parameters, radiation properties, peak gain, diversity gain, envelop correlation coefficient, and multiplexing efficiency. A good agreement between the simulated and measured results is observed.

**INDEX TERMS** MIMO antenna, diversity gain, multiplexing efficiency, microstrip patch.

## I. INTRODUCTION

In the near past, UWB technology has gotten much more attention for use in modern wireless and mobile communication systems due to its high data rates and low fabrication cost. Reflection and diffraction is always associated with dense medium which cause multipath fading problem in conventional UWB technology. MIMO technology has been proposed to ease the problem of multipath fading and to increase transmission quality in communication system [1].

A MIMO antenna consists of at least two radiating elements, placed at certain distance to have high isolation between them, but the available space is very limited in the modern portable wireless front-ends. Various techniques have been proposed for UWB-MIMO antenna for diversity application [2]–[6]. Mutual coupling between the perpendicularly placed antennas is reduced using L-shaped slots in the radiators and narrow slot in the ground plane [2]. Isolation between the MIMO elements is created by inserting a rectangular stub diagonally between the radiating elements [3]. Mutual coupling of perpendicularly placed radiators has been reduced using stubs on the ground plane with a compact size antenna in [4]. High isolation is achieved in [5] by using stubs on the ground plane and T-shaped slot in a co-shared radiator. Mutual coupling is reduced by introducing a rectangular stub in between the two radiators [6]. High isolation is obtained by using neutralization line in [7]. Other methods to increase isolation between the radiators is to introduce a reflector of T-shape [8], meandered line resonator in [9], different elements for polarisation diversity in [10], using electromagnetic band gap structures [11], defective ground structure [12] and a perpendicular feeding network in [13]. In [14], parasitic fragment-type element can be used to produce good isolation between the MIMO antenna elements. In [15], a compact MIMO antenna of two elements with high isolation is designed using electric-LC resonator. In [16], CSRR and stubs are used for mutual coupling reduction and miniaturization. Mutual coupling between wrench MIMO antennas is reduced by introducing a Y-shaped stub followed by a rectangular slot in the middle of the ground plane [17]. A MIMO antennas with a tree-shaped structure has isolation >16 dB over the UWB band [18]. However, all these structures have large dimensions, and some of the structures with isolation >20 dB employ split ground. There is always tradeoff between the operating bandwidth, size of antenna, and complexity in all of these proposed techniques.

A compact UWB-MIMO antenna is presented in this paper having very low mutual coupling ($|S21/S12| < -20$dB) between the MIMO radiating elements. The presented UWB-MIMO antenna consists of two monopoles fed by microstrip lines. F-shaped stubs are introduced in the ground plane to produce multiple resonance and high isolation between the radiating elements. Good agreement between the simulated and measured results is observed, showing that the designed antenna is best candidate for the modern portable wireless front-ends because of its low ECC, high diversity gain, high peak gain and most importantly very low mutual coupling between the radiating elements.

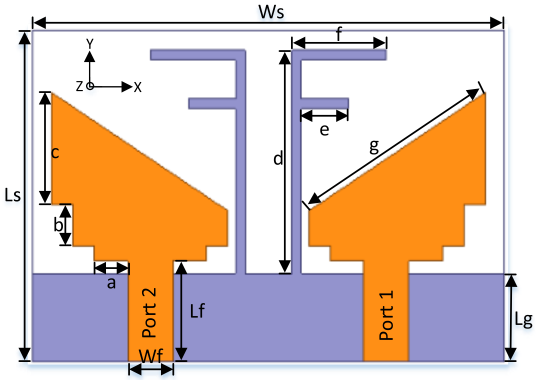


**FIGURE 1.** Top view of the proposed UWB MIMO Antenna.

## II. ANTENNA CHARACTERIZATION

The geometry and configuration of the proposed UWB-MIMO antenna is given in Fig. 1. The antenna is designed on commercially available substrate of FR-4 having dielectric constant $\varepsilon r = 4.4$ and height $hs = 1.6$ mm. The width of the feed line for both monopole is chosen as 3 mm to have line characteristic impedance of 50 Ω. The two radiating elements and the feed line are designed on the top of the substrate and the ground plane is designed on the bottom of the substrate. The upper patch is cut by triangular shape and place side by side to achieve wide band matching and good element spacing. Initially a lowered edge stepped cut rectangular shaped UWB patch radiator was designed [19], then modified to triangular shape with two step cut in the lower edge of the radiator to achieve a wide-band matching. The proposed design is somewhat similar to [16] in which two inverted L-shaped stubs were used to achieve miniaturization and CSRR were used to achieve isolation between the monopoles. However the proposed design is only concern with the isolation of the monopoles, further the proposed antenna also provide diversity gain, multiplexing efficiency which are the important parameters for any diversity antenna.

Table 1 tabulates the optimized parameters of the designed UWB-MIMO Antenna.

A second monopole of the same shape is placed near to it as shown in Fig. 1 having shared ground plane. Greater space for better isolation between the antenna elements is achieved by using triangular shaped monopoles instead of conventional rectangular radiators. Each of the antenna element of MIMO system is fed with 50 Ω microstrip feed line to have perfect impedance matching.

**TABLE 1.** Dimensions of optimized parameters of the proposed UWB-MIMO antenna.

| Parameters | Dimension (mm) | Parameters | Dimension (mm) |
|---|---|---|---|
| a | 3.54 | G | 22.3 |
| b | 4.31 | Wf | 3 |
| c | 11.46 | Lf | 10.3 |
| d | 23 | Lg | 9 |
| e | 5 | Ls | 30 |
| f | 10 | Ws | 50 |

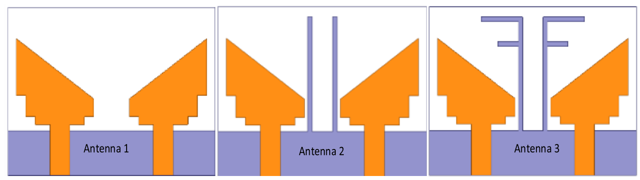


**FIGURE 2.** Geometry of the proposed UWB-MIMO antenna with modifications in ground plane.

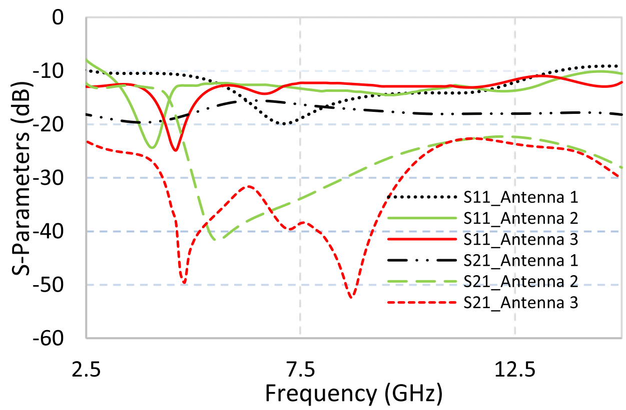


**FIGURE 3.** Simulated S-Parameters, to illustrate the effect of change in ground plane.

Fig. 2 shows the design evolution stages of the ground plane of the presented antenna. In the first stage a simple triangular shaped radiator were designed and tested for the desired results (Antenna 1), then it is modified by adding I-shaped stubs in the ground plane (Antenna 2). I-shaped stubs were further modified to F-shaped stubs for better MIMO performance (Antenna 3). Fig. 3 shows simulated reflection coefficient (S11) and transmission coefficient (S21) of the proposed antenna for simple ground plane, ground plane with I-shaped stubs and ground plane with F-shaped stubs. It is worth noticing that low mutual coupling is always desirable for high performance MIMO antennas. It can be seen that antenna 1 has poor isolation in the whole UWB range when the conventional ground plane is used. Mutual coupling between the proposed antennas is reduced by modifying the ground plane. High isolation between the MIMO antenna elements is achieved by printing I-shaped stubs on the plane. The stub used in the designing of antenna 2 is modified further to F-shape to further increase isolation between the MIMO antennas as obvious from Fig. 3. Antenna properties is highly effected by the position of the F-shaped stub. The Two F-shaped stubs are used in the designed antenna for two purposes. First, they reduce the mutual coupling between the monopoles by acting as reflector to separate the radiation of the monopoles as shown in the Fig. 3. Fig. 3 shows that more than 20 dB of isolation is produced by inserting F-shaped stubs. Secondly, they also act as radiator to produce two resonances at 4.6 and 6.8 GHz as shown in the Fig. 3. The resonance can be further increased by introducing multiple subs at different locations.

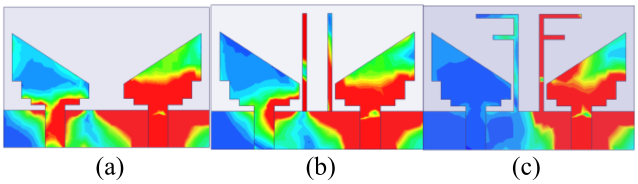


**FIGURE 4.** Surface current distribution for (a) conventional ground (b) I-shaped stub ground (c) F-shaped stub ground.

The performance of the proposed UWB-MIMO antenna is further analyzed by plotting surface current distribution with modified ground planes (introduction of different stubs) at 7.1 GHz. Surface current distribution of the proposed antenna is shown in Fig. 4. When port 1 is excited, high mutual coupling is achieved between the monopoles as current is highly coupled with other radiator as shown in Fig. 4(a). Mutual coupling is reduced by introduction of straight stub in the ground plane but still much current is coupled with the second radiator as shown in Fig. 4(b) and the performance of the MIMO antenna was unsatisfactory. F-shaped stub is placed on the ground plane to further increase the isolation between MIMO antenna elements. As shown in the Fig. 4(c) that by introduction of F-shaped stubs, very less current is coupled with the other radiator and hence greater isolation between the antennas is achieved.

Table 2 compares the performance of the proposed antenna with the other antennas used previously in the literature.

**TABLE 2.** Performance comparison with previously published work.

| Literature | Size (mm$^2$) | Bandwidth (GHz) | Isolation (dB) | ECC | Diversity Gain (dB) |
|---|---|---|---|---|---|
| Ref. [1] | 37×45 | 3.1-5 | >15 | <0.5 | NA |
| Ref. [2] | 32×32 | 3.1-10.6 | >15 | 0.04 | NA |
| Ref. [4] | 26×40 | 2.1-10.6 | >15 | 0.20 | NA |
| Ref. [10] | 25×40 | 3-10.6 | >15 | NA | NA |
| Proposed work | 50×30 | 2.5-14.5 | >20 | <0.04 | >7.4 |

## III. RESULTS AND DISCUSSIONS

The antenna is designed on commercially available substrate of FR-4 having dielectric constant $\varepsilon\_r = 4.4$ and height hs = 1.6 mm. High Frequency Structure Simulator (HFSS) is used for simulation and optimization of the proposed antenna.

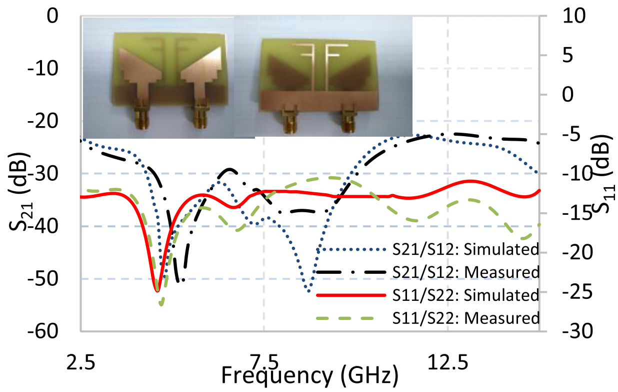


**FIGURE 5.** S-Parameters of the designed UWB-MIMO antenna.

### A. RETURN LOSS

Fig. 5 shows the simulated and measured S-Parameters for the designed UWB-MIMO antenna. The S-Parameters of the fabricated antenna (Fig. 5) is measured using Agilent Network Analyzer (VNA) in open air conditions and the results matched well with the simulated results. The designed antenna covers 2.5 GHz to 14.5 GHz bandwidth with $S_{11}/S_{22} < -10$ dB and $S_{21}/S_{12} < -20$ dB. One resonance in the $S_{11}$ curve is due to the main radiator and the second resonance is achieved by the introduction of the F-shaped stubs.

### B. RADIATION PATTERN AND GAIN

The measured and simulated results are compared in Fig. 6. A good agreement between simulated and measured results has been observed. For pattern measurement, the proposed antenna is fixed on turntable.

The fabricated antenna was tested in Anechoic Chamber to measure its radiation properties. It was observed that $\theta$-component was dominant in yz-plane while Ø-component was dominant in xz-plane. Ø-component in xz-plane as well as in yz-plane has omnidirectional pattern at lower frequencies while this pattern slightly change its shape for higher frequencies in both planes. The $\theta$-component of the electric field in xz-plane as well as in yz-plane has toroidal shape at lower frequencies while the shape slightly changes at higher frequencies.

Simulated peak gain of the proposed antenna is shown in Fig. 7. Peak gain of the proposed antenna varies from 0.3 dB to 4.3 dB, changing linearly for the entire range of UWB.

### C. DIVERSITY ANALYSIS

To validate the capability and performance of the proposed UWB-MIMO antenna, it is necessary to have low envelop correlation coefficient (ECC). The ECC can be evaluated

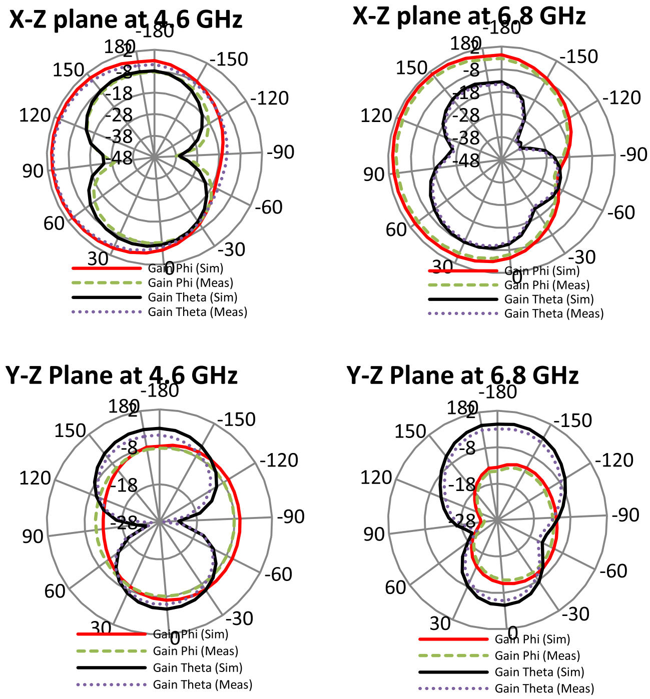


**FIGURE 6.** Simulated and measured radiation pattern at 4.6 and 6.8 GHz.

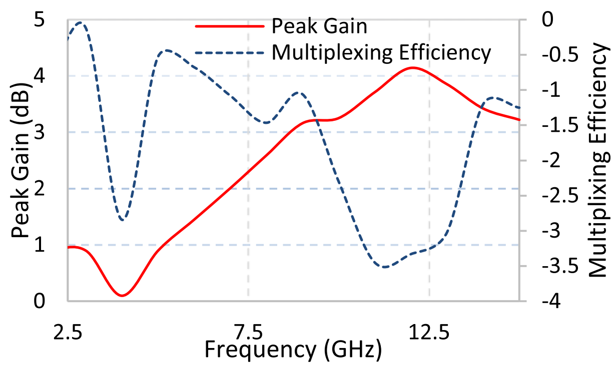


**FIGURE 7.** Peak Gain and Multiplexing Efficiency of the proposed antenna.

using S-parameters by the following relation [20].

$$ECC = \frac{|S_{11}^{*}S_{12} + S_{21}^{*}S_{22}|^2}{(1 - |S_{11}|^2 - |S_{21}|^2)(1 - |S_{22}|^2 - |S_{12}|^2)} \quad (1)$$

ECC should have ideally zero value but practical limit for an uncorrelated MIMO antenna is ECC < 0.5. The ECC of the proposed antenna has ECC less than 0.04. Fig. 8 shows the ECC of the proposed UWB-MIMO antenna. It can be noticed from the Fig. 8 that the proposed antenna has ECC < 0.04 for the entire UWB range.

Another important parameter for MIMO antenna performance is its diversity gain (DG). The diversity gain of the MIMO antenna can be calculated using the following relation.

$$DG = 10\sqrt{1 - (ECC)^2} \quad (2)$$

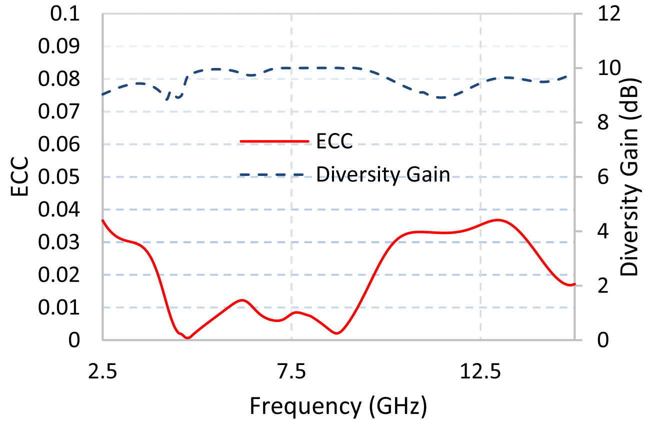


**FIGURE 8.** ECC and Diversity Gain of the proposed antenna.

Where ECC is the envelop correlation coefficient. Fig. 8 shows the DG with varying frequencies. It is noted from that the proposed antenna has diversity gain (DG > 7.4 dB) for the entire UWB range.

Fig. 7 shows the multiplexing efficiency with varying frequencies. Multiplexing efficiency ($\eta_{Mux}$) is calculated by the following relation [21].

$$\eta_{Mux} = \sqrt{(1 - |\rho_c|^2)\eta_1\eta_2} \quad (3)$$

Where $\rho_c$ is the complex correlation coefficient between the radiating elements, $ECC \approx |\rho_c|^2$ and $\eta_i$ is the total efficiency of the *ith* antenna radiator. Here we used i = 1,2 as we have two element MIMO system.

## IV. CONCLUSION

A compact two element MIMO antenna with shared ground plane for UWB applications has been proposed in this paper. The proposed antenna has simple structure and compact size of $50 \times 30$ mm$^2$. High isolation between the MIMO elements is achieved by introducing F-shaped stub in the ground plane of the MIMO antenna. Simulated results for Envelop Correlation Coefficient (ECC < 0.04), Diversity gain (DG > 7.4 dB) and Multiplexing efficiency shows that the antenna is good candidate for UWB-MIMO system.

## REFERENCES

[1] T. S. P. See and Z. N. Chen, "An ultrawideband diversity antenna," *IEEE Trans. Antennas Propag.*, vol. 57, no. 9, pp. 1597–1605, Jun. 2009.
[2] J. Ren, W. Hu, Y. Yin, and R. Fan, "Compact printed MIMO antenna for UWB applications," *IEEE Antenna Wireless propag. Lett.*, vol. 13, pp. 1517–1520, 2014.
[3] Y.-F. Liu, P. Wang, and H. Qin, "Compact ACS-fed UWB antenna for diversity applications," *IET Electron. Lett.*, vol. 50, no. 19, pp. 1336–1338, Sep. 2014.
[4] L. Liu, S. W. Cheung, and T. I. Yuk, "Compact MIMO antenna for portable devices in UWB applications," *IEEE Trans. Antennas Propag.*, vol. 61, no. 8, pp. 4257–4264, Aug. 2013.
[5] C.-X. Mao and Q.-X. Chu, "Compact coradiator UWB-MIMO antenna with dual polarization," *IEEE Trans. Antennas Propag.*, vol. 62, no. 9, pp. 4474–4480, Sep. 2014.
[6] P. Gao, S. He, X. Wei, N. Wang, Z. Xu, and Y. Zheng, "Compact printed UWB diversity slot antenna with 5.5-GHz band-notched characteristics," *IEEE Antennas Wireless Propag. Lett.*, vol. 13, pp. 376–379, 2014.

[7] S.-W. Su, C.-T. Lee, and F.-S. Chang, "Printed MIMO-antenna system using neutralization-line technique for wireless USB-dongle applications," *IEEE Trans. Antennas Propag.*, vol. 60, no. 2, pp. 456–463, Feb. 2012.

[8] A. D. Capobianco, M. S. Khan, M. Caruso, and A. Bevilacqua, "3–18 GHz compact planar antenna for short-range radar imaging," *IET Electron. Lett.*, vol. 50, no. 14, pp. 1016–1018, Jul. 2014.

[9] J. Ghosh, S. Ghosal, D. Mitra, and S. R. B. Chaudhuri, "Mutual coupling reduction between closely placed microstrip patch antenna using meander line resonator," *Prog. Electromagn. Res. Lett.*, vol. 59, pp. 115–122, Apr. 2016.

[10] S. Zhang, B. K. Lau, A. Sunesson, and S. He, "Closely-packed UWB MIMO/diversity antenna with different patterns and polarizations for USB dongle applications," *IEEE Trans. Antennas Propag.*, vol. 60, no. 9, pp. 4372–4380, Sep. 2012.

[11] A. Suntives and R. Abhari, "Miniaturization and isolation improvement of a multiple-patch antenna system using electromagnetic bandgap structures," *Microw. Opt. Technol. Lett.*, vol. 55, no. 7, pp. 1609–1612, 2013.

[12] F.-G. Zhu, J.-D. Xu, and Q. Xu, "Reduction of mutual coupling between closely-packed antenna elements using defected ground structure," *Electron. Lett.*, vol. 45, no. 12, pp. 601–602, Jun. 2012.

[13] G. Adamiuk, S. Beer, W. Wiesbeck, and T. Zwick, "Dual-orthogonal polarized antenna for UWB-IR technology," *IEEE Antennas Wireless Propag. Lett.*, vol. 8, pp. 981–984, 2009.

[14] L. Wang, G. Wang, and Q. Zhao, "Suppressing mutual coupling of MIMO antennas with parasitic fragment-type elements," in *Proc. IEEE 46th Eur. Microw. Conf. (EuMC)*, Oct. 2016, pp. 1303–1306.

[15] S. Pandit, A. Mohan, and P. Ray, "A compact planar MIMO monopole antenna with reduced mutual coupling for WLAN applications using ELC resonator," in *Proc. IEEE Microw. Conf. (APMC)*, Dec. 2016, pp. 1–4.

[16] M. S. Khan, A.-D. Capobianco, S. M. Asif, D. E. Anagnostou, R. M. Shubair, and B. D. Braaten, "A compact CSRR-enabled UWB diversity antenna," *IEEE Antennas Wireless Propag. Lett.*, vol. 16, pp. 808–812, 2017.

[17] A. K. Verma, R. Nakkeeran, and R. K. Vardhan, "Design of 2×2 single sided wrench shaped UWB MIMO antenna with high isolation," in *Proc. IEEE Int. Conf. Circuit, Power Comput. Technol. (ICCPCT)*, Mar. 2016, pp. 1–3.

[18] S. Zhang, Z. Ying, J. Xiong, and S. He, "Ultrawideband MIMO/diversity antennas with a tree-like structure to enhance wideband isolation," *IEEE Antennas Wireless Propag. Lett.*, vol. 8, pp. 1279–1282, 2009.

[19] A. Iqbal, O. A. Saraereh, and S. K. Jaiswal, "Maple leaf shaped UWB monopole antenna with dual band notch functionality," *Prog. Electromagn. Res. C*, vol. 71, pp. 169–175, Feb. 2017.

[20] S. Blanch, J. Romeu, and I. Corbella, "Exact representation of antenna system diversity performance from input parameter description," *Electron. Lett.*, vol. 39, no. 9, pp. 705–707, May 2003.

[21] R. Tian, B. K. Lau, and Z. Ying, "Multiplexing efficiency of MIMO antennas," *IEEE Antennas Wireless Propag. Lett.*, vol. 10, pp. 183–186, 2011.

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