A Four-Leaf Clover Shape MIMO Antenna for UWB Applications

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Abstract ─ This paper proposes a quad-element multiple-input multiple-output (MIMO) antenna for handheld wireless Ultra-wideband (UWB) devices, which has pocket dimensions of 40 mm × 40 mm. An elaborate tapered slot antenna fed by a gradient microstrip acts as the single radiation element. The slots evolved from exponential function are to achieve the UWB properties, and the four slots which aim to four directions constitute the four-leaf clover shape. The UWB antenna shows good impedance (S_{11} < -10 dB) match in a UWB band from 4 GHz to 13 GHz and performs high efficiency (above 80%) and high isolation (S_{21}, S_{31} < -20 dB). Realized gain is around 3 ~ 5 dB. The envelope correlation coefficient (ECC) is also investigated and it is within acceptance limits.

Index Terms ─ High isolation, multiple input multiple output (MIMO) antennas, slot antenna, Ultra-wideband (UWB).

I. INTRODUCTION

Ultra-wideband (UWB) technique provides some superiority such as high-speed data transmission, low cost and easily manufacture. However such a popular topic of technology suffers from multipath fading in the practical applications [1], [2]. Precisely, the multiple input multiple output (MIMO) technique was raised to resolve this issue, MIMO antennas are employed to enhance the channel capacity [2]. According to the requirement of the wireless communication, compact, wide operation band and high isolation MIMO antenna is an urgent demand in the mobile terminal and the portable applications [3], [4]. When the different antenna elements function in a cramped space, the inter-coupling between the antennas comes out to be intense and the MIMO antenna cannot achieve good impedance match and high isolation in a wide operating band under normal conditions [5], [6]. Several dual or quad elements UWB MIMO antennas are reported in recent years, plenty of methods are employed to eliminate coupling and enhance the isolation between the different elements [7], [8]. Some high isolation antennas were achieved by increasing the distance of the different antenna elements [9], and some others papers were to introduce the decoupling components such as parasitical slots or strips among the radiation elements or ground plane to achieve high isolation [10]-[13]. However, for most of compact devices where the space is very limited and they need the simplified structure for easier manufacture. Thus, establishing a compact and capable MIMO antenna in ultra-wideband with high isolation is still desired.

In this paper, an ultra-wideband quad-element MIMO antenna is proposed, realized demands mentioned above. The compact antenna possesses very high isolation while the four elements are distributed very close and without any decoupling component. Each element is transformed from tapered slot antenna thus the UWB properties are ensured. The feeding lines are optimized for the proper shape to actualize the radiation element has good impedance match in an ultra-wideband. The ingenious configuration of the radiation elements and feeding line increases the isolation of the proposed MIMO antenna significantly, and the envelope correlation coefficient (ECC) is also limited to the minimum.

II. ANTENNA DESIGN

The proposed quad-elements MIMO antenna is printed on Rogers RO4003 substrate with the thickness of 0.813 mm, dielectric constant of 3.38 and loss tangent of 0.0027. The structures of each layer are illustrated in Fig. 1. On the top of the substrate, the four tapered slot elements are arranged toward four different directions, at the back distributes four gradient feeding line and they vertical to the four slots respectively. Shorting vias connects the feeding line and the top metal layer. The slots are distributed vertically made the metal patch looks like a four-leaf clover.

The edge curves of the tapered slots are following the exponential function illustrated in Fig. 1 (a). Figure 2 shows the exponential functions with different bases

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lead to different S-parameter curves. The results are simulated by CST MICROWAVE STUDIO. To ensure the Ultra-wideband properties, we choose the base (a = 1.4) in our final scheme and the S_{11} is less than -10 dB from 4 ~ 15 GHz, as shown in Fig. 2 (b).

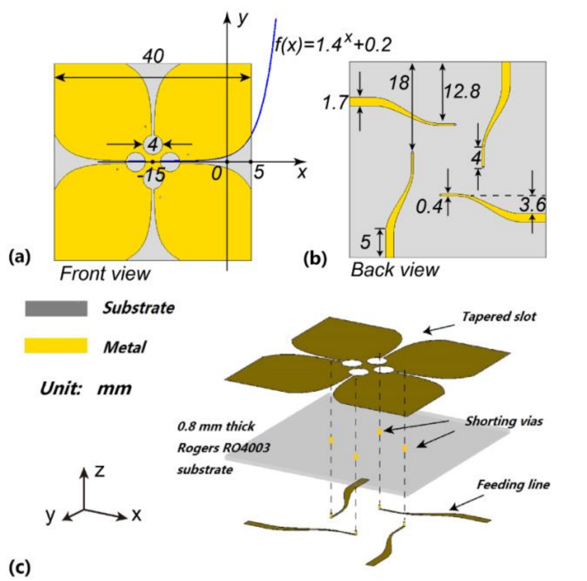

Fig. 1. The dimensions (a), (b) and analyze geometry (c) of the proposed four-leaf shape MIMO antenna.

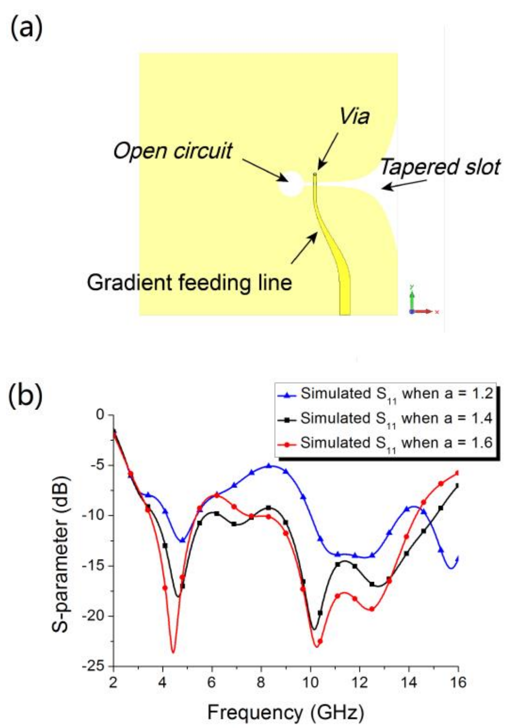

Fig. 2. The single radiation element (a), (b) is the simulated S_{11} with different bases of the exponential function.

For more compact dimensions, the shorting via and the ground are in different location at axis *X*, the feeding line must be curved and unequal in width to ensure the wide bandwidth. The gradient feeding line we adopted can contribute the realization of the slot antenna's UWB properties [14]. The S-parameter of feeding line with right angle, gradual change straightly, and gradient curve are illustrated in Figs. 3 (a), (b), and (c). From the figure, the third feed method shows more satisfactory impedance match from 4 ~ 14 GHz band than the others.

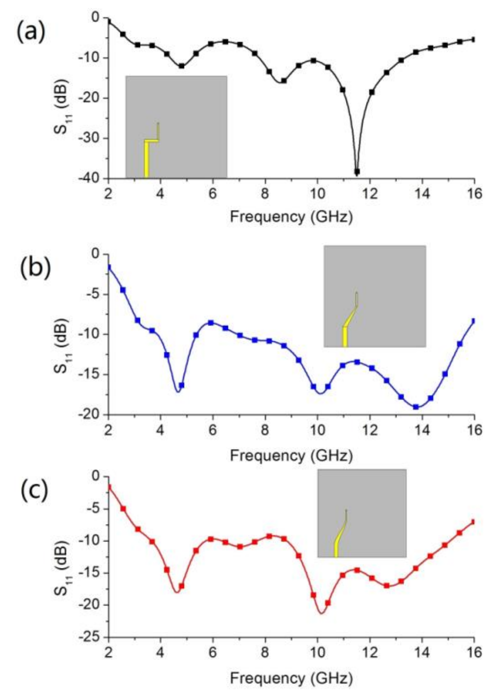

Fig. 3. The S-parameter from the single element with different feeding line.

III. RESULTS AND ANALYSES

A prototype is fabricated and measured to authenticate the characteristic of the proposed MIMO antenna. The prototype is shown in Fig. 4. The four leaves serve as the radiation element as well as the ground plane. Such a design can shrink the dimensions and make the antenna compact. Considering that the four elements of the four-leaf shape MIMO antenna are centro-symmetry and the results from all ports are similar, thus the port 1 results represent the single port results; the results from port 1 and 2 represent the dual-port results which are adjacent; the results from port 1 and 3 represent the dual-port results which are opposite.

The simulated and measured S-parameter of single and multiple ports are illustrated in Fig. 5. The measurement is performed on Agilent E8362B network analyzer. This figure shows that the measurements match well with the simulations, the S_{11} lower than -10 dB covers from 4 ~ 13 GHz (shown in Fig. 5 (a)). Meanwhile,

S_{21} and S_{31} are basically lower than -20 dB in this band (shown in Fig. 5 (b)). Thus, the proposed MIMO antenna can be sufficient to provide anticipated impedance match and slight inter-coupling for UWB MIMO devices.

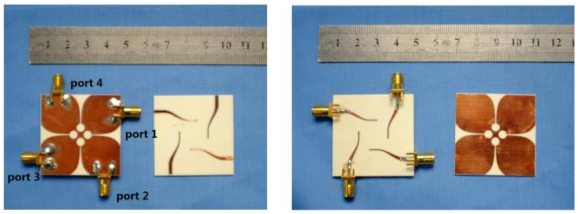

Fig. 4. Demonstration of the fabricated four-leaf shape MIMO antenna.

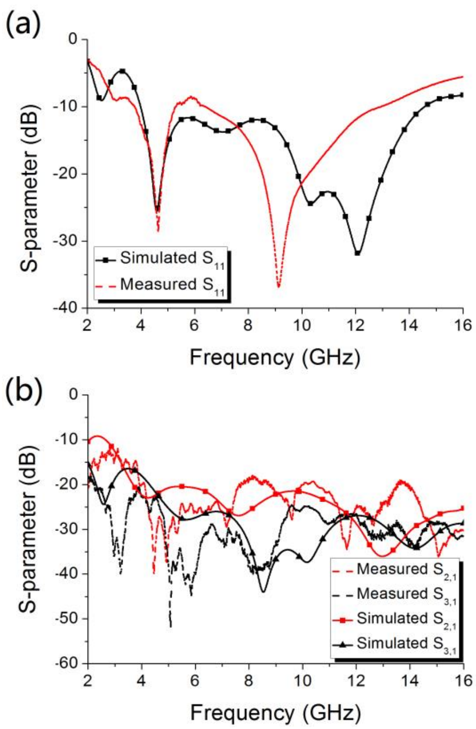

Fig. 5. Simulated and measured: (a) S_{11} and (b) S_{21}, S_{31} of the four-leaf shape MIMO antenna.

The surface current distributions for port 2 at the four frequencies are illustrated in Fig. 6. The currents mainly distribute at the edge of the tapered slot, and the gradient feeding line of the port 2. Even though the four elements are close, currents on the other elements are rarely founded, and that means very slight mutual coupling occurred between the different elements. The gain and efficiency is also simulated as the results shown in Fig. 7. The realized gain changes from 3 dB to 5 dB and the efficiency are above 80% through the entire band.

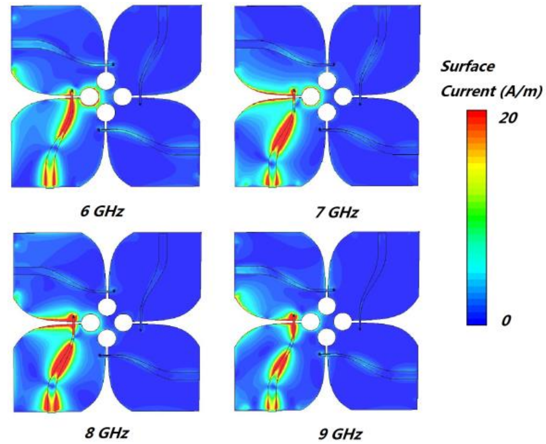

Fig. 6. Current distribution for port 2 in four different frequencies.

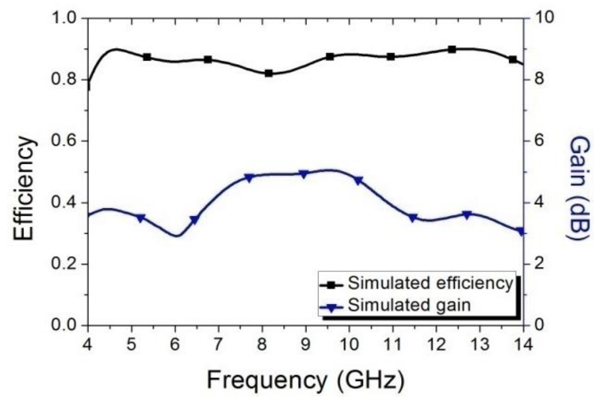

Fig. 7. Simulated gain and efficiency of the four-leaf shape MIMO antenna.

Since the back to back distribution of the four elements and the slots are toward four directions, the radiation patterns from the four elements are forced to radiate to four directions, as shown in Fig. 8. The ignorable overlaps from the four radiation patterns ensure the low correlation of the proposed MIMO antenna. The radiation patterns of the MIMO antenna at the three frequencies in *xoz*- and *xoy*-plane are measured and illustrated in Fig. 9. Since the high consistency of radiation patterns from the four ports, port 1 radiation patterns are measured as present. In the measurement, a broadband horn antenna (1 ~ 18 GHz) is employed as a receiving antenna, and the port 1 of the proposed MIMO antenna is used as transmitting antenna respectively. It can be seen that the radiation patterns of different frequencies are broadly the same and the patterns have directionality in *xoy*-plane, what suits well with the simulation results.

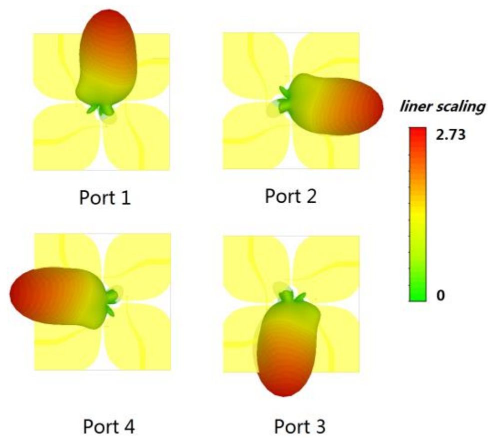

Fig. 8. Simulated 3-D radiation pattern of the four ports of the MIMO antenna at 7 GHz.

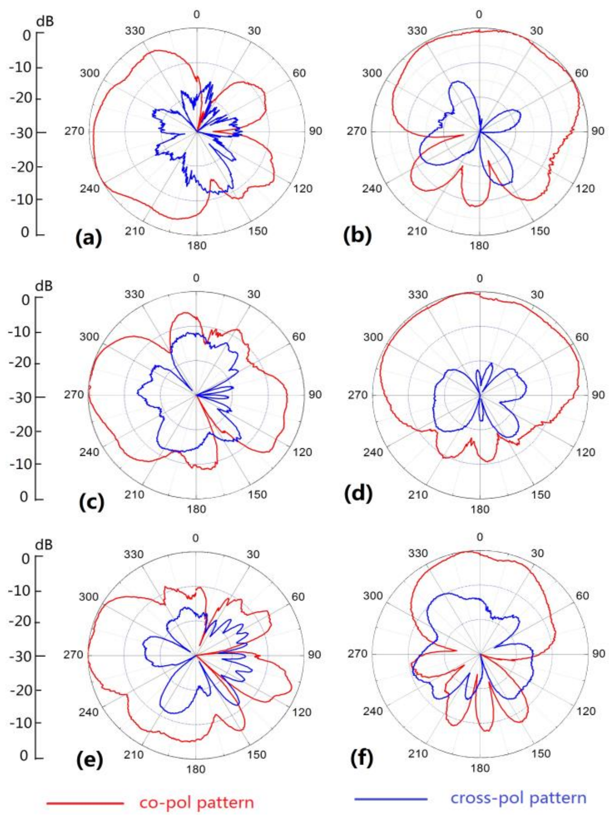

Fig. 9. Measured co-pol and cross-pol polarization of radiation pattern: (a) 6 GHz xoy-plane, (b) 6 GHz xoz-plane, (c) 7 GHz xoy-plane, (d) 7 GHz xoz-plane, (e) 9 GHz xoy-plane, and (f) 9 GHz xoz-plane.

The envelope correlation coefficient (ECC) is to judge multiple port performance of the MIMO antenna. The correlation among the embranchment signals received by different antennas is evaluated by this parameter, and lower ECC means more diversified patterns as a rule [15]. An acceptable standard for a desirable MIMO system is ECC < 0.5, and it could be calculated from the S-parameters and radiation efficiency of the MIMO antenna [16]:

$$\rho_{e,ij} = \frac{\left| S_{ii}^{*} S_{ij} + S_{ji}^{*} S_{jj} \right|^2}{\left(1 - \left|S_{ii}\right|^2 - \left|S_{ji}\right|^2\right)\left(1 - \left|S_{jj}\right|^2 - \left|S_{ij}\right|^2\right)\eta_{radi}\eta_{radj}} . \quad (1)$$

In which η_{radi} is the radiation efficiency of the port i radiation element. The simulated and measured ECC are illustrated in Fig. 10. The results of measurement agree well with the simulation and the values are below the 0.05 in the entire band. It verified the excellent properties of the proposed MIMO antenna. The comparison of the existing compact UWB MIMO antennas with the proposed four-leaf shape MIMO antenna is illustrated in Table 1. In comparison, the superiorities of this work are appeared both in size and isolation.

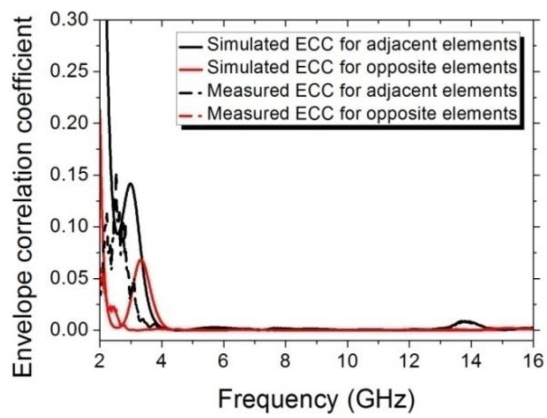

Fig. 10. Simulated and measured ECC of the four-leaf MIMO antenna.

Table 1: Comparison of compact UWB MIMO antennas

Ref.	Number of Ports	Planar Size (mm^2)	Bandwidth (%)	Isolation (dB)
[11]	4	40×40	60.6	-10
[13]	4	$\pi \times 80^2$	42.2	-15
[17]	2	26×26	109.5	-15
This work	4	40×40	105.6	-20

IV. CONCLUSION

An Ultra-wideband (UWB) quad-element MIMO antenna with a four-leaf clover shape is proposed hereof, which is adapted from planar tapered slot antenna. The edge curves following the exponential function and achieved the UWB property. The dimensions of the proposed MIMO antenna are 40×40×0.813 mm. The measured results show that 105.6% (4 ~ 13 GHz) bandwidth and obtain a high isolation levels (S_{21}, S_{31} < -20 dB) since the four directional radiation properties of the individual antenna elements. Efficiency is above 80% and the realized gain changes from 3 dB to 5 dB. Very low ECC value is provided by the MIMO antenna which guarantees the excellent multiple-input multiple-output performance of the four-leaf shape MIMO antenna in the relevant applications.

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REFERENCES

[1] S. H. Choi, et al., "A new ultra - wideband antenna for UWB applications," *Microw. Opt. Techn. Let.*, vol. 40, no. 5, pp. 399-401, 2004.

[2] D. Chen and C.-H. Cheng, "A novel compact ultra-wideband (UWB) wide slot antenna with via holes," *Prog. Electromagn. Res.*, vol. 94, pp. 343-349, 2009.

[3] K. Zhao, et al., "Body-insensitive multimode MIMO terminal antenna of double-ring structure," *IEEE Trans. Antennas Propag.*, vol. 63, no. 5, pp. 1925-1936, 2015.

[4] B. Mun, et al., "A compact frequency-reconfigurable multiband LTE MIMO antenna for laptop applications," *IEEE Antenn. Wirel. Pr.*, vol. 13, pp. 1389-1392, 2014.

[5] S. H. Simon and A. L. Moustakas, "Optimizing MIMO antenna systems with channel covariance feedback," *IEEE J. Sel. Area. Comm.*, vol. 21, no. 3, pp. 406-417, 2003.

[6] B. N. Getu and J. B. Andersen, "The MIMO cube-a compact MIMO antenna," *IEEE T. Wirel. Commun.*, vol. 4, no. 3, pp. 1136-1141, 2005.

[7] G. Zhai, Z. N. Chen, and X. Qing, "Enhanced isolation of a closely spaced four-element MIMO antenna system using metamaterial mushroom," *IEEE Trans. Antennas Propag.*, vol. 63 no. 8, pp. 3362-3370, 2015.

[8] M. A. Abdalla and A. A. Ibrahim, "Compact and closely spaced metamaterial MIMO antenna with high isolation for wireless applications," *IEEE Antenn. Wirel. Pr.*, vol. 12, pp. 1452-1455, 2013.

[9] J.-F. Li, et al., "Compact dual band-notched UWB MIMO antenna with high isolation," *IEEE Trans. Antennas Propag.*, vol. 61, no. 9, pp. 4759-4766, 2013.

[10] R. Chandel and A. Gautam, "Compact MIMO/ diversity slot antenna for UWB applications with band-notched characteristic," *Electron. Lett.*, 2016.

[11] H. Wang, et al., "A wideband compact WLAN/ WiMAX MIMO antenna based on dipole with V-shaped ground branch," *IEEE Trans. Antennas Propag.*, vol. 63, no. 5, pp. 2290-2295, 2015.

[12] M. S. Sharawi, et al., "A dual-element dual-band MIMO antenna system with enhanced isolation for mobile terminals," *IEEE Antenn. Wirel. Pr.*, vol. 11, pp. 1006-1009, 2012.

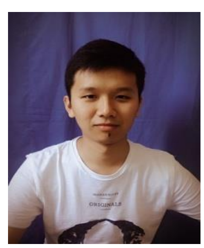
[13] Y. S. Chen and C. P. Chang, "Design of a four-element multiple-input–multiple-output antenna for compact long-term evolution small-cell base stations," *IET Microw. Antenna P.*, vol. 10, no. 4, pp. 385-392, 2016.

[14] H. G. Schantz, *The Art and Science of Ultra-wideband Antennas*. Artech House, 2015.

[15] S. Zhang, et al., "Reduction of the envelope correlation coefficient with improved total efficiency for mobile LTE MIMO antenna arrays: Mutual scattering mode," *IEEE Trans. Antennas Propag.*, vol. 61, no. 6, pp. 3280-3291, 2013.

[16] P. Hallbjörner, "The significance of radiation efficiencies when using S-parameters to calculate the received signal correlation from two antennas," *IEEE Antenn. Wirel. Pr.*, vol. 4, pp. 97-99, 2005.

[17] J. Y. Zhang, et al., "ACS-fed UWB-MIMO antenna with shared radiator," *Electron. Lett.*, vol. 55, no. 17, pp. 1301-1302, 2015.



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His research interests include high-gain antenna design with metasurface and compact wearable antenna.