2nd URSI AT-RASC, Gran Canaria, 28 May – 1 June 2018

Low-Profile and Dual-polarized Microstrip Antennas

Yue Li* [(1)], Wangyu Sun [(1)], and Yijing He [(1)]
(1) Department of Electronic Engineering, Tsinghua University, Beijing, 100084, China

Abstract

In this paper, two designs of dual-polarized and low-profile microstrip antennas are proposed. In order to enhance the impedance bandwidth, Antenna 1 applies grid-slotted radiating patch to build an additional resonant mode (antiphase TM_{20} mode), and coupled with basic TM_{10} mode. It is fed by modified Y-shaped feeding structure to coupling these two modes and for impedance matching. A broadened bandwidth around 39% is achieved for two ports with a low profile of 0.06 λ_0. Then, with the purpose of increasing the gain of dual-polarized microstrip antenna, Antenna 2 using cross-shaped patch with slot-loaded structure is presented and discussed. By exciting higher-order TM_{50} mode, the two loaded slots behave as the in-phase TM_{10} mode, forming a four-element magnetic-current array. Thus, maximum gain of 12.3 dBi, approximately 4 dB higher than conventional microstrip antenna, is achieved with a low profile of 0.027 λ_0. Design concepts of these two antennas can help to expand channel capacity of dual-polarized microstrip antenna in MIMO systems.

1. Introduction

In modern communication systems, dual-polarized antenna is playing an important role due to its advantages of increasing channel capacity and mitigating multi-path fading [1]. Therefore, many types of dual-polarized antenna are proposed recently [2-8]. Dual-polarized slot antenna [2] and loop antenna [3] fed by compact coplanar waveguide (CPW) are presented to meet the requirement of wide bandwidth, simplicity and high isolation. Co- located slots with high isolation are employed to achieve dual polarized antenna in a small volume and decrease the mutual coupling between these two polarizations [4-7]. A dual-polarized sabre-like antenna is reported in [8] to realize omnidirectional performance. Among these types, dual-polarized microstrip antenna has attracted wide attention benefited from performances of low weight, low cost, robustness and especially low profile [9]. In the demand for further increasing channel capacity, many methods have been investigated to achieve the broadband performance [10-12] and enhancement of the gain [13-17]. In this paper, two dual-polarized microstrip antennas (Antenna 1 and Antenna 2) are proposed to improve the performances of traditional microstrip antenna and maintain the advantage of low profile.

With the purpose of increasing the impedance bandwidth, a dual-polarized grid-slotted antenna (Antenna 1) is proposed inspired by the concept of the periodic-type metastructures. In a low profile, wide bandwidth (39%) with low profile (0.06 λ0) is achieved for both orthogonal polarizations by using Y-shaped feeding to match the multiple modes of the periodic grid-slotted surface. Second, with the purpose of enhancing the radiation gain, a high-gain low profile dual-polarized microstrip antenna (Antenna 2) using only one dielectric layer and simple feed is proposed. Antenna 2 is constructed by a pair of orthogonal positioned elements, which are with identical dimensions and the common center, operating in higher-order TM_{50} mode. Both slot-etched elements are radiating as a four-element in-phase magnetic current array and a broadside radiation pattern with low sidelobe can be achieved with nearly 4 dB higher gain than conventional microstrip antenna operating at basic mode.

2. Dual-polarized Grid-slotted Broadband Microstrip Antenna

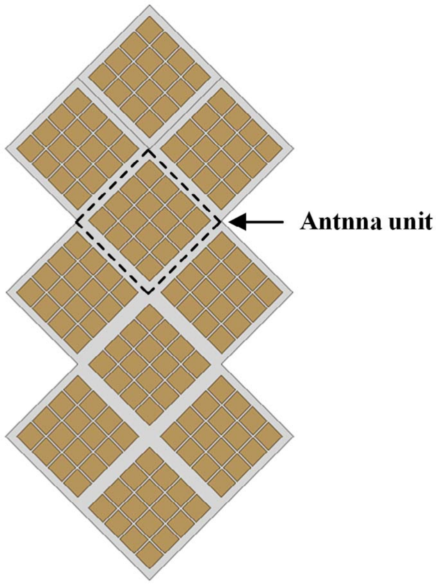

Figure 1. Structure of 10-units dual-polarized grid-slotted microstrip antenna array.

2.1 Structure

Nowadays, broadband and dual-polarized qualities are required in the antenna array designs of base stations in communication devices. However, existing base station antennas based on cross-dipole and stacked patches usually suffer from high profile of over 0.2 λ_0, which will be hard to be fabricated in such environment with limited height. Thus, in order to reduce the profile of base station antenna, we intend to design a dual-polarized low-profile (0.06λ_0) and broadband (over 39%) antenna array. The structure of a 10-units array is shown in Figure 1. This array is constructed by ten dual-polarized grid-slotted microstrip antenna unit. And the configuration of the proposed dual-polarized grid-slotted microstrip antenna unit (Antenna 1) is shown in Figure 2.

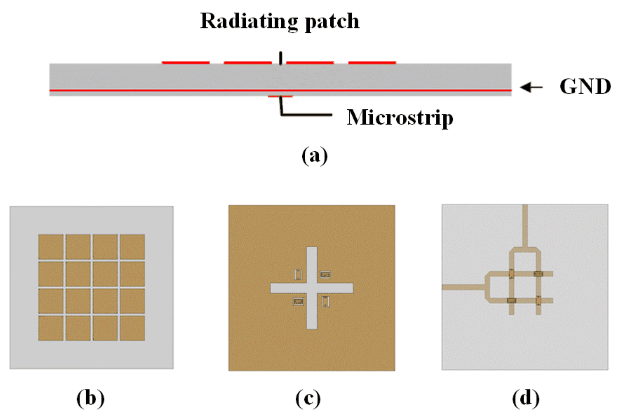

Figure 2. Dual-polarized grid-slotted microstrip antenna with Y-shaped feeding structure (Antenna 1): (a) side view, (b) top layer, (c) GND layer and (d) bottom layer.

It can be observed in Figure 2 (a) that this antenna is a three-layer structure and comprised of the grid-slotted radiating patch on the top layer, the ground plane on the middle layer and the cross Y-shaped feeding structure on the bottom layer. There are two layers of dielectrics with the same relative permittivity of 3.38 and loss tangent of 0.0027. The profile of this antenna is only 0.06 λ_0. As shown in Figure 2 (b-d), the grid-slotted radiating patch is composed by 4 × 4 small square patch units with identical dimensions. The radiating patch of the dual-polarized antenna is excited through two orthogonal coupling apertures (along *x*-axis and *y*-axis, respectively) on the ground plane fed by the cross Y-shaped feeding structures in the bottom layer. To avoid the intersection of the two microstrip stubs, four crossover structures are applied. Therefore, Antenna 1 can generate two orthogonal polarizations.

2.2 Operating Mechanism

There are two main factors in Antenna 1 to enhance the impedance bandwidth: grid-slotted radiating patch and Y-shaped microstrip feeding line. Firstly, the grid-slotted radiating can be considered as a two-dimension periodic structure comprising series capacitor-loaded metamaterial patch cells, which excites TM_{10} mode and antiphase TM_{20} mode. As resonant frequencies of two operating modes are close to each other, the bandwidth of this antenna can be enhanced greatly by coupling two modes together. Secondly, the Y-shaped feeding line instead of the straight one is used in Antenna 1. The Y-shaped feeding structure is composed of a straight section and two arm sections. Unlike the conventional straight microstrip feeding line, the Y-shaped tuning stub contains more adjustable freedom degrees and leads to a remarkable improvement for the impedance bandwidth.

2.3 Simulated Results

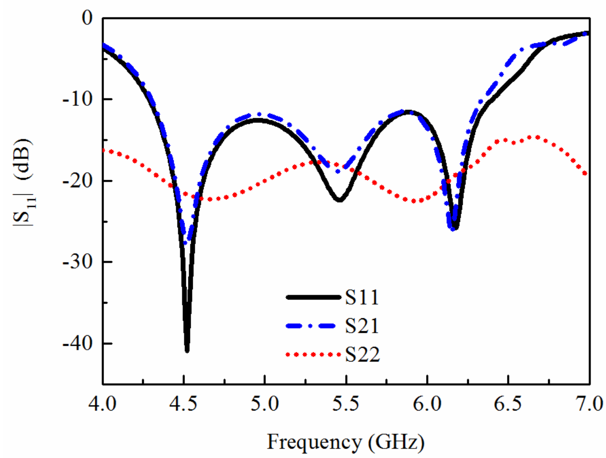

Figure 3. Simulated S parameters of the proposed dual-polarized grid-slotted microstrip antenna.

Figure 3 shows the simulated S parameters of the dual-polarized grid-slotted microstrip antenna. In this figure, we can observe that Antenna 1 achieves a -10-dB impedance bandwidths of 39% ranging from 4.29 to 6.40 GHz at port 1 and 39% ranging from 4.28 to 6.37 GHz at port 2. Over the whole bandwidth, the simulated isolation between two ports is below -15 dB. Compared with former microstrip antenna [5−7], the dual-polarized grid-slotted microstrip antenna can realize broader impedance bandwidth (39%) with a very low profile of 0.06 λ_0.

3. Dual-polarized Slot-loaded High Gain Microstrip Antenna

3.1 Structure

High gain property is highly demanded in many wireless communication systems. To obtain high gain property, microstrip antenna array is commonly used in satellites and radar systems with the merit of low profile. However, the complex and lossy feeding network of the array reduce the efficiency of the overall system. Here, we intend to design a high-gain and low-profile microstrip antenna array using slot-loaded higher-order mode, as shown in Figure 4. The antenna array is composed of some identical antenna unit and the geometry of the unit is illustrated in Figure 5. The proposed high-gain low-profile dual-polarized antenna consists of a cross-shaped printed patch with four etched slots, substrate, and ground. The substrate is F4B with relative permittivity of 2.50 and loss tangent of 0.001, and the thickness is 1.6 mm (0.027 λ_0). Two coaxial probes are used to feed the proposed antenna. The inner conductor of the coaxial cable is soldered with the patch, and the outer conductor is soldered with the ground. The location of the coaxial probe is offset from the center with an optimized distance of 5 mm to achieve good impedance matching.

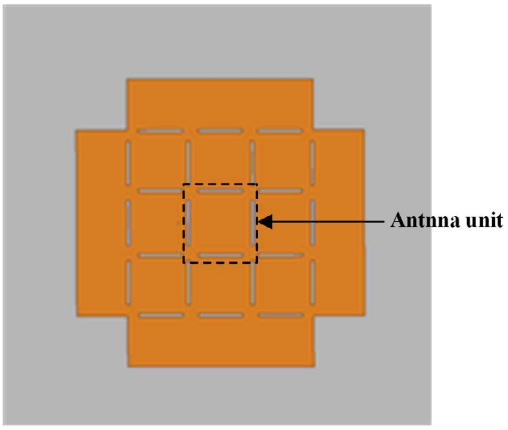

Figure 4. Structure of dual-polarized slot-loaded high gain microstrip antenna array.

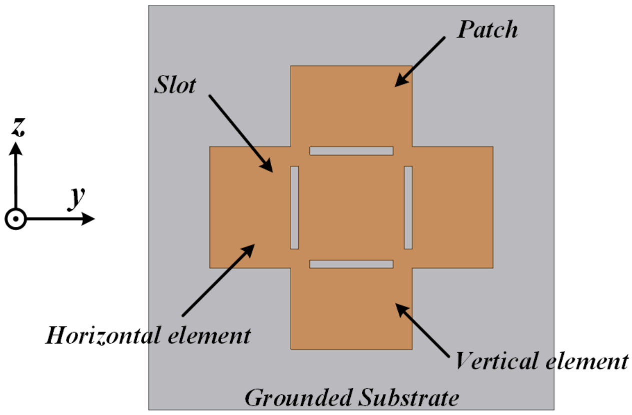

Figure 5. The top view of the structure and the geometry of dual-polarized slot-loaded high gain microstrip antenna.

3.2 Operating Mechanism

The proposed dual-polarized microstrip antenna can achieve high gain with low profile, low sidelobes and high isolation simultaneously. The antenna is formed by a pair of horizontal and vertical elements, which are with identical dimensions and orthogonally placed with the common center, operating in higher-order TM_{50} mode. Four identical slots are cut from the cross-shaped patch without increasing the antenna profile. For each element, the electric fields inside the two slots can be equivalent to fundamental TM_{10} mode, which is in phase with the TM_{50} mode. In fact, both slot-etched elements are radiating as a four-element in-phase magnetic-current array respectively and a broadside radiation pattern with low sidelobes can be achieved with 4 dB higher gain than conventional microstrip antenna. Although there is a cross part of the two polarization elements, the operating modes of the two oriental polarizations are independent, and almost do not interface with each other. Thus, a gain enhancement of approximately 4 dB can be obtained in the horizontal and vertical polarizations simultaneously.

3.3 Simulated Results

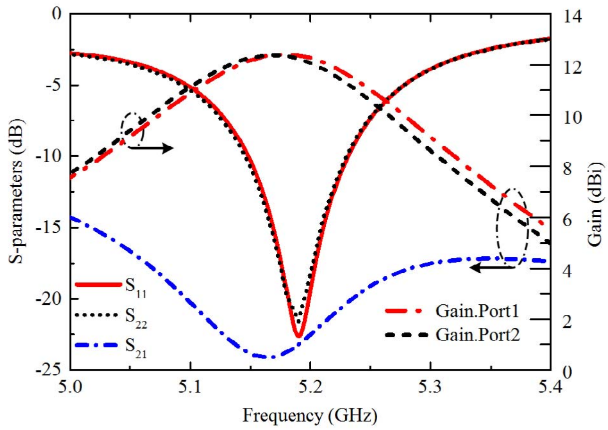

Figure 6. Simulated S parameters and gain of the proposed dual-polarized slot-loaded high gain microstrip antenna.

Figures 6 shows the simulated S-parameters and gain of the dual-polarized slot-loaded high gain microstrip antenna. The simulated -10 dB impedance bandwidth of S_{11} is from 5.15 GHz to 5.22 GHz with the center frequency of 5.19 GHz. The simulated reflection coefficients of the two ports are almost identical. Moreover, it shows that a good isolation lower than -24 dB between two feeding ports is obtained due to the orthogonal structure. In the operating band, the gain of the antenna has a simulated maximum gain of 12.3 dBi, approximately 4 dB higher than conventional microstrip antenna.

4. Conclusion

In order to improve the performances of microstrip antenna and further increase the channel capacity of dual-polarized antennas, two designs of low-profile and dual-polarized microstrip antenna are proposed in this paper. Grid-slotted radiating patch and cross Y-shaped feeding structure are applied to construct the dual-polarized grid-slotted broadband microstrip antenna. Two modes (TM_{10} mode and antiphase TM_{20} mode) are excited and coupled to enhance the impedance bandwidth. Extra tuning freedoms are introduced to improve the impedance matching. Finally, broad bandwidth of 39% for two polarizations can be achieved with a low profile of 0.06 λ_0. As the second design, cross-shaped patch with slot-loaded structure is used to realize the dual-polarized, high-gain and low-profile microstrip antenna. By exciting higher-order TM_{50} mode in each element, these two loaded slots behave as the in-phase TM_{10} mode, forming a four-element magnetic-current array. Thus, maximum gain of 12.3 dBi, approximately 4 dB higher than single basic-mode microstrip antenna, is achieved with a low profile of 0.027 λ_0. Design strategies of these two antennas providing enhanced the performance for dual-polarized diversity or MIMO communication systems.

6. Acknowledgements

These works were supported by the National Natural Science Foundation of China 61771280, and in part by the China Postdoctoral Science Foundation Funded project 2015T80084.

7. References

1. S. Gao, A. Sambell, "Dual-polarized broadband microstrip antennas fed by proximity coupling", IEEE Trans. Antennas Propag., **53**, 1, January 2005, pp. 526-530, doi: 10.1109/TAP.2004.838763.

2. Y. Li, Z. Zhang, W. Chen, Z. Feng, M. F. Iskander, "A Dual-Polarization Slot Antenna Using a Compact CPW Feeding Structure," *IEEE Antennas Wireless Propag. Lett.*, **9**, 2010, pp. 191-194, doi: 10.1109/LAWP.2010.2044865.

3. Y. Li, Z. Zhang, Z. Feng, M. F. Iskander, "Dual-mode loop antenna with compact feed for polarization diversity," *IEEE Antennas Wireless Propag. Lett.*, **10**, 2011, pp. 95-98, doi: 10.1109/LAWP.2011.2112752.

4. Y. Li, Z. Zhang, J. Zheng, and Z. Feng, "A Dual-polarized Monopoleslot Co-located MIMO Antenna for Small-volume Terminals'," *Electr. Lett.*, **47**, 23, 2011, pp. 1304, doi: 10.1049/el.2011.2548.

5. Y. Li, Z. Zhang, J. Zheng, Z. Feng, "Compact azimuthal omnidirectional dual-polarization antenna using highly isolated collocated slots," *IEEE Trans. Antennas Propag.*, **60**, 9, September, 2012, pp. 4037-4045, doi: 10.1109/TAP.2012.2207072.

6. Y. Li, Z. Zhang, J. Zheng, Z. Feng, "Design of Dual-Polarized Monopole-Slot Antenna With Small Volume and High Isolation," *IEEE Trans. Antennas Propag.*, **60**, 5, May, 2012, pp. 2511-2514, doi: 10.1109/TAP.2012.2189743.

7. Y. Li, Z. Zhang, Z. Feng, M. F. Iskander, "Design of omnidirectional dual-polarized antenna in slender and low-profile column," *IEEE Trans. Antennas Propag.*, **62**, 4, April, 2014, pp. 2323-2326, doi: 10.1109/TAP.2014.2303817.

8. P Liu , Y Li , Z Zhang , Z Feng, "Omnidirectional Dual-Polarized Antenna With Sabre-Like Structure," *IEEE Trans. Antennas Propag.*, **65**, 6, June, 2017, pp. 3221-3225, doi: 10.1109/TAP.2017.2690534.

9. K. D. M. Pozar and D. H. Schaubert, "Microstrip Antennas: The Analysis and Design of Microstrip Antennas and Arrays,". *New York: IEEE Press*, 1995

10. F. Yang, X. X. Zhang, X. Ye, Y. Rahmat-Samii, "Wideband E-Shaped Patch Antennas for Wireless Communications," *IEEE Transactions on Antennas and Propagation*, **49**, 7, July 2001, pp. 1094-1100, doi: 10.1109/8.933489.

11. A. U. Zaman, L. Manholm, A. Derneryd, "Dual polarized microstrip patch antenna with high port isolation," *Electron. Lett.*, vol. 43, no. 10, pp. 551-552, May 2007, doi: 10.1049/el:20070723.

12. W. Liu, Z. N. Chen, X. M. Qing, "Metamaterial-based low-profile broadband aperture coupled grid-slotted patch antenna," *IEEE Trans. Antennas Propag.*, **63**, 7, July 2015, pp. 3325-3329, doi: 10.1109/TAP.2015.2429741.

13. H.-D. Chen, C.-Y.-D. Sim, and J.-Y. Wu, "Broadband high-gain microstrip array antennas for WiMAX base station," *IEEE Trans. Antennas Propag.*, **60**, 8, August 2012, pp. 3977–3980, doi: 10.1109/TAP.2012.2201116.

14. Q. U. Khan, M. B. Ihsan, D. Fazal, F. M. Malik, S. A. Sheikh, M. Salman, "Higher Order Modes: A Solution for High Gain, Wide Band Patch Antennas for Different Vehicular Applications," *IEEE Transactions on Vehicular Technology.*, **66**, 5, May 2017, pp. 3548–3554, doi: 10.1109/TVT.2016.2604004.

15. P. Juyal and L. Shafai, "A high gain single feed dual mode microstrip disc radiator," *IEEE Trans. Antennas Propag.*, **64**, 6, June 2016, pp. 2115–2126, doi: 10.1109/TAP.2016.2543804.

16. L. Chang, Z. Zhang, Y. Li, and Z. Feng. "Air Substrate 2-D Planar Cavity Antenna with Chessboard Structure," *IEEE Antennas Wireless Propag. Lett.*, **16**, 2017, pp. 321–324, doi: 10.1109/LAWP.2016.2574815.

17. L. Chang, Z. Zhang, Y. Li, and M. F. Iskander, "Air Substrate Slot Array Based on Channelized Coplanar Waveguide," *IEEE Antennas Wireless Propag. Lett.*, **16**, 2017, pp. 321–324, doi: 10.1109/LAWP.2016.2613965.