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Design and Analysis of a Wideband Multiple Microstrip Dipole Antenna with High Isolation

Zhao Zhou, Zhaohui Wei, Zhaoyang Tang, and Yingzeng Yin

***Abstract*—A wideband multiple microstrip dipole antenna (MMDA) with dual polarization is proposed in this letter. The antenna consists of a radiator, a cross-shaped slot coupler, a pair of microstrip baluns, and a reflector. When baluns are excited, the cross-shaped slot coupler would work as a four-way equal-split power divider and generate four differential signals at four ends of the slotlines. Afterwards, the signals would be coupled to four modified dipoles to radiate and synthesize slant ±45° linear polarizations. The proposed design is verified by the fabrication and testing of a prototype antenna. Measured results agree well with the simulated ones, giving a wide impedance bandwidth from 1.68 to 2.75 GHz, a high port-to-port isolation (better than 37 dB) within the operating frequency bandwidth, and a good radiation pattern. Besides, the proposed antenna maintains a compact structure measuring 0.78λ_0×0.78λ_0 ×0.18λ_0.**

***Index Terms*—dual-polarized antenna; high isolation; multiple microstrip dipole; slot coupler; wideband antenna.**

I. INTRODUCTION

Due to rapid development of modern communications, base station antennas with wide impedance band, high port-to-port isolation, stable radiation pattern, low cross polarization and low profile are in great demand. Meanwhile, dual-polarized antennas become popular in base stations, which contributes to their good performance in reducing multipath fading and increasing channel capacity. During recent years, different dual-polarized antennas have been proposed [1-14] as base station antennas having variable structures such as patch antenna [1-3], magneto-electric (ME) dipole antenna [4-8], crossed-dipole antenna [9-11], crossed slot antenna [12][13] and multi-dipole antenna [14] to name just a few.

Patch antennas become popular with advantages of low profile, low cost, and ease of mass fabrication. However, it is extremely difficult to achieve wide impedance bandwidth with patch antennas. To make up for this shortcoming, multiple layers and complicated feeding structures are usually applied. A stacked patch antenna is proposed in [1] with an impedance bandwidth of 24% (1.7-2.2GHz) and an isolation of 36dB. A dual-polarized shorted microstrip patch antenna coupled to hook-shaped probes [2] gains a bandwidth (3.14-4.58GHz) over 37% and an isolation of 40dB. A dual-polarized antenna with stacked patch for radiation and F-probe for feeding is presented in [3], which realizes a bandwidth of 45% (1.71-2.72GHz) and an isolation of 36dB. In 2006, Luk and Wong presented a new type of ME dipole antenna [4] applied in base stations, with an impedance bandwidth of 43.8% and a stable radiation pattern. Although, ME dipole antennas with dual polarization [5-8] were gradually investigated and proposed. But, they have limitations because of the non-planar structures. On the other hand, crossed-dipole antenna is preferred for its stable radiation pattern and planar structure. Broadband dual-polarized radiation has been reported in literature using different radiator designs such as crossed bow-tie dipole [9], combination of hollow quadrant and arrow-headed patch [10], and loop radiator [11]. Cross-shaped slot antenna excited by two orthogonal stepped microstrip feedlines is also an alternative for dual polarization. In addition to the stepped microstrip feedlines, stepped-impedance (SI) slot [12] and wide crossed slot [13] have also been employed for impedance matching over a broad bandwidth. A multi-dipole antenna is introduced in [14] to achieve dual polarization and a high isolation of 40dB covering a broad bandwidth. However, its fabrication may be difficult owing to its crown-shaped structure.

In this letter, a multiple microstrip dipole antenna with dual polarization is proposed. A cross-shaped slot coupler is introduced to connect feeding baluns and radiator, four modified dipoles. The slot coupler works as a four-way equal-split power divider and generates four differential signals at four ends of the slotlines. Finally the signals would be coupled to four modified dipoles. Theoretically, a single dipole generates a specific linear polarization. However, four dipoles arranged properly may radiate and synthesize a new slant linear polarization. Various differential signals can be achieved when different ports are excited by means of the slot coupler due to its physical characteristic. When port 1 is excited, four dipoles will radiate and synthesize a slant +45° linear polarization and a slant –45° linear polarization when port 2 is excited. The proposed antenna realizes a wide impedance bandwidth (1.68~1.75GHz), a high port-to-port isolation higher than 37dB, and a stable radiation pattern while maintaining a small size in terms of wavelength.

II. ANTENNA DESIGN

A. *Configuration*

The proposed antenna consists of four modified dipoles, a cross-shaped slot coupler, a pair of baluns and a reflector as shown in Fig.1. All the four modified dipoles are etched on the top layer of a 0.8-mm-thick FR-4 substrate (ε_r =4.4, $tan\delta$ =0.02), while the cross-shaped slot coupler is printed on the bottom layer of this substrate. The baluns, mounted below the radiator and perpendicular to each other, are also built on a FR-4 substrate with a thickness of 0.8mm. Besides, a reflector is placed at the bottom to generate a unidirectional radiation pattern.

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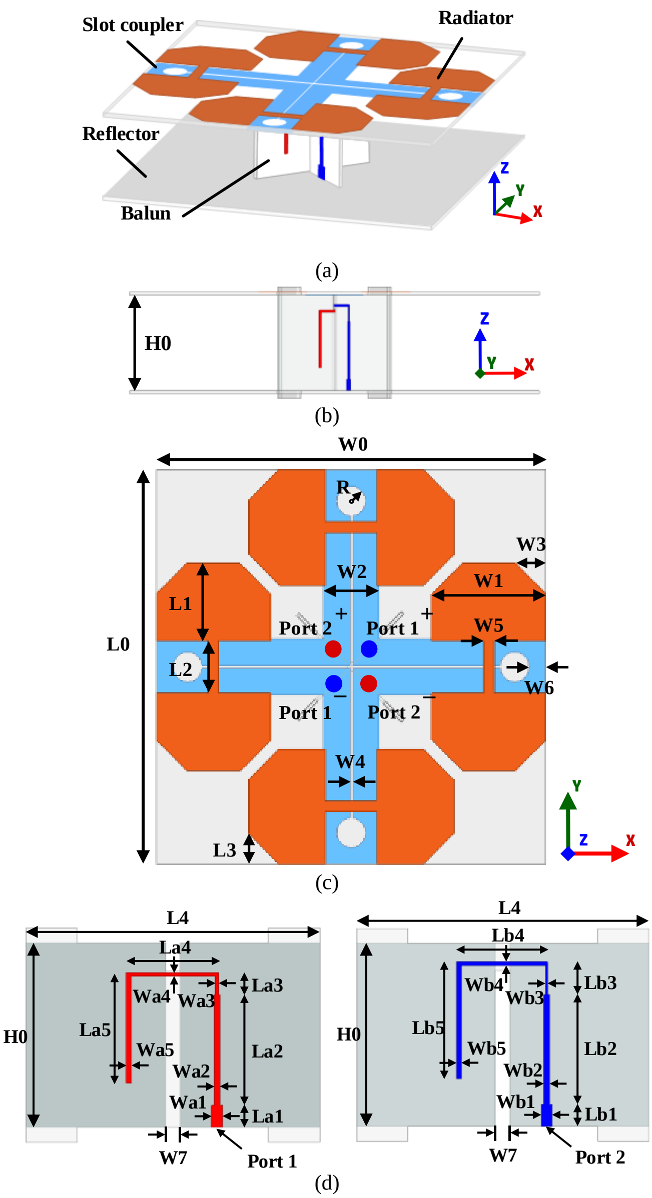

Fig.1 Geometry of the proposed dual-polarized antenna. (a) 3-D view. (b) Side view. (c) Top view. (d) Feeding baluns.

TABLE I
PARAMETERS OF THE PROPOSED ANTENNA

Parameter	Value(mm)	Parameter	Value(mm)	Parameter	Value(mm)
H0	25	W6	4	Lb1	3
L0	106	W7	2	Lb2	15
L1	21	La1	3	Lb3	4.5
L2	14	La2	15	Lb4	12.5
L3	7.2	La3	3	Lb5	16
L4	40	La4	12.6	Wb1	1.5
W0	106	La5	15	Wb2	0.8
W1	29.5	Wa1	1.5	Wb3	0.3
W2	15	Wa2	0.8	Wb4	0.5
W3	7.2	Wa3	0.5	Wb5	0.7
W4	0.6	Wa4	0.5	R	3.5
W5	3	Wa5	0.7		

B. *Design Guideline*

1) Radiator etched on the top layer consists of four rotating symmetrical dipoles. Distance between two parallel dipoles is fixed at $0.56\lambda_0$, where λ_0 is the free-space wavelength at center frequency. Length of dipole's arm is set as $0.32\lambda_s$ ($L1$ = 21mm), where λ_s is the dielectric wavelength at center frequency. Width of dipole's arm is enlarged while dipole corners are truncated to avoid overlapping and improve impedance matching bandwidth.
2) Slot coupler etched on the bottom layer of FR-4 consists of two cross-shaped slotlines with four circular apertures attached at the ends. Radius of circular aperture (R) is set as 3.5mm after optimization.
3) A pair of baluns is designed and optimized for impedance matching and balanced feeding. A reflector is placed 25mm below the radiator to generate a unidirectional radiation pattern.
4) All parameters are analyzed and optimized to obtain a good performance. Optimized dimensions of the proposed antenna are given in Table I.

III. ANTENNA ANALYSIS

A. *Slot Coupler*

A cross-shaped slot coupler is employed to connect radiator and feeding baluns. Two slotlines are arranged in a cross to form a four-way equal-split power divider. Four circular apertures are separately attached to four ends of the slotlines to generate four differential signals at the connecting joints between the slotlines and the circular apertures. According to [15], a slotline attached with circular apertures will behave like open circuit at the ends. The larger the radius of the circular apertures the better the open-circuit behavior will be. Here, as the radius (R) of the circular apertures is much larger than the width ($W4$) of the slotlines, so the slot coupler will behave like open circuit at the ends. Furthermore, the circular apertures will behave like resonators as the width ($W4$) of the connecting slotlines is narrow compared to the radius (R) of the circular apertures, as has already been confirmed by experimental studies of Chramiec in [16]. After refine adjustment of the radius (R), the circular apertures can similarly behave like one-fourth wavelength resonators over a wide band. Thus short-circuit behavior will be achieved at the ends of the slotlines over the wide band. As currents flow along two edges of each slotline are in opposite direction when port 1 or 2 is excited, four stable differential signals will be generated at four ends of the slotlines during the wide band.

Current distribution of the slot coupler when port 1 is excited is exhibited in Fig.2. Current minima occur at the ends of the slot coupler, which verifies the open-circuit behavior at the ends. After some adjustment for the radius (R = 3.5mm), the circular apertures finally behave like one-fourth wavelength resonators. Current maxima occur at the ends of the slotlines, which verifies the short-circuit behavior. Differential signals are successfully generated at the ends of the slotlines, and then coupled to microstrip lines that connect the arms of the modified dipoles. Terminals of the microstrip lines are marked separately as port A1$^{+/-}$, port A2$^{+/-}$, port B1$^{+/-}$ and port B2$^{+/-}$.

B. *Equivalent Circuit*

To get an insight of the working principle of the proposed

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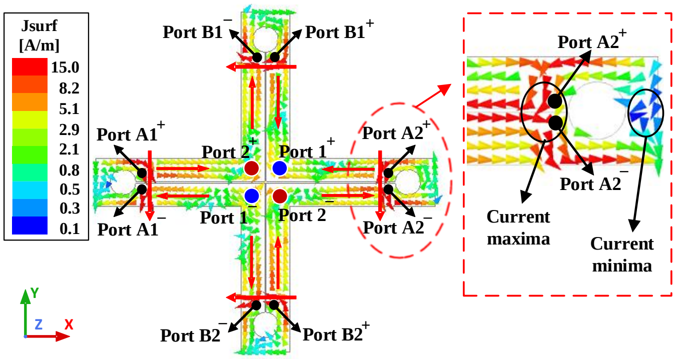


Fig.2 Current distribution of the slot coupler when port 1 is excited.

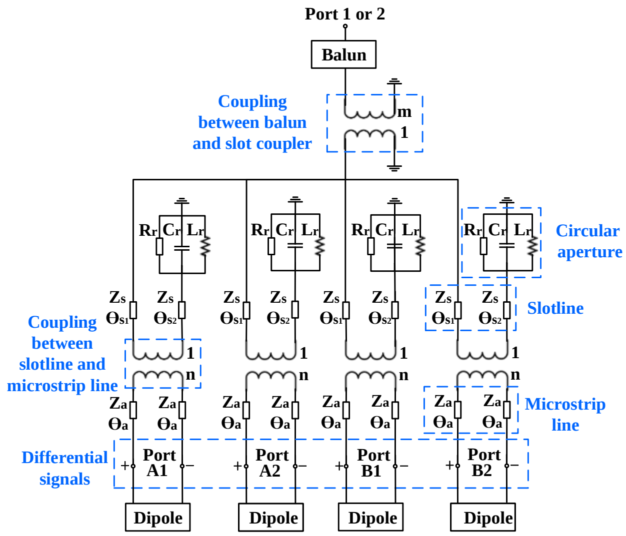
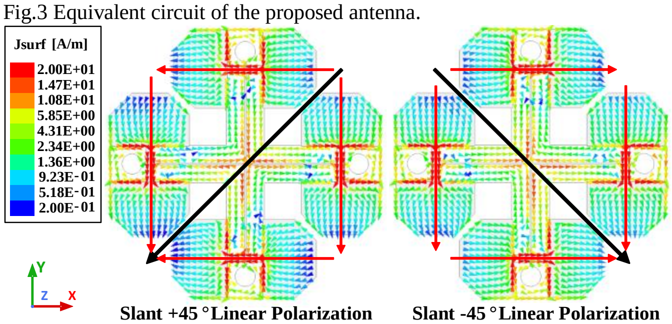


Fig.3 Equivalent circuit of the proposed antenna.



(a) (b)

Fig.4 Current distribution of the proposed antenna when different ports are excited. (a) Port 1. (b) Port 2.

antenna, an equivalent circuit is built as given in Fig.3. Here, Z_s and Z_a stand for the characteristic impedances of the slotline and the microstrip line respectively. θ_{s1} or θ_{s2} is the electrical length of the slotline and θ_a is the electrical length of the microstrip line. Here, the resonant circuit comprising of R_r, C_r and L_r represents the circular aperture. The energy coupling between the microstrip line and the slotline is equivalent to a transformer having a turns ratio equal to *n*, while the balun is equivalent to a transformer having a turns ratio given by *m*. Z_s, Z_a, θ_{s1}, θ_{s2} and θ_a can be calculated based on closed-form expressions listed in [15]. However, precise closed-form expressions for the remaining lumped elements do not exist. To determine values of these lumped elements, the equivalent circuit of Fig.3 is built, analyzed and optimized in ADS (Advanced Design System). Simulated results from ADS are given in Fig.6 to compare with measured results. A good agreement of results confirms the validity of the proposed equivalent circuit.

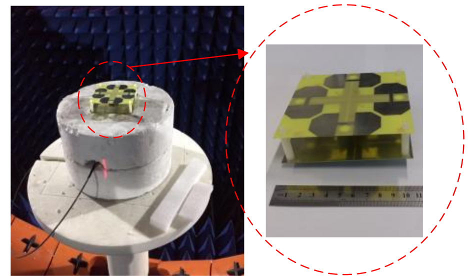


Fig.5 Prototype of the proposed antenna.

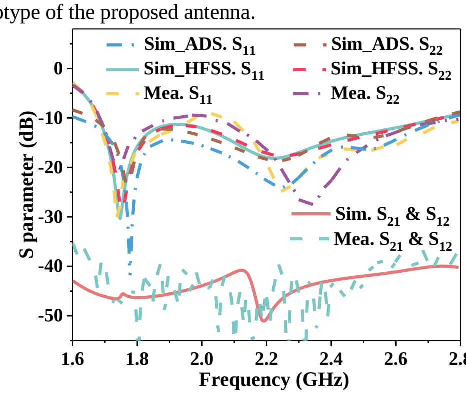


Fig.6 Simulated and measured reflection coefficients and isolations of the proposed antenna.

C. *Principle of Radiation*

Proposed radiator consists of four modified dipoles arranged symmetrically around the center of the antenna. Assuming that port 1 is excited, energy would be divided and transformed into four differential signals by the slot coupler, and then coupled to four dipoles. Fig.4 (a) and (b) show current distributions of the proposed antenna when port 1 or 2 is excited respectively. It can be seen that currents on all dipoles have equivalence in amplitude and phase. Red long arrows represent directions of the currents on the dipoles while black long arrows represent directions of polarizations. It is observed that, four dipoles generate a slant +45 °linear polarization when port 1 is excited, while they give a slant –45 °linear polarization when port 2 is excited. Hence, a ±45° dual-polarized radiation for the proposed antenna is achieved.

IV. EXPERIMENTAL RESULTS

In order to verify the theoretical analysis, a prototype of the proposed antenna is fabricated and tested, as exhibited in Fig.5. The vector network analyzer and the SATIMO near-field measurement system are used to measure reflection coefficients, isolations, and radiation characteristics, respectively. As seen in Fig.6, the simulated and measured results agree well: reflection coefficients better than -10dB and isolations better than 37dB within a wide band of 48% (1.68-2.75GHz) are realized successfully. Considering the symmetric geometry, only the slant +45 °polarization radiation patterns are given for brevity. Fig.7 depicts the simulated and measured radiation patterns for H- and V-plane at 1.7, 2.3, and 2.7GHz when port 1 is excited. The cross-polarization is better than -20dB at boresight and the F/B (front-to-back) ratio is better than 15.5dB. As seen in Fig.8, the measured gain is 8.9 ± 0.7dBi with 3-dB beamwidth at 58.5 °± 4.5 °over the operating band, while the simulated one is

TABLE II
COMPARISON OF THE PROPOSED AND REFERENCE ANTENNAS

Reference	Bandwidth	Dimension(λ_0^3)	Isolation (dB)	Gain (dBi)	HPBW(deg)	Number of Ports	Polarization	Efficiency
[5]	65.9% (VSWR<2)	1.28*1.28*0.23	>36	~9.5	61 °±3 °	2	±45 °	Not Given
[6]	24.9% (VSWR<2)	0.82*0.82*0.15	>29	~8.2	63.5 °±3.5 °	4	±45 °	Not Given
[7]	68% ($\|S_{11}\|$< -10dB)	1.24*1.24*0.23	>36	6.6 ~ 9.6	~ 56 °	4	H/V	~85%
[10]	48% (VSWR<1.5)	1.10*1.10*0.23	>22	12 ~ 14.5	61.3 ° ± 5.5 ° for port 1 62.7 ° ± 6.2 ° for port 2	2	±45 °	Not Given
[12]*	31.2% ($\|S_{11}\|$< -10dB)	1.33*1.33*0.15	>30	~13.7	Not Given	2	H/V	~87.7%
[13]	47% ($\|S_{11}\|$< -10dB)	1.05*1.05*0.28	>40	~7	Not Given	2	H/V	Not Given
[14]	45% (VSWR<1.5)	0.88*0.88*0.43	>32	8 ±0.7	65 ° ±4 °	4	±45 °	Not Given
Proposed	48% ($\|S_{11}\|$< -10dB)	0.78*0.78*0.18	>37	8.9 ±0.7	58.5 ° ±4.5 °	2	±45 °	~82%

Note: Where * represents its antenna element, λ_0 is the free-space wavelength at center frequency.

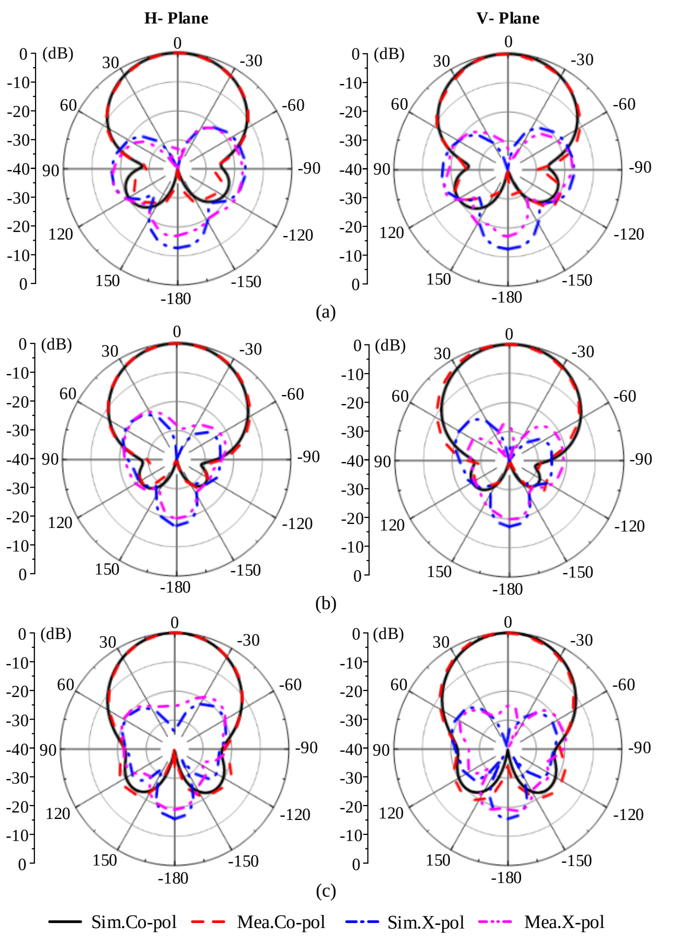


Fig.7 Simulated and measured radiation patterns at (a) 1.7GHz. (b) 2.3GHz. (c) 2.7GHz. as port 1 is excited.

9.2 ± 0.5dBi with 3-dB beamwidth at 58 ° ± 4 °. Some differences between simulated and measured results are probably caused by the welding error, fabrication error, or the loss in coaxial cable and SMA connectors.

Table II compares the performance of the proposed antenna with some already published results, where λ_0 is the free-space wavelength at center frequency. Compared to [5-7], the proposed antenna is feasible to fabricate for its planar structure. Moreover, the proposed antenna has a higher port-to-port isolation than [10], a wider bandwidth than [12], a lower profile than [14] and a better radiation pattern than [13] while maintaining a planar structure more compact than all designs above. It's worthy to mention that the proposed antenna achieves an average efficiency of 82% within the operating band.

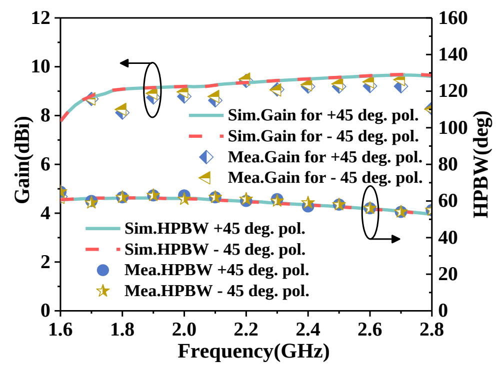


Fig.8 Simulated and measured gains and HPBWs at horizontal plane.

V. CONCLUSION

A multiple microstrip dipole antenna is designed, analyzed and investigated in this letter. A cross-shaped slot coupler is introduced to work as a four-way equal-split power divider and generate four differential signals. Four modified dipoles are employed as radiator to generate slant ±45 ° dual-polarizations. Furthermore, the proposed antenna achieves a high port-to-port isolation over 37dB within a wide band from 1.68 to 2.75GHz for $|S_{11}|$ < -10dB, while guarantees a stable radiation pattern with gain of 8.9 ± 0.7dBi and 3-dB beamwidth of 58.5 ° ± 4.5 °. In addition, the proposed antenna has a compact geometry of $0.78\lambda_0 \times 0.78\lambda_0 \times 0.18\lambda_0$. Consequently, the proposed dual-polarized antenna is a good candidate for base station or 2G/3G/4G applications.

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