A Broadband Dual-Polarized Base Station Antenna Element for European Digital Dividend, CDMA800 and GSM900 Applications

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***Abstract*—In this paper, a novel broadband dual-polarized (slant $\pm 45^{\circ}$) base station antenna element operating at 790-960 MHz is proposed. The antenna element consists of two pairs of symmetrical dipoles, four couples of baluns, a cricoid pedestal and two kinds of plastic fasteners. Specific shape metal reflector is also designed to achieve stable radiation pattern and high front-to-back ratio (FBR). All the simulated and measured results show that the proposed antenna element has wide impedance bandwidth (about 19.4%), low voltage standing wave ratio (VSWR < 1.4) and high port to port isolation ($S_{21} < -25$ dB) at the whole operating frequency band. Stable horizontal half-power beam width (HPBW) with $65^{\circ} \pm 4.83^{\circ}$ and high gain (> 9.66 dBi) are also achieved. The proposed antenna element fabricated by integrated metal casting technology has great mechanical properties such as compact structure, low profile, good stability, light weight and easy to fabricate. Due to its good electrical and mechanical characteristics, the antenna element is suitable for European Digital Dividend, CDMA800 and GSM900 bands in base station antenna of modern mobile communication.**

Keywords-broadband antenna; dual-polarized; base station antenna element.

I. INTRODUCTION

With the significant development of modern mobile communication system and explosive growth of mobile communication users, base station antennas with broadband and dual-polarized are preferred in modern base station antenna applications because they can reduce installation cost, improve system capacity and signal quality greatly. Modern base station antenna design has lots of requirements, such as broadband, low VSWR, high port to port isolation, stable radiation pattern, high gain and so on.

To achieve these requirements, many kinds of base station antennas with different structures are proposed in recent literatures [1]–[6]. A microstrip patch antenna fed by two L-probes was proposed in [1]. The impedance bandwidth of this antenna is 20.8% of $S_{11} < -10$ dB at lower band, while the radiation pattern is asymmetrical with high sidelobe, thus this antenna is not suitable for practical applications. A patch antenna with orthogonal linearly polarized was proposed in [2], operating frequency band at lower band (from 890-960 MHz) of the proposed antenna is not too wide enough to cover CDMA800 and GSM900 bands. Although the magneto-electric dipole antenna [3] and irregular patch antenna [4] have wide impedance bandwidth of VSWR < 1.5 (25.5% and 20.4% respectively) and relatively good electrical characteristics, complex structures limit the two antennas' wide application. According to mobile communication theory, we know that slant $\pm 45^{\circ}$ polarization is better than vertical-horizontal polarization when dealing with multi-path fading signals, thus slant $\pm 45^{\circ}$ dual-polarized base station antennas also received significant attention and got great development. In 2014, S. Zuo *et al.* designed a slant $\pm 45^{\circ}$ dual-polarized antenna with a parasitical crossed-strip for broaden bandwidth [5]. The proposed antenna has wider impedance bandwidth (34.9% of $S_{11} < -10$ dB) than former antenna. By using the conversion equation mentioned in [7], $S_{11} = -10$ dB is equivalent to VSWR $= 1.9$, which doesn't meet the general standard (VSWR < 1.5) of modern base station antenna design. A differential fed printed antenna with slant $\pm 45^{\circ}$ dual-polarized was proposed in [6]. The antenna adopted differential feeding and had symmetrical structure, while realized gain of the antenna (7.8 ± 1 dBi) is relatively low. For these reasons, many aspects can be further improved.

In this paper, a broadband slant $\pm 45^{\circ}$ dual-polarized base station antenna element operating at 790-960 MHz frequency band is presented. The antenna element has good electrical characteristics, including VSWR < 1.4, $S_{21} < -25$ dB, front-to-back ratio (FBR) > 26 dB at whole operating frequency band and stable radiation pattern in both horizontal and vertical plane. In addition, the antenna element has great mechanical properties such as compact structure, high reliability, good stability, light weight and easy to fabricate.

A prototype of the proposed antenna element is fabricated by integrated metal casting technology, and measured by vector network analyzer in an anechoic chamber. Simulated and measured results show that the proposed antenna element meet the modern antenna design requirements. Due to the good electrical and mechanical characteristics, the antenna element can be used in base station antennas of modern mobile communication system for European Digital Dividend (790-862 MHz), CDMA800 (825-880 MHz) and GSM900 (889-960 MHz) bands. What's more, the antenna element with octagon-aperture structure can be integrated with high-frequency elements to form a dual-band or multi-band array base station antenna.

This paper is organized as follows. Section II introduces the structure of the proposed antenna element. Simulated and measured results are presented in Section III. Section IV shows comparative analysis with other three modern base station antenna elements and conclusion is drawn in Section V.

II. Antenna element design

The configuration of the proposed broadband dual-polarized antenna element, U shape metal reflector and coordinate system are shown in Fig. 1. Fig. 1(a), Fig. 1(b) and Fig. 1(c) are top view, side view and full view of the proposed radiating element, respectively. The antenna element consists of two pairs of symmetrical dipoles, four couples of baluns, a cricoid pedestal and two kinds of plastic fasteners (four for each kind of plastic fastener). Each pair of opposite dipoles excite a polarization and the co-polarization are orthogonal to the cross-polarization. The angle between polarization direction and antenna radiation direction is 45 degree, so it is called slant $\pm 45°$ dual-polarization.

The antenna element has the following characteristics: 1) the size of the element is $0.485\lambda_0 \times 0.485\lambda_0 \times 0.198\lambda_0$ (λ_0 is the wavelength corresponding to the center frequency of the operating frequency band). The diameter of the octagon-mouth is $0.485\lambda_0$ which can reduce the mutual coupling with internal high-frequency antenna element (i.e., a high-frequency antenna element is embedded in the proposed low-frequency antenna element); 2) each dipole consists of two asymmetric radiation arms, and each radiation arm is composed of a straight part, a slant part and a loading part. The angle between the straight part and the slant part is about 135 degree in XOY plane, while the loading part is orthogonal to the slant part in XOZ (or YOZ) plane. The loading part can effectively expand bandwidth and improve radiation performance by generating mutual coupling with adjacent dipole; 3) each radiation arm is connected to a balun to obtain balance feed. Feeder line positioning slots are provided in the middle of baluns to fix coaxial cables and feeding patches are located on the top of baluns to be soldered with the inner conductor of coaxial cables. 4) the bottom of four couples of baluns are connected to a circular base bottom. There are four screw holes in the circular base bottom to install the antenna element on metal reflector easily. 5) two kinds of plastic fasteners are employed on the antenna element at different positions. Plastic fasteners 1 (marked by green color) are placed at the top of each couples of baluns to protect the feeding patches, and plastic fasteners 2 (marked by red color) are placed at the loading part of radiation arms to increase the mutual coupling between two adjacent dipoles. These plastic fasteners are made of polyoxymethylene (POM), with a relative permittivity of 2.7 and dielectric loss tangent of 0.0023.

In order to illustrate the influence of plastic fasteners on antenna's electrical performance, simulated VSWR versus frequency of the antenna element with different plastic fasteners are depicted in Fig. 2. The simulated VSWR without

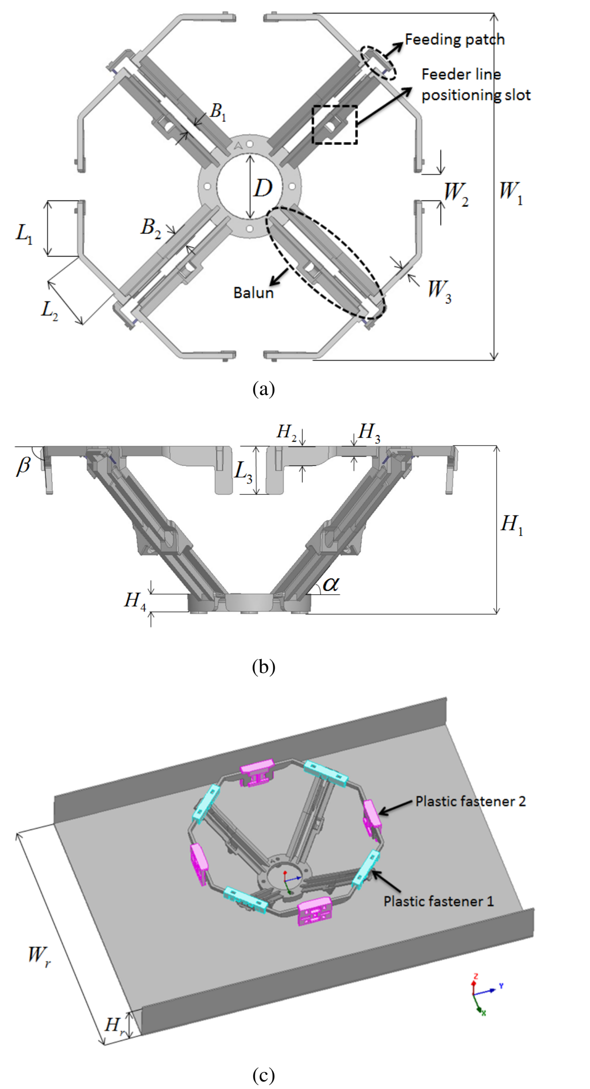


Fig. 1. The proposed antenna element. (a) top view; (b) side view; (c) full view.

plastic fastener and only employed plastic fasteners 1 are quite similar, and their values are larger than 3. However, the simulated results only with plastic fasteners 2 are in better agreement with that of both plastic fasteners, and their values are less than 1.4. The simulated results show that plastic fasteners 1 have little effect on antenna's electrical performance, while plastic fasteners 2 improve the impedance bandwidth greatly by increasing mutual coupling between two adjacent dipoles because POM has larger relative permittivity than air. More detailed explanations of plastic fasteners impacting on antenna's electrical performance have been given in [8].

Since the radiation pattern, FBR and HPBW are associated with reflector, a U shape metal reflector is designed which can pilot the antenna element radiating to desired direction. Four holes are drilled on the plate to fix the radiating element and allow coaxial cables to go through. By elaborately designing width and height of the metal reflector, high FBR and stable

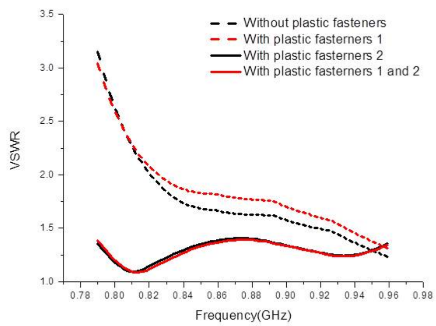


Fig. 2. Effects of plastic fasteners on the proposed antenna element's VSWR performance.

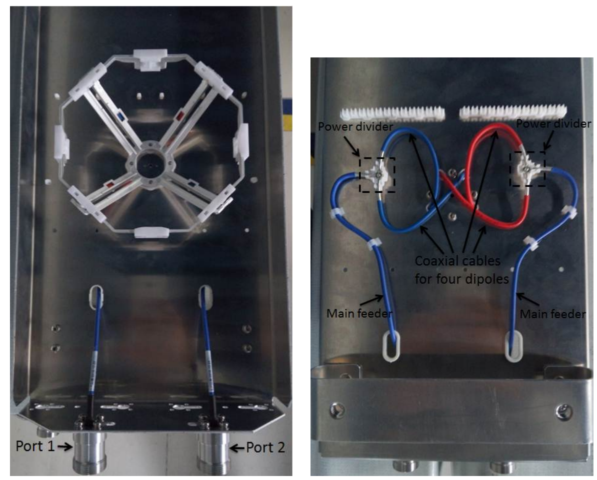
TABLE I
SPECIFIC PARAMETERS OF THE ANTENNA ELEMENT AND METAL REFLECTOR

Symbol	Description	Value
D	Diameter of cricoid pedestal	32 mm
L_1	Length of the slant part of radiation arm	24 mm
L_2	Length of the straight part of radiation arm	23 mm
L_3	Length of the loading part of radiation arm	19.5 mm
W_1	Diameter of octagon-mouth	166.5 mm
W_2	Gap between two adjacent loading parts	14.2 mm
W_3	Width of radiation arm	2.5 mm
B_1	Gap between two adjacent balun	4.4 mm
B_2	Width of balun	7.4 mm
H_1	Height of radiating element	68 mm
H_2	Width of the slant part	8 mm
H_3	Width of the straight part	4 mm
H_4	Height of cricoid pedestal	8 mm
W_r	Width of metal reflector	255 mm
H_r	Height of metal reflector	48 mm
α	Angle of balun and cricoid pedestal	40.6°
β	Angle of loading part and horizontal plane	93°

HPBW on both horizontal and vertical plane are achieved. The horizontal plane (H-plane) of the radiating element is $\varphi = 0°$ and the vertical plane (E-plane) is $\varphi = 90°$. All parameters of the antenna element are optimized and specific value of parameters are listed in Table I.

III. SIMULATION AND MEASURE RESULTS

Simulation results of VSWR, port to port isolation and radiation pattern of the proposed antenna element are obtained by HFSS16. A prototype of the antenna element is shown in Fig. 3, where the front view is the radiating element and the back view is feeder lines. The antenna element is electroplated with nickel and tin, which improve the electrical connection with coaxial cables. Inner conductor of coaxial cables are soldered with feeding patches and outer conductor are soldered on baluns, thus the antenna element is fed by coaxial cable directly. Each pair of opposite dipoles receive equal amplitude feed from one port through soldered corresponding coaxial cables of opposite dipoles and main feeder together on a power divider. Measured results of VSWR and port to port isolation are obtained by vector network analyzer in an anechoic chamber. Radiation pattern of the antenna element is measured by far-field test system.

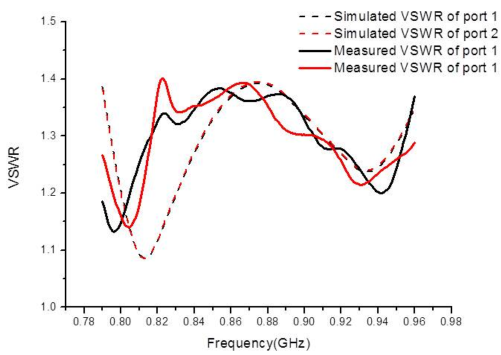


(a) (b)

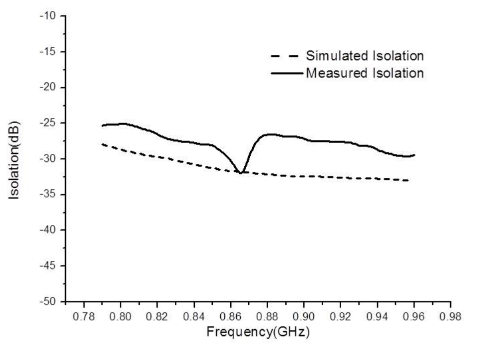
Fig. 3. A prototype of the proposed antenna element. (a) front view; (b) back view.

Simulated and measured results of VSWR, S_{21} and realized gain of the proposed antenna element are presented in Fig. 4. Due to the discrepancies in accuracy of fabricating and assembly, and the differences between realistic environment and simulation environment, measured results are not as good as simulated results. Fig. 4(a) shows simulated and measured VSWR versus frequency. A similar trend between simulated and measured results is achieved. The maximum VSWR of port 1 and port 2 are less than 1.4 at working frequency band. In Fig. 4(b), simulated and measured results of port to port isolation versus frequency are shown, which are lower than -25 dB over the entire bandwidth. Measured and simulated realized gain are shown in Fig. 4(c) and measured result has relatively good agreement with simulated one. The radiating element has high realized gain (> 9.66 dBi) at the whole operating bands, and peak gain is 10.24 dBi at 960 MHz. Therefore, the proposed antenna element has wide impedance bandwidth (about 19.4%) of VSWR < 1.4 and $S_{21} < -25$ dB from 790 MHz to 960 MHz, which meet base station antenna design requirements.

Measured radiation patterns of the antenna (co-polarization along $+45°$ direction and cross-polarization along $-45°$ direction) in H-plane and E-plane at 790 MHz, 892 MHz and 960 MHz are shown in Fig. 5 and Fig. 6, respectively. Due to the symmetry, another polarization mode is omitted. Radiation patterns of the co-polarization are stable over the whole working band in H-plane and become better with the increasing frequency in E-plane. The cross-polarization



(a)



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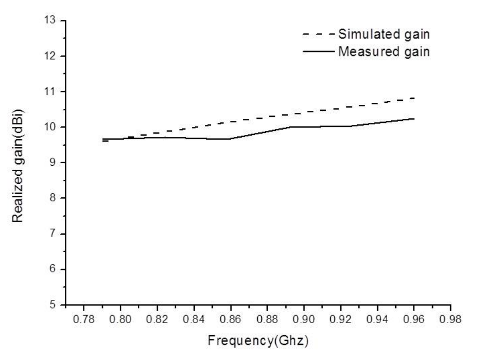
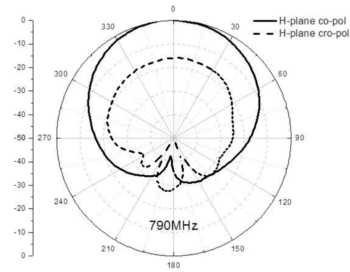
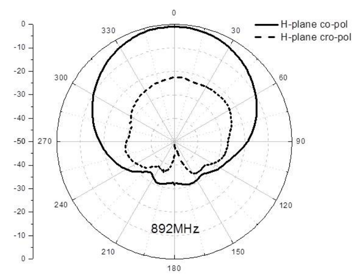


(c)

Fig. 4. (a) Voltage standing wave ratio (VSWR), (b) isolation (S_{21}) and (c) realized gain of the antenna element.



(a)



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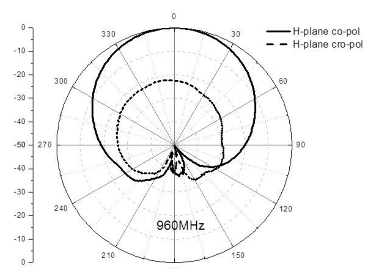


(c)

Fig. 5. H-plane radiation patterns of the proposed antenna element. (a) H-plane at 790 MHz; (b) H-plane at 892 MHz; (c) H-plane at 960 MHz.

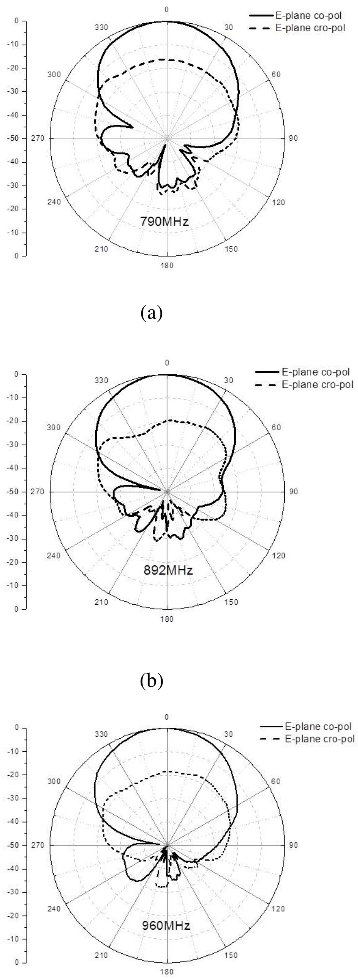
are become better with the increasing frequency in both H-plane and E-plane. Measured results show that the proposed element has good directional radiation patterns. In addition, stable HPBW, high FBR and relatively high cross polarization discrimination (XPD) are achieved. Specific values of HPBW, FBR and XPD (0° and 60°) in H-plane are shown in Table II.

TABLE II
SPECIFIC RESULTS OF THE RADIATION PARAMETERS IN H-PLANE

Fre (MHz)	HPBW	FBR (dB)	XPD 0° (dB)	XPD 60° (dB)
790	69.83	29.07	16.13	10.38
824	69.28	28.62	19.79	14.67
858	68.43	26.42	24.96	12.76
892	65.21	29.62	21.66	12.95
926	65.09	33.57	19.39	12.90
960	63.76	33.73	22.48	13.33

IV. COMPARATIVE ANALYSIS

In order to demonstrate the excellent performance of the proposed antenna element, we compared the designed antenna



(a)

(b)

(c)

Fig. 6. E-plane radiation patterns of the proposed antenna element. (a) E-plane at 790 MHz; (b) E-plane at 892 MHz; (c) E-plane at 960 MHz.

TABLE III
COMPARISONS WITH OTHER MODERN ANTENNA ELEMENTS.

	this work	[9]	[10]	[11]
Bandwidth (Mhz)	790-960	820-960	790-960	800-990
VSWR	< 1.4	< 1.4	< 1.5	< 2
Isolation (dB)	< -25	Not Given	< -26	< -30
Max gain (dBi)	10.24	9.57	10.2	8.8
FBR (dB)	> 26	> 25	> 22	Not Given

element with other three modern antenna elements presented in [9]–[11]. Table III shows antenna performance of this work and the reference antenna elements according to bandwidth, VSWR, port to port isolation (S_{21}), maximum realized gain and FBR. Comparison results show that the proposed antenna element outperforms the references in terms of FBR. In addition, the proposed antenna element has low VSWR and sightly increases realized gain.

V. CONCLUSION

A broadband dual-polarized base station antenna element with good electrical and mechanical characteristic is presented in this paper. The antenna element has wide impedance bandwidth about 19.4% of VSWR < 1.4. A model of the antenna element is simulated and fabricated, and all the results show that the radiating element has high port to port isolation ($S_{21} < -25$ dB), high front-to-back ratio (FBR >26 dB), high gain(> 9.66 dBi) and stable half-power beam width in horizontal plane with $65° \pm 4.83°$ over the whole operating band. In addition, the antenna element has lots of advantages, including compact structure, low cost, good stability, easy to fabricate and so on. The proposed antenna element is a good candidate in European Digital Dividend, CDMA800 and GSM900 bands for base station antennas of modern mobile communication system.

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