Polarization Rotated Waveguide Antennas for Base-Station Applications

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***Abstract*—A novel base-station antenna element is proposed. It consists of a surface composed of parallel strips rotating in the polarization direction and a segment of a rectangular waveguide. The surface is designed on a single-sided substrate, which has the same area as the aperture of the waveguide. In assembling, the non-copper side of the substrate is placed atop the aperture of the waveguide antenna with a small air-gap. To achieve the polarization rotation, the parallel strips on the surface are rotated by 45° with respect to the orientation of the waveguide antenna. By adding the surface, the linear polarization direction of the rectangular waveguide antenna rotates by 45° to comply with the requirements of cellular industry. To verify the simulation results, the proposed antenna is fabricated and measured. Results show that the antenna has an operating bandwidth from 698-960 MHz, where a stable radiation pattern is also achieved.**

***Index Terms*— base-station antenna, polarization rotation, waveguide antenna, ,**

I. Introduction

± 45° dual-polarized antennas have been widely used in cellular base-stations, as they can lower the multipath propagation effects and enhance signal reception quality in modern mobile communication system [1]. Therefore, many efforts have been demonstrated in design of ±45° dual-polarized antennas with high performance [2-8]. In general, the main types of base-station antennas include dipole antennas [2-7], slot antenna [9] and microstrip patch antennas [2, 10]. Dipole antenna, which is very popular in base-station applications, have wide impedance bandwidth by using balun or other matching technologies, stable radiation pattern and boresight gain can be also achieved over the same band [3-5]. In addition, two dipole elements can be easily rotated and placed crosswise, thus forming a ±45° dual polarized radiation. Slot antenna and patch antenna are usually used as single-polarized antenna for base-station applications, nonetheless, several dual polarized antenna designs have been implemented using slot or patch antenna as the element [9, 10]. The main drawback of such designs is their relatively narrow impedance bandwidth. To widen the band, special feeding structures are needed to improve the impedance matching and, as a result, the complexity and cost are both increased. Moreover, for the several main types of base-station antennas mentioned above, a ground which is much larger than the radiator is also required to achieve the desired radiation performance, thus leading to a relatively bulky profile. Therefore, there has been an on-going pursuit for base-station antennas that cover a wide frequency band with simple and low cost structures.

Traditionally, open-ended waveguides are used as antennas for applications where the required gain is not particularly high. An open-ended rectangular waveguide is linearly polarized and the polarization direction is along the short walls. The advantages of waveguide antennas include moderate directivity, good impedance matching and stable radiation patterns over broad bandwidth, simple construction and adjustment. Although a broad bandwidth with good impedance matching and stable radiation patterns are requirements of a base-station antenna, waveguide antennas are rarely applied to base-stations, especially for ±45° dual polarized antennas. There are two reasons for this. First, two waveguide antennas have to be physically rotated to generate ±45° linearly polarized patterns. Second, they cannot be placed crosswise and overlapped in a compact way like the dipole antennas. If the polarization direction of a waveguide antenna can be rotated without rotating the antenna itself, it would be much easier for two of them to be combined in a compact way to form a base-station antenna element.

In this letter, a novel method is presented to rotate the polarization direction of a waveguide antenna using a surface of parallel strips (SPS). The metallic SPS is designed on a single-sided substrate, which has the same area as the aperture of the waveguide. In assembling, the substrate is placed at a small distance above the aperture of the waveguide antenna. To achieve the polarization rotation, the parallel strips on the SPS are rotated to make an angle of 45° with the walls of the waveguide antenna. By combining the SPS with the waveguide antenna, the linear polarization direction is rotated by 45° , which is perpendicular to the direction of the strips. The waveguide antenna together with the SPS (WA-SPS) is designed using ANSYS HFSS [11]. Two WA-SPSs with orthogonal polarizations are put together either shoulder to shoulder or one on top of the other to form a ±45° dual-polarized antenna. Simulated results have shown that the operating bandwidth is from 698 to 960 MHz (31.6%), where the VSWR < 1.5, half power beamwidth (HPBW) in horizontal plane is from 59° to 70°, isolation between the two ports is above 25 dB. The results show that the proposed antenna can be a potential candidate for base-station applications, of which the main advantage is stable beam pattern and simple configuration. To verify the results of simulation, the proposed antenna is fabricated and measured. Simulated and measured results show good agreement.

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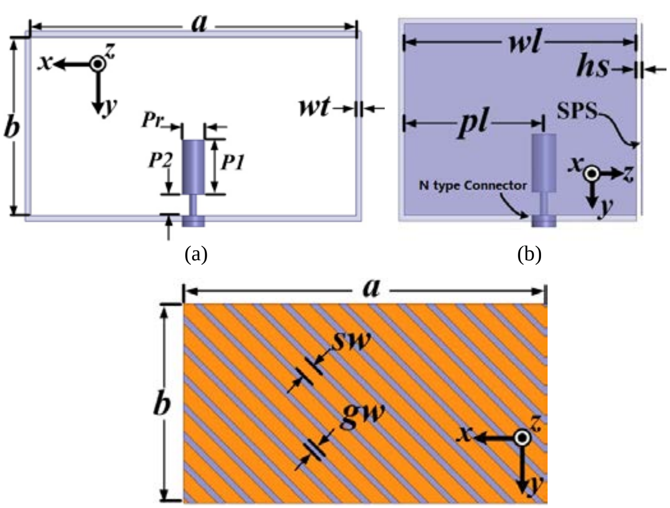
II. Antenna Design

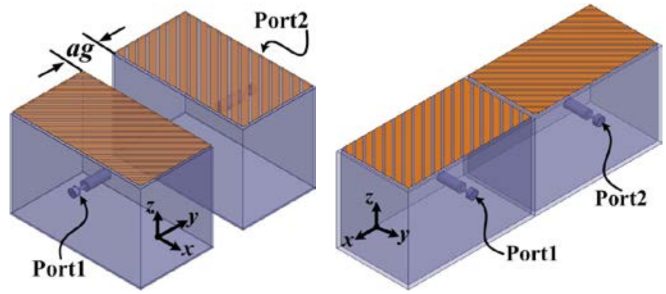
The waveguide used here has an aperture size of 300×165mm^2, of which the dominant propagation mode is TE_{10} and the co-polarization direction is along y-axis as shown in Fig. 1(a) and (b). To make the whole antenna lighter, the material of the waveguide is chosen to be aluminum. The waveguide is fed by a N type connector as shown in Fig. 1(a), where the pin of the N type connector is connected to a cylindrical rod to obtain wider impedance bandwidth. The SPS is printed on a single-sided substrate, which has the same area as the waveguide aperture as shown in Fig. 1(c). In assembling, the SPS is placed at a small distance atop the open-end of the waveguide antenna as shown in Fig. 1(b). The substrate employed in this work is FR 4, which has a thickness of 0.8 mm and a relative permittivity of 4.4. The parallel strips on the SPS are copper and rotated by 45° with respect to x-axis, as shown in Fig. 1(a). Simulation work has shown that the width of and gap between the strips have significant effect on both radiation and impedance matching. Therefore, the geometric size of the strips is firstly optimized to achieve stable radiation characteristics over the operating frequency band, the position and size of the N type connector with a cylindrical rod are then optimized to obtain good impedance matching over the same frequency band. As mentioned before, two WA-SPSs with orthogonal polarizations can be put together either in a line or in a row to form a ±45° dual-polarized antenna, as shown in Fig. 2(a) and (b) respectively. For clarity, the two ways of configuration shown in Figs. 2(a) and (b) are described as Con1 and Con2, respectively. Note that the two WA-SPSs are separated by a distance of 70 mm in Con1 to enhance the isolation between Port1 and Port2. In practice, other isolation techniques can be used to remove the space and, alternatively, the space can be used for placing higher frequency band elements. These two different configurations can be selected flexibly according to different application needs.



(a) (b)

(c)

Fig. 1 Geometries of (a) & (b) waveguide antenna and (c) SPS. (a) Top view and (b) side view.



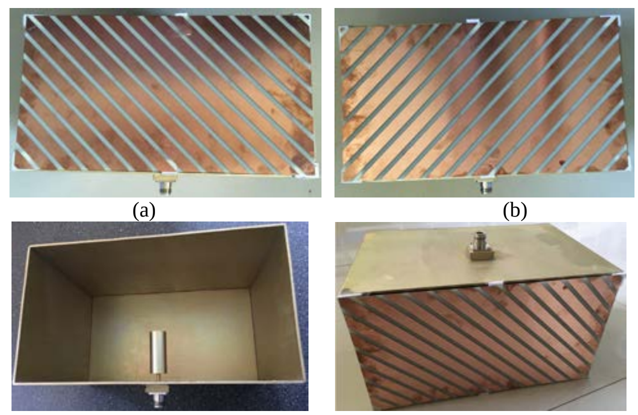
(a) (b)

Fig. 2 Two configurations for proposed WA-SPS. (a) Con1 and (b) Con2.

The dimensions of the final designs are listed in Table I, wherein the values were used to fabricate the antenna as shown in Figs. 3.

TABLE I DIMENSIONS OF PROPOSED ANTENNA (UNIT:MM)

a	***b***	***Pr***	***P1***	***P2***	***wt***	***wl***	***pl***	***hs***	***sw***	***gw***	***ag***
300	165	21	50	20	2	200	120	4	12	5	70



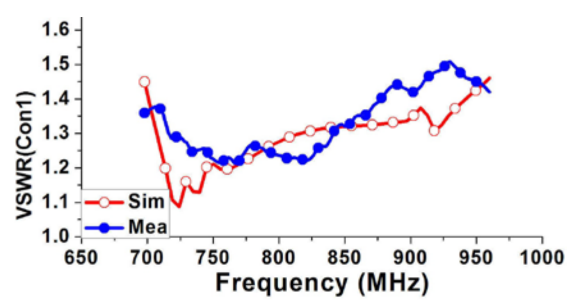
(a) (b)

(c) (d)

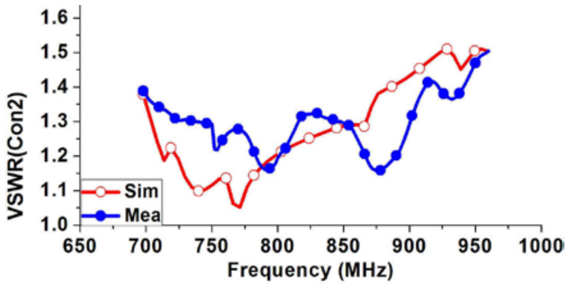
Fig. 3 Prototypes

III. Simulation And Measurement Results

Both the simulated and measured VSWR for the Con1 and Con2 are compared in Figs. 4(a) and (b), respectively. It is observed that the VSWR is lower than 1.5 in the band from 698 to 960 MHz in both simulation and measurement, with a fractional bandwidth of 31.6%. Due to the symmetric structure of the antenna, only VSWR of Port 1 is shown here.



(a) Con1



(b) Con2

Fig. 4 VSWRs of (a) Con1 and (b) Con2

It can be seen from Figs. 4 that the VSWRs of Con1 and Con2 are slightly different from each other. This is because different placement methods would lead to difference in the input impedance observed from the feed port, nonetheless, the difference is insignificant so that the VSWR can be kept lower than 1.5 for both Con1 and Con2. Besides, the small differences between simulation and measurement results for Con1 and Con2 were caused by fabrication errors, mainly related to the manufacturing precision of feeding ports and the flatness of the FR4 dielectric laminate.

To observe the polarization rotation of the waveguide antenna by using the SPS, the E-filed distributions at the aperture of the waveguide antenna without and with SPS are shown in Fig. 5.

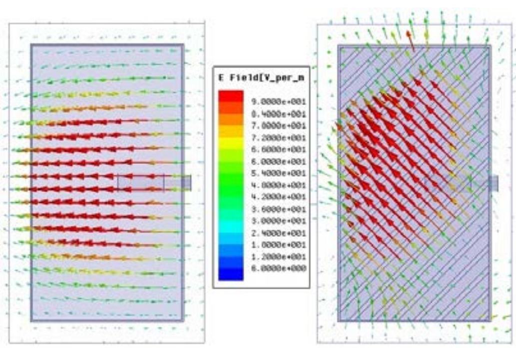


Fig. 5 E-field distributions without (left) and with (right) SPS.

It is observed from Fig. 5 that by using the SPS, the polarization direction is rotated by 45° and perpendicular to the direction of the strips. Owing to the strong near-field coupling between the waveguide and the SPS, current distribution occurs on the strips and the direction is along the stripline, as a result, 45° linearly polarized wave is radiated from the SPS.

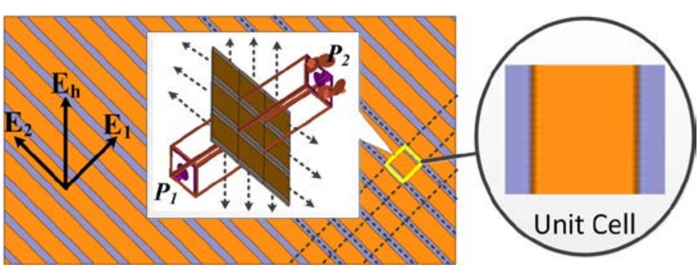


Fig. 6 Analysis of the SPS using single unit cell

The polarization rotation can be further explained by breaking the SPS into identical unit cells and analyzing one of them, which is enclosed by a yellow rectangular loop as shown in Fig. 6, the unit cell is also enlarged on the right side of the same figure for clarity. This analysis method has been used in our previous research work on metasurface [12, 13]. In the analysis, we start with using a periodic boundary to extend the single unit cell into a surface with infinite size, as shown in Fig. 6. A TE plane wave, which is equivalent to the wave radiated from the waveguide antenna, with the polarization direction along $\boldsymbol{E_h}$ is then applied onto the non-copper side of the surface from $\boldsymbol{P_1}$ to $\boldsymbol{P_2}$. The incident wave can be resolved into two orthogonal components, of which the polarization directions are along $\boldsymbol{E_1}$ and $\boldsymbol{E_2}$ respectively. Computer simulation is used to obtain the transmission coefficients (S21) for both $\boldsymbol{E_1}$ and $\boldsymbol{E_2}$ between $\boldsymbol{P_1}$ and $\boldsymbol{P_2}$, as shown in Fig. 7.

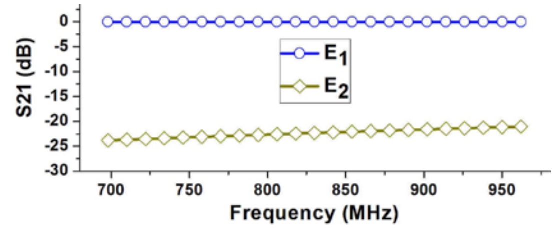
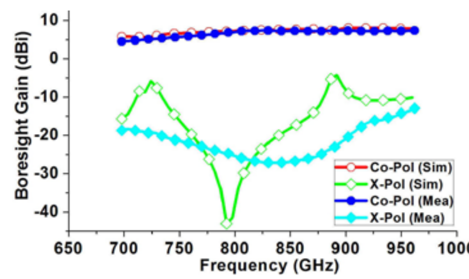
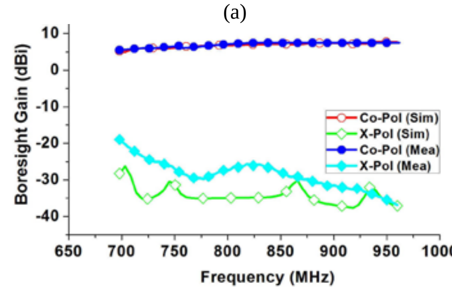


Fig. 7 S21s of incident waves with orthogonal polarizations

It can be seen from Fig. 7 that the S21 is near zero, which means the SPS is almost transparent for the component $\boldsymbol{E_1}$, however, for the component $\boldsymbol{E_2}$, the S21 is around -25 dB, which means almost all the power is reflected by the SPS. Moreover, the distance between the N type connector and SPS is about 1/4 wavelength at the center frequency of the operating band, thus for the component $\boldsymbol{E_2}$, the reflected power is cancelled out by the incident power at the position of the N type connector. As a result, only component $\boldsymbol{E_1}$ is radiated out from the SPS and the polarization rotation is achieved.



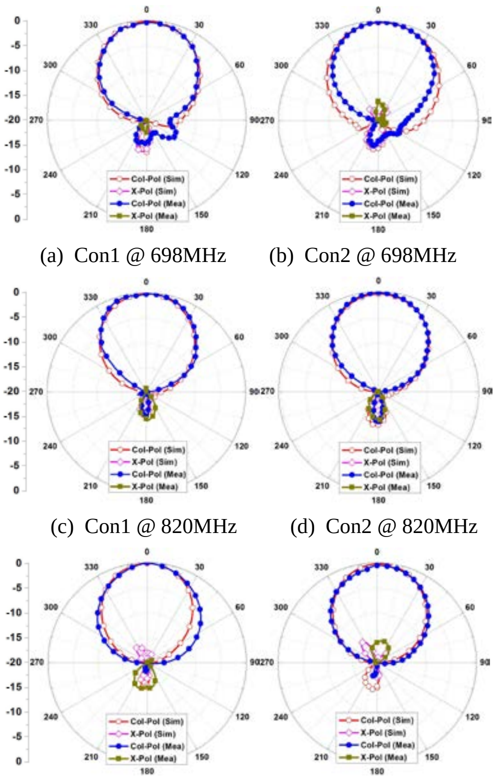
(a)



(b)

Fig. 8 Boresight gains of (a) Con1 and (b) Con2

The boresight gains of the Con1 and Con2 are shown in Figs. 8(a) and (b) respectively. For both the configurations, the cross polarization isolation (XPI) at boresight is higher than 12 dB over the whole frequency band, indicating good polarization purity. The measured boresight gains are from 5.8 to 7.2 dBi and from 5.7 to 7.1 dBi for Con1 and Con2, respectively.



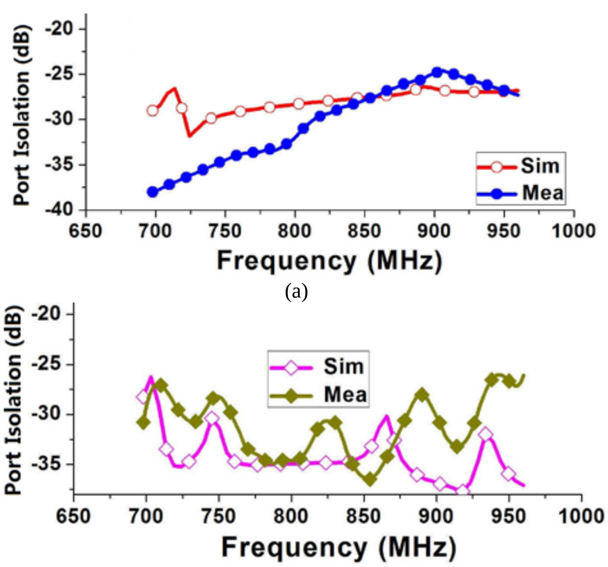
(a) Con1 @ 698MHz (b) Con2 @ 698MHz

(c) Con1 @ 820MHz (d) Con2 @ 820MHz

(e) Con1 @ 960MHz (f) Con2 @ 960MHz

Fig. 9 Radiation patterns of Con1 and Con2 at different frequencies.

Radiation patterns in the *xz*-plane are shown in Fig. 9, where the stable patterns are achieved across the whole operating band. To be more specific, the summary of measured radiation characteristics is listed in Table II. In the frequency band of 698-960 MHz, the cross polarization isolation (XPI) is higher than 11.3 dB within half power beamwidth (HPBW) of the main lobe, stable HPBW of 65°±5° is also achieved.



(a)

(b)

Fig. 10 Port isolations of (a) Con1 and (b) Con2

The port isolations, as shown in Figs. 10(a) and (b), indicate that the isolations between the two ports for both Con1 and Con2 are higher than 25 dB.

TABLE II. SUMMARY OF RADIATION CHARACTERISTICS

Antenna	Frequency (MHz)	Gain (dBi)	HPBW (°)	XPI	
				Boresight (dB)	Minimum value within HPBW (dB)
Con1	698	5.8	70	20.6	18.8
	820	7	63	31	17.5
	960	7.2	61	18.7	12.7
Con2	698	5.7	66	19.2	19.3
	820	6.9	61	26	13.2
	960	7.1	59	32	11.3

IV. Conclusions

We have presented the design of a ±45° dual-polarized waveguide antenna using surface of parallel strips (SPS). The final operating frequency band of the proposed antenna is from 698 to 960 MHz, with a fractional bandwidth of 31.6%. In this bandwidth, the VSWR is lower than 1.5, the half power beamwidth (HPBW) is 65°±5°, the boresight gain is 6.5±0.7 dBi. The cross polarization isolation (XPI) is more than 12 dB at the boresight and more than 10 dB within the HPBW. Results have shown that the proposed antenna can be a potential candidate for the base-station antenna with dual slant polarisation.

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