A Dual-band Dual-polarized Antenna and a Switchable Multi-beam Antenna Array

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Abstract— A dual-band, dual-polarized antenna and a switchable multi-beam antenna array are introduced in this paper. Composed of two orthogonal annular dipoles, the proposed ±45° polarization diversity antenna has two simulated impedance bands: 2.39 GHz ∼ 2.85 GHz and 3.39 GHz ∼ 3.97 GHz, with VSRS < 1.5 and isolation > 28.5 dB. The simulated gain of the antenna is 8.5 dBi at the lower frequency band, and 9.1 dBi at the higher frequency band. In order to compose a $5*3$ polarization diversity antenna array, two 3-to-15 feed networks are employed and placed together, one for each polarization. The whole feed network is manufactured using microwave substrate AD255C with thickness of 0.762 mm and dielectric constant of $\varepsilon_r = 2.55$ and its size is limited to $340\,\text{mm} * 200\,\text{mm} * 30\,\text{mm}$. The output phase as well as the amplitude of each output port of each network is identical. To realize switchable multi-beam capability in horizontal plane, two microwave switches are used for the array. Connected to 3 out of 6 input ports, one switch has 4 gears and the input phase of the feed network is selected from 4 groups of fixed values. Thus the input phase of the antenna elements can be controlled. In other words, this antenna array can radiate at 4 different angles (within ±30° at 2.6 GHz), yet not simultaneously. Simulated results of the antenna and antenna arrays are presented and discussed. Both the return loss, port isolation and the gain are good enough for civil communication applications.

1. INTRODUCTION

In recent years, the tremendous development of electronic science has greatly pushed wireless communication technology forward to satisfy the increasing demands for various wireless communication services such as cellular networks for 3G/4G mobile phones, WiFi and WiMax. As a key factor of wireless communication, base station antennas are consequently put in the face of challenges for wider bandwidth, higher gain and more channel capacity. Since a dual-polarized (usually ±45° polarized) antenna owes an inherent advantage over a linear one in channel capacity and multi-path effects, it has been widely employed in mobile communication base station applications. Meanwhile, if the space available is limited or greater channel capacity is expected, a dual-band antenna then can be very helpful.

A classical way to obtain a ±45° polarized microstrip antenna is to use two excitation sources on the diagonal lines of the patch [1], but the bandwidth is often limited even if stack patches are brought in to provide extra resonance. Transformed dipole antennas have been proved to have a much wider impedance bandwidth than a regular dipole in previously studies [2–4]. By using a cross-pair of such dipoles it can be down to simultaneously obtain two orthogonal polarizations. None of these studies, however, have looked into antenna arrays yet most realistic base antennas are basically arrays. In this paper, a $5*3$ antenna array using the proposed dual-band dual-polarized annular dipole-pair antenna as its element is presented. To make the array produce switchable, multiple beams, a power-dividing phase-shifting microwave switch is used to control the input phase of the feed network, thus the beams is able to cover a certain range in the horizontal plane.

2. DUAL-BAND DUAL-POLARIZED ANNULAR DIPOLE-PAIR ANTENNA

Shown in Fig. 1 is the proposed antenna consisting of two orthogonal annular dipoles for each polarization. Due to mirror image principle, these two dipoles are about 1/4 wavelength away from ground plane with the help of a substrate post made of Teflon with relative permittivity $\varepsilon_r = 2.1$. Each dipole employs a 50 Ω coax as its feed. The outer conduct connects to one arm of the dipole and the inner conduct to the other by using a metal bridge. And a hole is drilled at the center of the post to let the coaxes through.

The S parameters of the antenna are both simulated using Ansoft HFSS and measured with Agilent vector network analyzer. As plotted in Fig. 2, since these two dipoles are not exactly the same (due to excitation matters), simulated S_{11} and S_{22} don't agree very well especially at the higher frequency band, both of them, however, are lower than −14 dB (i.e., VSWR < 1.5) within frequency bands 2.39 GHz $\sim$ 2.85 GHz and 3.39 GHz $\sim$ 3.97 GHz. If VSWR < 2 bandwidth is required instead of VSWR < 1.5, the dual-band dual-polarized antenna becomes a wideband polarization diversity antenna with its frequency band from 2.30 GHz to 4.18 GHz. That's 58% in terms of relative bandwidth. Certainly, this antenna can also be designed to have a wideband other than two spate bands even if VSWR is required to be less than 1.5 [4], but that is not the aim of this paper. As the vertical gap between two bridges inevitably differs from the simulating model because of the narrow space and some practical matter when soldering, the resultant S_{21} also deviate from the simulated one a lot, yet it still remains -20 dB below (not shown in the picture) which is good enough for civil use.

Simulated far field radiation patterns when only one dipole is actually excited are shown in Fig. 3

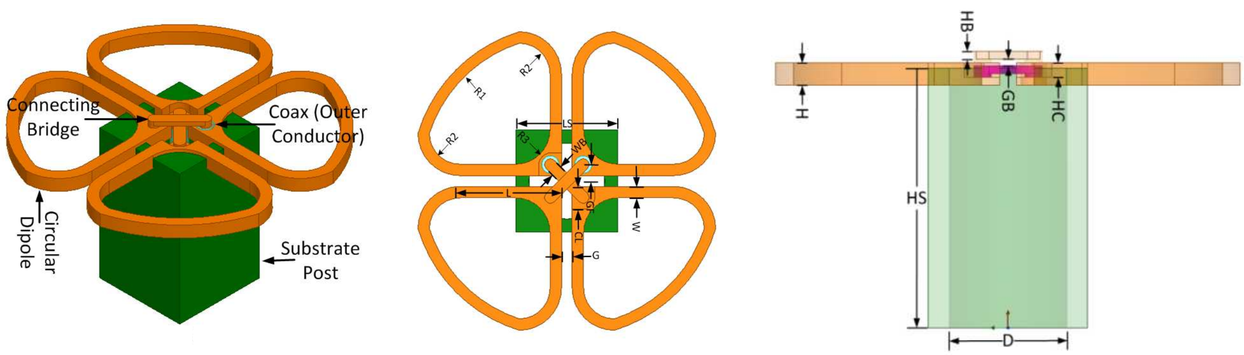

Figure 1: Antenna structure and geometry dimensions. (a) Overall structure. (b) Vertical view. (c) Lateral view. Primary dimension parameters (mm): $L = 10.4$; $W = 1.6$; $WB = 0.8$; $G = 1.5$; $GF = 2.3$; $GB = 0.6$; $R1 = 19.7$; $R2 = 4.3$; $R3 = 4.8$; $H = 2$; $HB = 0.7$; $HC = 1.3$; $HS = 23.2$; $D = 5.3$.

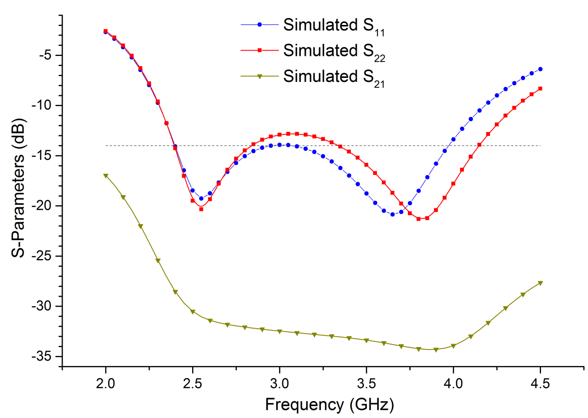

Figure 2: Simulated S parameters.

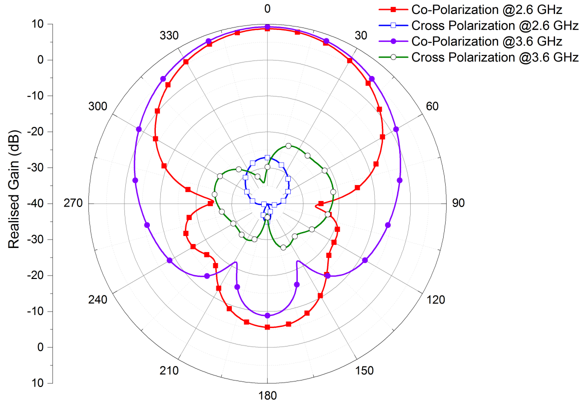

Figure 3: Simulated far field radiation pattern.

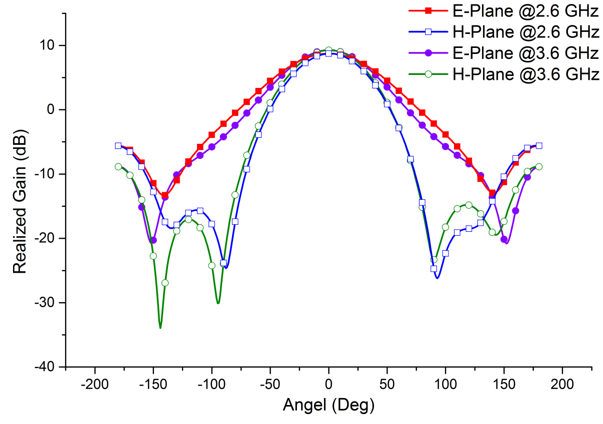

Figure 4: Simulated gain in E-plane and H-plane.

and Fig. 4 at 2.6 GHz and 3.6 GHz. The peak gain is better than 8.5 dB and 9.1 dB respectively. In E-plane, the 3-dB beamwidths at 2.6 GHz and 3.6 GHz are 60.5° and 61.5°, while in H-plane are 83.7° and 67.7°. This dipole also owes a low cross-polarization in both E-plane and H-plane. At 2.6 GHz, it is −25 dB below, and is even better (< -35 dB) at 3.6 GHz.

3. PIMARY DUAL-POLARIZED ANTENNA ARRAY

The primary $5 * 3$ antenna array and the corresponding feed network is shown in Fig. 5. This feed network is designed and manufactured on substrate AD255C with thickness of 0.762 mm and dielectric constant of $\varepsilon_r = 2.55$. It has 3 input ports on both sides and each side feeds one polarization. The input phase of each port of antenna elements is in phase since the feed network is not supposed to produce switchable multiple beams if the switch is not connected. In horizontal plane the power distribution is equal at each port because only 3 antenna elements are placed in this plane, making it very difficult for this specific distribution to come into force.

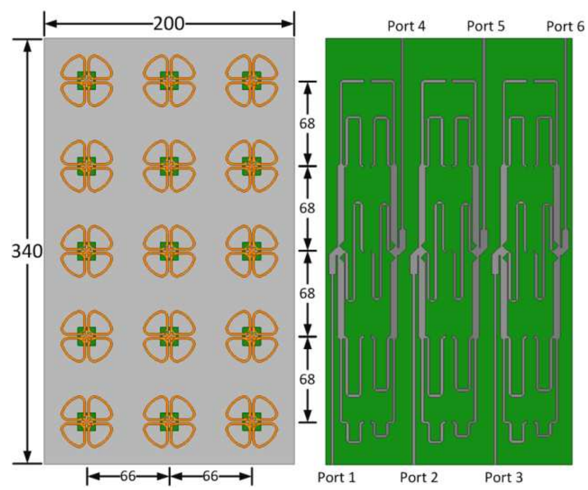

Figure 5: Primary antenna array and feed network. Dimensions are in mm.

4. SWITCHABLE MULTIBEAM DUAL-POLARIZED ANTENNA ARRAY

We designed a switch that has 4 gears and distributes the input power equally to 3 out ports. The gears are controlled by two control level C1 and C0. Once C1 and C0 are determined, the input phase of the feed network is then selected from 4 groups of values to control the input phase of the antenna elements. In other words, this antenna array can radiate at 4 different angles (shown in Table 1) to cover ±30° range in the horizontal plane at 2.6 GHz, yet not simultaneously. As this paper emphasizes on the antenna and antenna array instead of microwave circuits, further details of this switch are omitted here. The whole manufactured antenna array together with the switches connected to the feed network is shown in Fig. 6. Due to our hasty time, we are not able carry out the experiments to get the measured radiation patterns in time, so only simulated far filed results in horizontal plane are presented (see Fig. 7 and Fig. 8). It's clear from these results that the array successfully to obtain gain that is over 16.5 dB within the whole range.

Table 1: The output phase of the switch at 2.6 GHz.

Beam No.	Beam angel (°)	Control level		Output phase (°)	
		C1	C0	Simulated	Measured
Beam 1	21.3	0	0	0/−60/−160	0/−55.4/−159.7
Beam 2	7.6	0	1	0/−60/−60	0/−60.0/−60.2
Beam 3	−8.1	1	0	0/60/60	0/62.7/59.8
Beam 4	−21.2	1	1	0/60/160	0/61.7/161.8

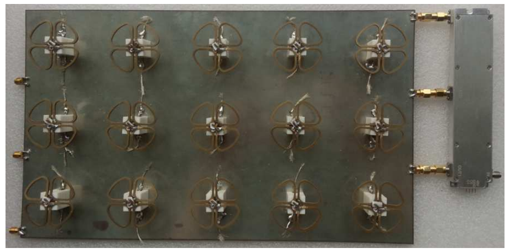

Figure 6: Manufactured antenna array and switch.

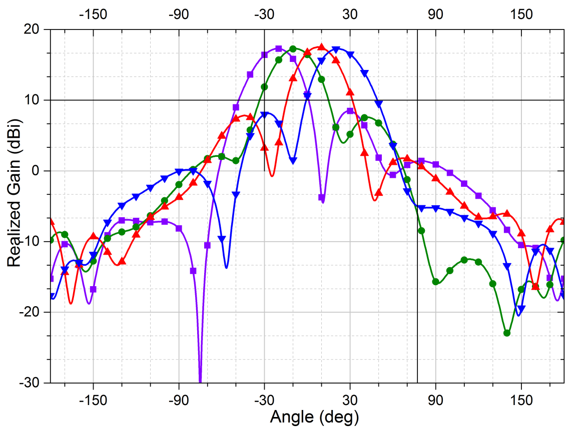

Figure 7: Figure 1 simulated gain of the antenna array.

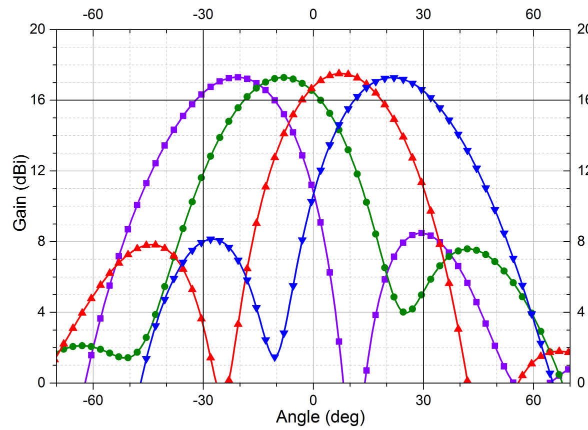

Figure 8: Detailed simulated gain of the antenna array.

5. CONCLUSION

A dual-band dual polarized antenna composed of two orthogonal annular dipoles with high isolation and low cross polarization is presented in this paper. To demonstrate its use in wireless communication base stations, a polarization diversity antenna array is introduced which employs the proposed antenna as its element. Besides, two microwave switches with equal output power and four group of fixed output phase are connected to the feed network in order to make the array produce four selective multiple beams. Simulated results show that these beams manage to cover the $\pm 30^\circ$ range in horizontal plane with gain over 16.5 dB.

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