Design of Wideband Pattern Diversity Antenna for Mobile Communications

Biqun Wu, Student Member, IEEE, and Kwai-Man Luk, Fellow, IEEE

Abstract—A wideband four-port diversity antenna that is capable of exciting four different linear polarizations is presented. The antenna consists of four magneto-electric dipoles arranged in a ring configuration. These dipoles are supported by a cross-shaped feed over a modified ground plane. Three 180°hybrids are used to combine the signals from the four magneto-electric dipoles to produce two orthogonal broadside modes and one conical mode with horizontal polarization. A cross-shaped feed loaded below the four magneto-electric dipoles which are supported by four shorting-pins can radiate a conical beam with vertical polarization. The performance of the proposed antenna is studied numerically and experimentally. The prototype antenna is fabricated and tested successfully. It can achieve about 30% overlapped bandwidth with the centre frequency of 2.2GHz. The isolation between any two ports is greater than 17dB. The two orthogonal conical modes exhibit about 10 dBi average gain. For the two orthogonal broadside modes, an average gain of 6 dBi and 8dBi can be achieved. Measured radiation patterns of the four degenerate modes are stable within the operating band.

Index Terms—Microstrip Antennas, Wideband Antennas, Diversity Antennas, Multiple polarizations, Pattern Diversity.

I. INTRODUCTION

THE great success of the mobile communication services has fostered the development of various wireless communication systems, where high quality performance is required. Fortunately, a wideband complementary antenna is designed as the magneto-electric dipole with a perturbation of its radiation pattern. This concept is further developed using slot antennas instead of microstrip patches [15]. However, these designs suffer from the multipath-fading effects in urban areas [2]. Comparing with classical antennas with a single radiation mode, the pattern diversity antenna, which is capable of radiating and receiving signals from different radiation modes, has the advantages of less installation space, low coupling effect and low installation costs [4]. Several antenna structures offering pattern and polarization diversities have been proposed in the literature [4]-[5]. Unfortunately, the available pattern and polarization diversity antennas suffer from narrow bandwidth [4] and incomplete pattern diversity modes [5]. Thus their applications are limited.

Microstrip antennas are widely used for achieving directional radiation patterns due to their low profile, light weight, low costs, and flexible structure. However, they have the disadvantages of narrow bandwidth and unstable radiation patterns due to their low profile, light weight, low costs, and flexible structure. Excellent electrical characteristics such as low back radiation, stable antenna gain across the operating band, and symmetric E- and H-plane radiation patterns were demonstrated. These attractive features can mitigate the problems of the microstrip patch antennas. Different radiation patterns can be produced by different antenna configurations. The dual-polarized broadside modes can be produced by a microstrip patch antenna and a planar electric dipole, which is equivalent to a combination of a magnetic dipole and an electric dipole. Excellent electrical characteristics such as low back radiation, stable antenna gain across the operating band, and symmetric E- and H-plane radiation patterns were demonstrated. These attracting features can mitigate the problems of the microstrip patch antennas.

The conical beam with vertical polarization can be produced by a round-wave shorted patch antenna and a planar electric dipole, which is equivalent to a combination of a magnetic dipole and an electric dipole. Excellent electrical characteristics such as low back radiation, stable antenna gain across the operating band, and symmetric E- and H-plane radiation patterns were demonstrated. These attractive features can mitigate the problems of the microstrip patch antennas.

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narrow impedance bandwidth and low antenna efficiency. By using the structure of the magneto-electric dipole and the constant current loop concept, a novel wideband antenna structure radiation horizontally polarized conical beam is proposed [9].

In this paper, a wideband four-port diversity antenna which can radiate four different shapes of patterns will be presented. It produces two orthogonal broadside and two orthogonal conical patterns at overlapped operating band. The proposed antenna is a combination of a monopolar plate-patch antenna and four magneto-electric dipoles.

II. ANTENNA DESCRIPTION AND GEOMETRY

The geometry of the proposed antenna operated at around 2.2 GHz is shown in Fig. 1-2, with detailed dimensions shown in TABLE 1. The dimensions were selected after a detailed parametric study for good performance. For the upper part of the proposed antenna, it consists of four magneto-electric dipoles in a ring configuration. The configuration of each magneto-electric dipole is a combination of an electric dipole and a magnetic dipole. Each magneto-electric dipole, which is an electric dipole, is constructed by a pair of sectorial-shape horizontal plates. The electric dipole is connected to the lower part of the antenna, which is equivalent to a folded magnetic dipole. The magnetic dipole is due to a pair of vertically-oriented shorted patch at the ground level. The coaxial cables act like the transmission line with 50 ohm characteristic impedance and the outer metallic shields form the ground plane. The feeding network consisting of three hybrid rings is located under the ground plane. And it is fabricated on a microwave substrate with thickness of 1.0 mm and relative permittivity of 2.65. The feeding network consists of two stages for mode decomposition. The block diagram of the feeding network is shown in Fig. 2. At first stage, both input ports of two hybrid rings are connected to the center core of four coaxial cables. And both isolation ports produce two orthogonal broadside resonant modes. And the output summation port produces horizontal polarized conical beam modes. A modified ground plane is 150 mm. Width of 50 ohm transmission line is 2.7 mm and the width of 70.7 ohm line of hybrid rings is 1.5 mm. The RG402/UT141 coaxial cable with core diameter of 0.91 mm and overall diameter of 3.58 mm is used for antenna fabrication.

III. OPERATING PRINCIPLE

A. Conical Mode with Vertically Polarization
also referred as TM01 mode. The parallel resonance, which is patch with slots to generate the top-loaded monopole mode, horizontal plates can be functioned as a circular microstrip antenna constituted by the upper horizontal plates above the modified ground plane. Coaxial cables act as short-circuit to the capacitance of the modified ground plane.

The top-loaded monopole resonance of antenna [13] [16] is situated well below the inductance of shorting metallic shield of coaxial cables set in generated by the anti-resonating circuit formed by the vertically polarization, it has two resonant modes-parallel and horizontal polarization. To provide in-phase phenomenon can generate a rotationally symmetric beam with horizontal polarization. T o produce a rotational symmetric conical loop is produced above the modified ground plane. And this phenomenon can generate a rotationally symmetric beam with horizontal polarization. Top provide in -phase excitation for the four ports of the magneto-electric dipoles, two stages of hybrid rings are required. The block diagram is shown at Fig. 2.

C. Two Orthogonal Broadside modes

Four magneto-electric dipoles are in ring configuration and are located at 45°, 135°, 225°, 315° with radius equal to 55mm from centre of ground plane. To generate two orthogonal broadside modes, also called TM11 modes, the four dipoles are separated into two groups in which the current flows of the L-shaped coupling strips are perpendicular to each other. For each group including two L-shaped strips, one L-shaped strip is located 180° different from the other. To produce a broadside mode, the two L-shaped strips are fed with 180° out of phase. Theoretically, this configuration could reduce the unwanted cross-polarization from the four vertical co-axial cables.

IV. SIMULATION AND MEASUREMENT RESULTS

A prototype with dimensions shown in Table I was fabricated and tested. Simulated results of SWR, radiation pattern and gain were obtained by commercial EM software- Zeland IE3D. Experimental results were measured by an Agilent network analyzer and a near field antenna measurement system, called SATIMO an antenna measurement system. The near field radiation patterns can be automatically transformed to far field radiation patterns by FFT methods. The SWR bandwidth of four polarizations with the simulated results are obtained by cascading two separated s-parameters of fan antenna an d feeding network to the ideal modeling environment. And the simulated SWR results are obtained in the assumption of zero metallic layer thickness used in modeling the electromagnetic simulation and measurement results. The measured results have good agreement with the simulated results. However, the overall response is very close to the simulation one. Due to fabrication inaccuracy and measurement tolerance, measurement results cannot perfectly match with the simulated results. The measured results slightly deteriorate comparing with the simulated results. Moreover, the simulated results are obtained in the assumption of zero metallic layer thickness used in modeling the electromagnetic simulation and measurement environment. And the simulated SWR results are obtained by cascading two separated s-parameters of fan antenna and feeding network to the ideal modeling environment. The simulated and measured impedance results are obtained by cascading two separated s-parameters of fan antenna and feeding network to the ideal modeling environment.

When the four magneto-electric dipoles are excited simultaneously, an approximately horizontal constant current loop is produced above the modified ground plane. And this phenomenon can generate a rotationally symmetric beam with horizontal polarization. Top provide in -phase excitation for the four ports of the magneto-electric dipoles, two stages of hybrid rings are required. The block diagram is shown at Fig. 2.

B. Conical Mode with Horizontally Polarization

When the four magneto-electric dipoles are excited simultaneously, an approximately horizontal constant current loop is produced above the modified ground plane. And this phenomenon can generate a rotationally symmetric beam with horizontal polarization. Top provide in -phase excitation for the four ports of the magneto-electric dipoles, two stages of hybrid rings are required. The block diagram is shown at Fig. 2.

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(−31.6%) and 1.94GHz and 2.62GHz (−30%) respectively, which is much better than that of most of the horizontally polarized conical beam antenna design found in the literature [4][14][15]. Simulated and measured impedance bandwidths for the -45° polarized dipole (broadside mode with -45° polarization) are ranging from 1.62GHz to 2.63GHz (−47.5%) and from 1.60GHz to 2.81GHz (−55%) respectively. For -45° polarized dipole (broadside mode with -45° polarization), the simulated and measured impedance bandwidths are ranging from 1.62GHz to 3.0GHz (−58.1%) and from 1.73GHz to 2.72GHz (−44.5%) respectively. The main challenge of designing diversity antenna with four modes is tuning all the resonant modes to resonate at a similar frequency range. For the proposed antenna, the simulated and measured overlapped frequency bands of four different resonant modes are ranging from 1.81GHz to 2.49GHz (−31.6%) and 1.94GHz to 2.62GHz (−30%) respectively, which are the frequency band of magnetic monopole.

Fig. 3 and 4 also show the simulated and measured antenna gain over the operating band. The measured gain of four modes is about 1 dB below the simulated gain with similar response. The measured isolation of two orthogonal broadside-ports is lower than -32dB over the operating band. And measured isolation between electric monopole and two orthogonal are lower than -30 dB. Similarly, the measured isolation between magnetic monopole and two orthogonal are lower than -20 dB and -18 dB. Finally, the measured isolation between two orthogonal conical modes is lower than -17 dB. To summarize, all the measured isolations are all lower than -17 dB at the whole operating band.

Fig. 6-8 shows the measured radiation patterns of the two orthogonal broadside modes and the two orthogonal conical modes over the operating band. When one port is measured, the others are open-circuited. The radiation patterns of the four modes are symmetrically polarized and with similar response. For electric monopole (conical mode with -45° polarization), the radiation pattern in the elevation plane is symmetric across the operating band. The levels of cross-polarization are about 13 dB, which may due to the presence of the shorting posts which also radiate unwanted electromagnetic wave. And the maximum beam of the conical pattern is located at about 30°, which is too close to the notch edge of the frequency band. This is because a bulky ground plane will affect the beam width of the radiation patterns. The back lobe levels in the elevation plane are about -15 dB at the operating band.
<table>
<thead>
<tr>
<th>Port</th>
<th>Radiation Pattern</th>
<th>Simulated SWR (GHz)</th>
<th>Measured SWR (GHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Conical beam with horizontal polarization</td>
<td>1.81-2.49 (31.6%)</td>
<td>1.94-2.62 (30%)</td>
</tr>
<tr>
<td>2</td>
<td>Conical beam with vertical polarization</td>
<td>1.5-2.94 (64.9%)</td>
<td>1.5-3.0K (66.7%)</td>
</tr>
<tr>
<td>3</td>
<td>Broadside mode with -45° polarization</td>
<td>1.62-2.63 (47.5%)</td>
<td>1.6-2.81 (55%)</td>
</tr>
<tr>
<td>4</td>
<td>Broadside mode with +45° polarization</td>
<td>1.63-3.0K (59.2%)</td>
<td>1.73-2.72 (44.5%)</td>
</tr>
</tbody>
</table>

Fig. 5 Measured Isolation versus frequency

Fig. 6 Measured conical mode radiation patterns (elevation plane and azimuth plane) with vertical polarization of proposed antenna: (a) 1.9GHz (b) 2.1GHz (c) 2.3GHz

Fig. 7 Measured conical mode radiation patterns (elevation plane and azimuth plane) with horizontal polarization of proposed antenna: (i) 1.95GHz (ii) 2.2GHz (iii) 2.4GHz
Fig. 8 Measured b roadside m ode w ith +/-45° polarized r adiation patterns (elevation p lane) o f p roposed a ntenna: (i) 1.95GHz (ii) 2.1GHz (iii) 2.3GHz

V. CONCLUSION
A wideband diversity antenna has capability of exciting four radiation patterns, which include two or thogonal broadside patterns and two or thogonal conical patterns. By optimizing the location of co-axial cables and other antenna parameters, the resonant frequencies of four modes could be shifted into an overlapped frequency band. Thus two orthogonal broadside modes and conical modes could be excited at an overlapped operating band. The isolation between the ports is very low, with high efficiency and is perspective of the proposed antenna. Comparing with most conventional wideband pattern diversity antennas available in literature [1-5] [8] [10 -11], this kind of antenna can greatly improve the system performance by providing a full coverage radiation pattern in E- and H- planes, while hich introduces additional degrees of freedom in steering and beam forming when implemented in an array configuration.

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VII. REFERENCES

VIII. BIOGRAPHIES
Biqun Wu was born in Guangdong, China. He received the B.Eng. degree (first class honors) in electronic engineering from City University of Hong Kong, in 2007. His research interest focuses on patch antenna design.

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