Pattern Reconfigurable WidebandCircularly-Polarized Quadrifilar Helix with Broadside and Backfire Radiation Patterns

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Abstract—This paper introduces a pattern reconfigurable wideband circularly-polarized (CP) quadrifilar helical antenna (QHA) with both broadside and backfire radiation modes. A compact 1:4 power divider network is proposed to feed the QHA for obtaining the wide bandwidth. To realize pattern diversity, PIN diodes on the power divider are to reconfigure the sequences of the output phases such that the direction of radiation pattern can be controlled alternatively for the broadside or the backfire radiation. The fabricated antenna prototype is compact and light-weight. Measured results show that the broadside and backfire radiation modes can be switched by applying opposite voltages on the two DC bias. The proposed QHA has the wide impedance bandwidth of 43% and the wide 3-dB AR bandwidth of 38%. The measured broadside and backfire radiations have the wide 3-dB gain beamwidth of 140° and 120°, with the maximum gain of 2.3 and 3.0 dBi, respectively. The proposed antenna can be used in many applications as subway and railway communications, base station for narrow street coverage, RFID or satellite systems.

Index Terms—pattern reconfigurable, quadrifilar helix antenna, broadside and backfire radiation modes.

I. Introduction

With the rapid development of wireless communication systems in recent years, antennas with reconfigurable functions such as frequency, polarization and pattern reconfigurable antennas have drawn much attention for many attractive features [1]—[3]. For example, antenna with pattern diversity can increase the channel capacity of wireless system, enhance the signal-to-noise (SNR) ratio and provide larger radiation coverage by reconfiguring the main beam.

Many efforts have been contributed to pattern reconfigurable antennas as in [4]—[8]. For an instance, four sequential rectangular patches with a reconfigurable feeding network in [4] can generate either broadside or conical-beam radiation patterns. In [5], a top-loaded monopole with a patch embedded with diodes and varactors is able to radiate either directional or omni-directional waves. In addition, a cross-shaped patch with four reconfigurable parasitic patches in [6] can realize a null scanning pattern by adjusting the varactors between the patches. In [7], the antenna with a loop-and-dipole structure switches the main beam towards three directions by controlling the switches for MIMO applications. Moreover, a reconfigurable Yagi-Uda antenna proposed in [8] can change the radiation into four directions by controlling RF switches.

All above examples exhibit different pattern diversity characteristics. In this paper, we propose a new pattern reconfigurable QHA with both broadside and backfire radiation patterns. We applied a compact feeding network for the QHA to obtain a wide bandwidth. Furthermore, we introduced PIN diodes on the transmission lines of the feeding network to reconfigure the phase differences of the four sequential outputs. In this manner we alter the antenna radiation between broadside and backfire modes through two DC bias. The designed antenna has the wide overlapped impedance and AR bandwidth of 38% and the wide 3-dB beamwidth of 140 degree. In addition, the antenna has a compact size and light weight. This unique pattern diversity feature makes it useful in different applications such as subway and railway communication, satellite communication, RFID or communication inside a narrow street scenario.
II. Antenna Design

A. Antenna Configuration

The antenna consists of a QHA with a compact feeding network as seen in Fig. 1. This compact feeding network contains two identical Wilkinson power dividers stacked back to back with a common ground. The transmission lines are bented for size-reduction. Four output ports are aligned sequentially to feed the helix with a short-circuited ring on the top. For achieving reconfigurable patterns, we inserted PIN diodes in the transmission lines to reconfigure the shape of the feeding network so that broadside and backfire modes can be switched. In addition, another substrate for DC bias lines is placed below the feeding network. All the detailed parameters are listed in the table I.

B. Reconfigurable Compact Feeding Network

One of the characteristics in this QHA is that the broadside or backfire radiation pattern can be obtained by the different phase outputs of the feeding network. For example, if the QHA is right-handed winding, the broadside radiation pattern with left-handed circular polarization (LHCP) is generated when the phases of the four sequential outputs are clockwisely delayed. On the contrary, the backfire radiation mode is observed when the four output phases are anti-clockwisely delayed. Therefore, we modified our prior work as in [9] to realize a reconfigurable feeding network which output phases are switchable.

Figure 2 shows the geometry of the reconfigurable feeding network. Two sets of the PIN diodes (Type Bar50-02L from Infineon Technologies [10] marked with red and green color) are introduced in the feeding network. The characteristics of the PIN diode as shown in Fig. 3 exhibit good isolation (more than 18 dB) and low insertion loss (less than 0.45 dB) within the antenna operating band. If all the red diodes are turned on and all the green diodes are turned off, the four output phases are clockwisely delayed, such that the broadside radiation pattern is generated. On the opposite, if all the green diodes are turned on and all the red diodes are turned off, the backfire radiation pattern is generated. Therefore, by controlling the status of the PIN diodes, the broadside mode and backfire mode can be altered as shown in Table II and Fig. 4.
C. Design of the Quadrifilar Helical Radiator

Another important design consideration is the helical structure which will determine the radiation pattern. To design the QHA to operate at the center frequency 1.5 GHz, the length of each helical arm is optimized to 83 mm according to the analysis in reference [9]. The radiation beamwidth of the QHA is strongly dependent on the winding shape of the helix. Figure 5 shows the radiation patterns of different helical structures at the same resonant frequency. The QHA with less turns has broader radiation beamwidth but lower gain. The radiation beamwidth and broadside gain of QHA are varying in a contradictory manner. This parametric study provides a guideline to obtain the desired radiation patterns of the QHA for different applications. For example, satellite navigation systems like the GPS of the U. S. or CNSS of China require antennas have broader radiation pattern as the 1/4 turn helix in Fig. 5. On the contrary, other systems like RFID prefer antennas with high broadside gain as the 1/2 turn helix.

III. Measured Results

The proposed antenna was fabricated as shown in Fig. 6. In order to obtain the broader beamwidth, quarter turn helix was chosen in the final implementation. The QHA radiator was coiled by copper wires. All the substrates have the same permittivity $\varepsilon_r = 2.65$, the thickness of 1 mm and the loss tangent of 0.001 from Wangling Ltd. PIN diodes with surface mount type 0403 (1 mm × 0.6 mm) were soldered between the transmission lines for switching. Two DC bias lines were adopted for controlling the diodes. One DC line was connected to the two quarter-wave transformers as DC#1 and another was connected to the four output ports as DC#2. The antenna is fed by a coaxial cable in the center.
Figure 7 shows the measured reflection coefficients and the axial ratio bandwidths for both broadside and backfire modes of the proposed antenna. A wide overlapped bandwidth for an impedance bandwidth of 43% and an axial ratio bandwidth of 38% is obtained. Figure 8 exhibits the measured broadside gain across the operating band for both modes. The maximum gain is 2.3 dBi for the broadside mode and the peak gain for backfire mode is 3.0 dBi. Measured radiation patterns at the center frequency for both modes are found in Fig. 9. The broadside radiation mode is realized when DC#1 is set to 3V and DC#2 is 0V. The pattern has the broad beamwidth of 140 degree with the broadside peak gain of 2.3 dBi. The backfire radiation mode can be achieved when DC#1 is 0V and DC#2 is set to 3V. In this state, the pattern is pointing downward with the beamwidth of 120 degree and the peak gain of 3.0 dBi.

IV. Conclusion

A pattern reconfigurable quadrifilar helical antenna is studied in this paper. The QHA can obtain either broadside or backfire radiation pattern by controlling the PIN diodes on the feeding network. Good cardioid-shaped radiation patterns are realized for both radiation modes. In addition, the antenna has a compact size and light weight. The proposed antenna with the unique pattern diversity is suitable to be used for many applications such as subway and railway communication, satellite communication, RFID or communication inside a narrow street scenario.

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References


