Wideband Dual-Polarized Antenna For Spectrum Monitoring Systems

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***Abstract*—An antenna merging inverted-cone monopole and cross bow-tie dipole are presented for achieving dual polarizations while maintaining a wide bandwidth. The proposed design consists of an inverted-cone hollow tube, a small circular ground, and a cross bow-tie dipole with a conductor ring. The inverted-cone monopole is fed by a 50-Ω *N*-type connector to realize a vertical polarization (VP). The cross bow-tie dipole is excited by a broadband feeding network to achieve a horizontal polarization (HP). More importantly, the cross bow-tie dipole not only serves as the radiating element for the HP, but also acts as the ground plane for the inverted-cone monopole. Additionally, the antenna can achieve omnidirectional radiation patterns in particular frequency band for VP and HP, respectively. Simulated results show that the inverted-cone monopole achieves a wide-impedance bandwidth (for $|S_{11}| < -10$ dB) from 190 to 850 MHz, and the cross bow-tie dipole realizes a wide operating bandwidth from 80 to 880 MHz. A prototype of the proposed antenna is fabricated and tested. Measured results are in good agreement with simulated ones.**

***Index Terms*—Cross bow-tie dipole, dual polarizations, inverted-cone monopole, omnidirectional radiation patterns.**

I. Introduction

SPECTRUM monitoring systems have attracted great attention due to their practical applications. Generally, spectrum monitoring systems require that the antennas have characteristics of broad operating bandwidth, dual polarizations, omnidirectional radiation patterns, and compact sizes. However, according to existing reported literature, the design of such antennas with the above features is quite challenging now.

Up to now, single-polarized omnidirectional antennas are widely used in spectrum monitoring systems. To achieve vertical polarization (VP), coaxial collinear antenna [1], dipole [2], and cavity-backed loop [3] were proposed. However, their bandwidths are relatively narrow. Therefore, ultrawideband monopole, e.g., the inverted-hat [4], is a good candidate for bandwidth improvement. To realize horizontal polarization (HP) omnidirectional radiation pattern, a conventional solution is to employ a small loop [5]. Nevertheless, it is extremely difficult to obtain a good impedance matching over a wide band. Thereupon, a series of sophisticated loop and dipole structures [6], [7] were proposed to improve the impedance matching and bandwidth. Unfortunately, single-polarized antenna has limited applications in modern spectrum monitoring systems. Therefore, designing a compact dual-polarized antenna is an imperative and challenging task.

Combining two separate single-polarized antennas is the most efficient way to achieve dual polarizations. However, it is a challenge to integrate two elements in the same volume-limited platform due to the trenchant application requirements. Several solutions were proposed to solve the difficulties [8]–[11]. In [8], a narrowband design with two orthogonal slots etched on the slender columnar cuboid was developed. To improve the bandwidth, the antenna that consists of a modified low-profile monopole and four curved dipoles was proposed in [9]. A wider bandwidth antenna was also presented in [10] using a modified asymmetric biconical and six printed dipoles, while its dimension is not suitable for miniaturization. Although all of the existing solutions used their delicate designs to integrate VP and HP elements into one platform successfully, the elements are individual and there are no sharing parts for the VP and HP elements.

In this letter, a wideband dual-polarized antenna is proposed for the 80–800 MHz spectrum monitoring system. An inverted-cone monopole is utilized for the VP, while the cross bow-tie dipole is employed for the HP and served as the ground plane for the inverted-cone monopole simultaneously. In this case, no extra ground is needed for the monopole, resulting in a compact size. In addition, a conductor ring is added to improve the impedance matching for the cross bow-tie dipole at the low frequency band [12]. The proposed design has the following features: 1) The cross dipole not only acts as the radiating element for the HP but also serves as the ground plane for the VP simultaneously. 2) VP and HP are implemented in a compact volume. 3) Good isolation can be obtained between monopole and cross dipole.

II. Antenna Design and Analysis

A. Antenna Design

The configuration of the proposed dual-polarized antenna is shown in Fig. 1. It consists of an inverted-cone hollow tube, a small circular ground, and four bow-tie arms with a rectangular conductor ring. The small ground and feeding structure are located at the center of four bow-tie arms, as shown in Fig. 1(a). Fig. 1(b) depicts the side view of the proposed antenna and the geometry of the inverted-cone hollow tube. In addition, the

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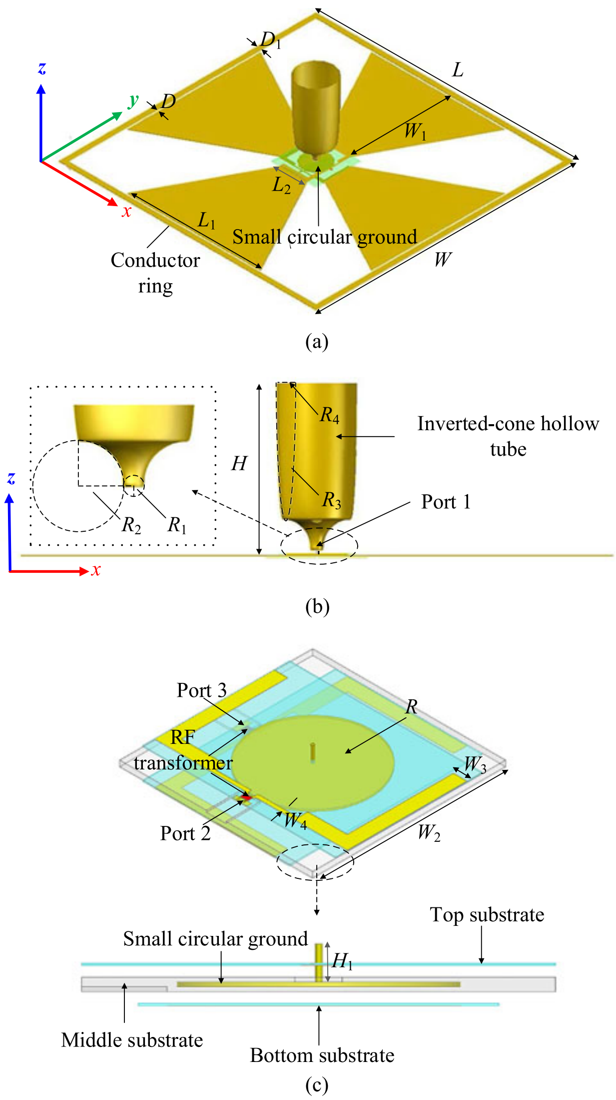

Fig. 1. Configuration of the proposed dual-polarized antenna. (a) Three-dimensional view. (b) Side view. (c) Feeding structure (L = 1160 mm, L_1 = 600 mm, L_2 = 120 mm, W = 1160 mm, W_1 = 450 mm, W_2 = 200 mm, W_3 = 14 mm, W_4 = 4 mm, R = 60 mm, R_1 = 12.7 mm, R_2 = 53.34 mm, R_3 = 266.7 mm, R_4 = 12.7 mm, H = 333.74 mm, H_1 = 10 mm, D = 10 mm, and D_1 = 20 mm).

small ground is integrated into the middle substrate of the feeding structure, which is illustrated in Fig. 1(c). The length and width of the dual-polarized antenna are denoted by L and W, respectively.

For the VP inverted-cone monopole, a 50-Ω N-type connector is employed to feed the monopole, whose inner coaxial probe and outer conductor are connected to the small ground and inverted-cone tube, respectively. Both the small ground and bow-tie arms serve as the ground plane for the inverted-cone monopole. In order to achieve a nearly stable radiation over a wide bandwidth, the surface of the inverted-cone tube is constructed by two circular and an elliptically contoured surfaces, as shown in Fig. 1(b). The radii of the small circular ground and two circular surfaces are R, R_1, and R_2, respectively. R_3 and R_4 represent the major and minor axes of the elliptical surface, respectively. The height between the small circular ground and inverted-cone tube is denoted by H_1.

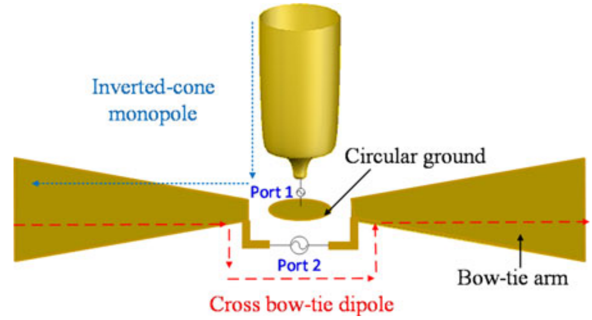

Fig. 2. Simplified operating schematic of the proposed dual-polarized antenna.

For the HP cross bow-tie dipole, the feeding striplines are printed on the top and bottom substrates, respectively. Each of the striplines is connected by a 50–200-Ω RF balun. A rectangular conductor ring is added to improve the impedance matching at the low frequency band [12]. D is the gap between bow-tie arms and conductor ring, and the width of the conductor ring is D_1. As shown in Fig. 1(a) and (c), L_1, L_2, and W_1 represent the size of the bow-tie arms. W_2, W_3, and W_4 are widths of substrates and printed feeding striplines, respectively.

B. Antenna Analysis

The proposed dual-polarized antenna integrates two types of elements: inverted-cone monopole and cross bow-tie dipole. The inverted-cone monopole's width and height determine its lowest frequency. The high frequency performance is determined by the number of elliptical segments and by adjusting the outer surface profile. Its feed generates outward traveling waves producing a vertically polarized radiation over the horizon. Moreover, in order to radiate a horizontally polarized omnidirectional radiation at the lower frequency, the cross bow-tie dipole is employed in our design and excited by an input signals with 90° phase difference [13].

A small circular ground is designed at the center of the four bow-tie arms as the sharing part of two radiating elements, which have different functions in the designed antenna system. The simplified operating principle of the proposed dual-polarized antenna can be displayed in Fig. 2. When the inverted-cone monopole (Port1) is excited, the currents flow from the small ground to the bow-tie arms through electromagnetic coupling, which excite the ground current distributions of the typical monopole antenna on bow-tie arms successfully. When cross bow-tie (Ports 2 and 3) are excited, the gaps between circular ground and bow-tie arms act as an open circuit, so that most of the currents flow from one bow-tie arm to the other arm via port, because the port serves as a short circuit for the antenna, which pledges the cross bow-tie dipole can be excited triumphantly.

III. Simulated Results and Experimental Verification

A prototype is fabricated to characterize the performance of the proposed dual-polarized antenna. In this design, the feeding striplines are printed on FR4 substrates with relative permittivity of 4.4, loss tangent of tanδ = 0.02, and thickness of 1 mm. Two ADT4 50–200-Ω RF baluns are soldered on the top and bottom substrates, respectively. Fig. 3 illustrates the photograph

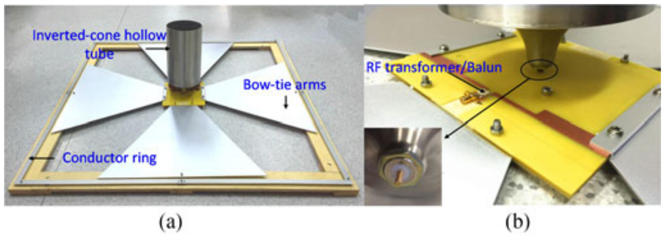

Fig. 3. Photograph of the fabricated (a) dual-polarized antenna and (b) feeding structure.

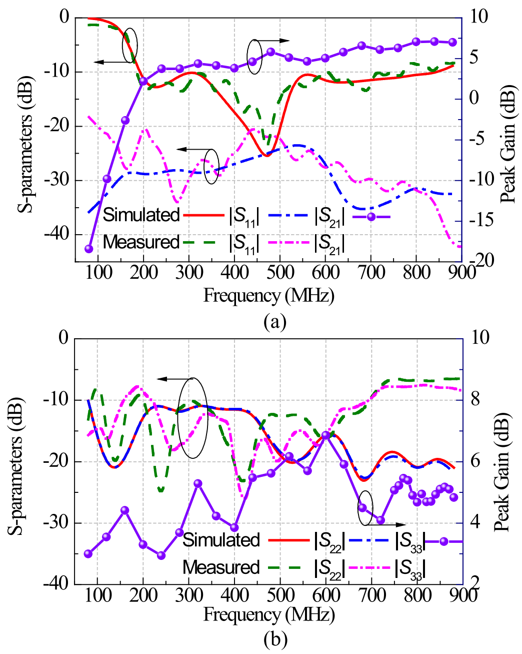

Fig. 4. Measured and simulated S-parameters of the proposed dual-polarized antenna. (a) Inverted-cone monopole and its mutual coupling $|S_{21}|$ with cross bow-tie dipole. (b) Cross bow-tie dipole.

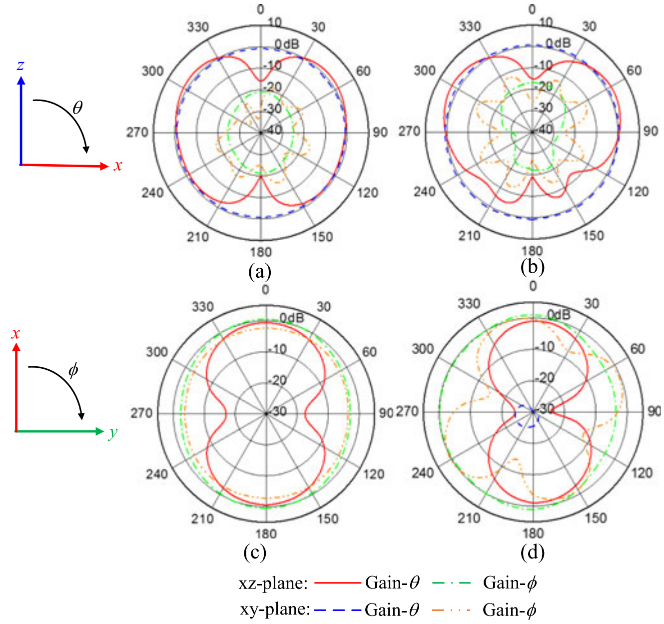

Fig. 5. Simulated radiation patterns of the proposed inverted-cone monopole at (a) 200 MHz, (b) 400 MHz, and the proposed cross bow-tie dipole at (c) 100 MHz and (d) 200 MHz under the same amplitude, and 90° phase difference excitation.

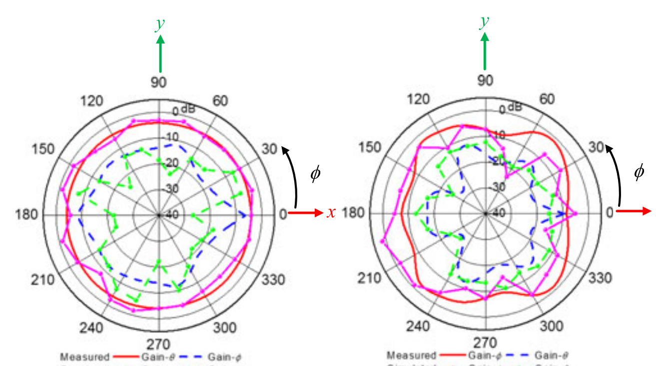

Fig. 6. Measured and simulated xy-plane radiation patterns of the dual-polarized antenna at 800 MHZ. (a) VP. (b) HP.

of the fabricated dual-polarized antenna. It should be noted that due to the parasitic characteristic of the RF balun, HFSS is not suitable for simulating the performance of the whole antenna. Instead, we create a 50-Ω lumped port (Port 1) to excite the inverted-cone monopole and two 200-Ω lumped ports (Ports 2 and 3) with the same amplitude, and 90° phase difference for the cross bow-tie dipole by assuming the RF balun is an ideal device. Additionally, due to the limitation of the measurement environment at the low frequency, we only measured the xy-plane radiation pattern of the dual-polarized antenna at 800 MHz in the free space.

The performance of the proposed dual-polarized antenna without phase shifter and power divider is measured using a calibrated Agilent vector network analyzer. The comparison between the simulated and measured S-parameter results is shown in Fig. 4(a) and (b). It is clear that the simulated 10-dB return-loss bandwidth is from 190 to 850 MHz for the inverted-cone monopole, while the measured one is from 190 to 780 MHz. Additionally, the simulated operating frequency range of the cross bow-tie dipole ($|S_{22}|$ and $|S_{33}| < -10$ dB) is from 80 to 880 MHz. The measured 10-dB bandwidths are nearly across 80 to 700 MHz except some low frequency bands, which are mainly caused by the wood bracket for measurement. Moreover, the measured bandwidth of the cross bow-tie dipole is 180 MHz narrower than the simulated one, and this is mainly due to the parasitic operating bandwidth of the RF balun, which is about from 1 to 700 MHz. Fig. 4(a) also displays the mutual coupling between monopole and cross dipole antennas, which is below –23 dB for the simulated result and –20 dB for the measured one. The simulated peak gain values of the monopole and cross bow-tie are plotted in Fig. 4(a) and (b), respectively. The simulated peak gain values of the monopole are 1 dB at 190 MHz, and increase to 7 dB at 850 MHz. In addition, the simulated peak gain values of the cross bow-tie dipole are 3 dB at 80 MHz and increase to 6.8 dB at 600 MHz, then drop to 4.8 dB at 880 MHz. Additionally, the simulated radiation patterns of the inverted-cone monopole and cross bow-tie at different frequencies are presented in Fig. 5. Fig. 6 presents the measured radiation

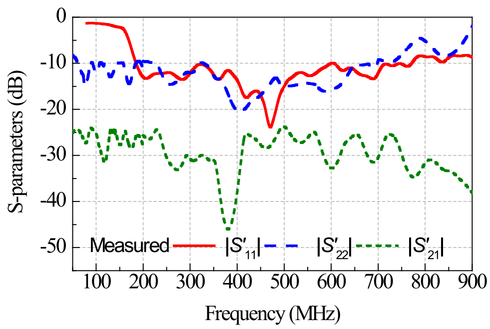

Fig. 7. Measured S-parameters of the proposed dual-polarized antenna integrated with power divider and phase shifter.

TABLE I
PERFORMANCE COMPARISON OF EXISTING DUAL-POLARIZED ANTENNAS

Ref.	Sizes (λ_L) (λ_L at the Lowest Frequency)	Type of Polarization	Bandwidth (10-dB Return Loss)	Bandwidth (3-dB Gain Variation)
[9]	$0.68 \times 0.68 \times 0.15$	VP	55.3%	25.6%
		HP	25.6%	25.6%
[10]	$0.45 \times 0.45 \times 0.31$	VP	17.4%	17.4%
		HP	35%	35%
[11]	$0.57 \times 0.43 \times 0.43$	VP	35%	35%
		HP	30%	30%
This work	$0.31 \times 0.31 \times 0.21$	VP	121.6%	86.57%
		HP	159%	57.78%

pattern in the xy-plane of the dual-polarized antenna at 800 MHz. The differences are caused by the measurement tolerance. It is clear from Figs. 5 and 6 that the inverted-cone monopole exhibits the desired monopole-like patterns at all frequencies and the cross bow-tie can achieve omnidirectional radiation at the low frequency. The bandwidths of gain variation less than 3 dB are from 190 to 480 MHz for VP and from 80 to 145 MHz for HP.

In order to characterize the cross bow-tie dipole experimentally, a simple power divider combined with a 90° phase shifter is utilized for merging Ports 2 and 3. Due to the ultrawideband from 80 to 800 MHz, two 90° phase shifters [14] are designed and fabricated to test the performance of our proposed cross bow-tie dipole, whose 10-dB return-loss bandwidth are from 80 to 200 MHz and from 200 to 800 MHz, respectively. The phase deviations are all within ±6°. Fig. 7 shows the measured S-parameters of the proposed antenna with power divider and phase shifters. It is seen that the bandwidth is from 190 to 780 MHz for the inverted-cone monopole and from 80 to 700 MHz for the cross bow-tie dipole. The two antennas exhibit a good isolation (at least 24 dB), in spite of the fact that they are sharing the same radiation aperture.

It should be highlighted that our proposed dual-polarized antenna can operate efficiently for the 80–800-MHz spectrum monitoring system because the final design is a tradeoff between performance and antenna size. For example, for the VP application, in order to prevent the radiation pattern splitting seriously at the higher frequency, we have to sacrifice the return loss and gain at the lower frequency. Albeit the gain value at 80 MHz is –17 dB, it still can be used based on a high-sensitivity receiver. For the HP application, although the gain variations in xy-plane increase ineluctably at the higher frequency, it is still can be employed in the practical application as long as we know the blind spots from the radiation pattern.

Table I summarizes the performance comparison of existing dual-polarized antennas. Compared to other dual-polarized antennas, our proposed antenna exhibits the advantages in terms of return-loss bandwidth, gain variation bandwidth, and the antenna size.

IV. CONCLUSION

A wideband dual-polarized antenna has been presented. This antenna uses a small circular ground plane to combine the inverted-cone monopole and cross bow-tie dipole together. The operating principle of the proposed antenna has been analyzed based on the simplified schematic. The S-parameters of the antenna have been verified by experimental measurements, which demonstrate that our proposed antenna has a great potential for spectrum monitoring systems.

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