A Low-Profile, Wideband, Vertically-Polarized Antenna with Directional Radiation Patterns in the Azimuth Plane

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***Abstract*—A low-profile, wideband, vertically-polarized antenna with directional radiation characteristics in the azimuth plane is proposed. The antenna is composed of four half-loops with the shape of bent diamond arms that are fed at the center and short circuited to the ground plane at their ends. Two of the loops are fed in phase and the other two are fed out of phase. Then, these two antenna arrays are fed using a proper feed network to obtain a cardioid-shaped radiation pattern over a very large bandwidth (6:1). The antenna has electrical dimensions of $0.77\lambda_{min} \times 0.77\lambda_{min} \times 0.09\lambda_{min}$ at its lowest frequency of operation.**

I. INTRODUCTION

HF/VHF/UHF bands are commonly used for many communications applications including military systems. Monopole whip antennas are widely used at these frequency bands. However, whip antennas are generally very high-profile and can only provide omni-directional radiation patterns. In certain applications, HF, VHF, or UHF antennas that provide directional radiation patterns are required. Examples include applications where multiple antennas are mounted on the same platform, resulting in co-site interference between antennas operating in the same band. Another application is jamming and electronic warfare applications where a significant amount of RF energy is to be directed towards a given direction while minimizing radiation in undesired directions.

In this paper, we present a low-profile, vertically-polarized antenna capable of providing directional radiation patterns along the azimuth plane over a very wide bandwidth. The proposed antenna is composed of four individual wideband radiators placed in a compact volume and it provides a cardioid-shaped radiation pattern. Cardioid-shaped radiation patterns have long been used for direction finding applications at low RF/microwave frequencies [1]. These patterns are also suitable for achieving directional radiation patterns for the aforementioned applications due to the high front-to-back ratios they provide. In what follows, the antenna design and principles of operations along with simulation results of a prototype are presented and discussed.

II. ANTENNA DESIGN

Cardioid-shaped patterns can be created by properly combining an omni-directional pattern with a figure-eight pattern in the azimuth plane [1]. In [1], a vertical monopole over a large ground plane is used to produce the omni-directional pattern while the required figure-eight pattern is created by a horizontal slot antenna in the same ground plane. The proper combination of these two patterns leads to a combined cadioid-shaped pattern.

For ultra-wideband applications, antennas covering a larger frequency band are needed. Fig. 1 shows the topology of such an antenna. It consists of four half-loop antennas placed in close proximity of each other. Each half loop is in the shape of a bent-diamond arm and is loaded by a top hat. Each loop is fed at its center and its other end is short circuited to the ground plane. These antennas are compact, low profile and ultra-wideband antennas [2]. When two of the half-loops (antennas 1 and 2) are fed in-phase, they provide an omni-directional pattern over an extremely broad bandwidth [2]. When the other two half-loops (antenna 3 and antenna 4) are fed 180° out of phase, they provide a figure-eight-shaped radiation pattern in the azimuth plane [3]. Total physical dimensions of the entire antenna are 34 cm × 34 cm × 4 cm.

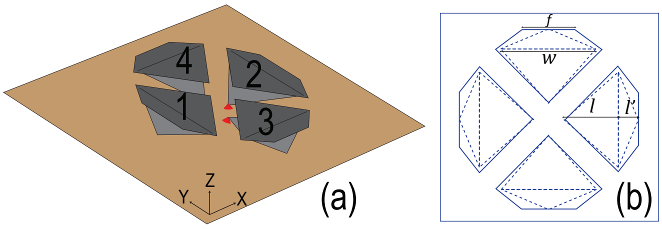

Fig. 1. (a) Three dimensional (3-D) topology of the proposed antenna. (b) Top view of the antenna. The labled values are as follows: W=18, f=10, l=10, l'=3.8. All the values are in cm.

To create a cardioid-shaped pattern, the realized gain of the common-mode array and that of the differential-mode array must be equal towards the direction of the maximum radiation. The presence of a null and a maximum in the radiation pattern can then be assured by matching the phases of the radiated fields of the two arrays along the direction of maximum radiation. This can be accomplished using an amplification (attenuation) unit and a phase shifter as shown in Fig. 2. Alternatively, one can use a broadband, unequal power divider along with an appropriate phase shifter to accomplish this.

To illustrate the principles of operation of this antenna, in this paper we use the feed network shown in Fig. 2 while

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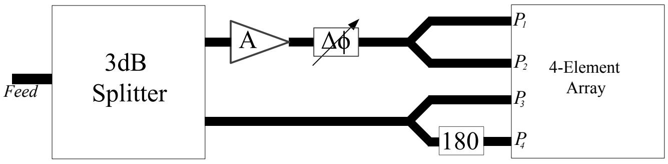

Fig. 2. Topology of the feed network.

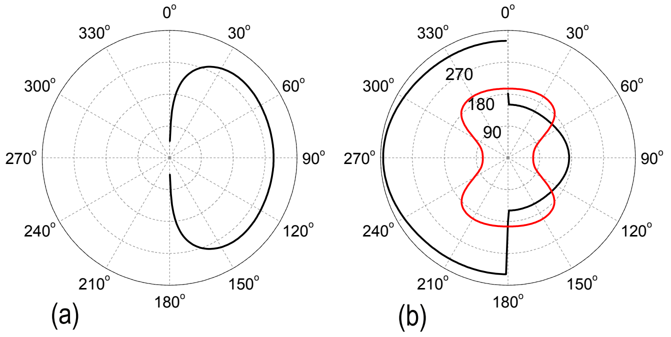

Fig. 3. (a) Realized gain values of the two arrays and the normalized combined cardioid-shaped pattern (b) Phases of the fields radiated by the two arrays.

acknowledging that using a feed network composed of an unequal power divider and a phase shifter is likely a better solution. As seen in Fig. 2, a 3-dB power splitter is used to divide the input signal power between the two antenna arrays. Then, the required amplification (or attenuation) unit and phase shifter are placed before the common-mode array. Fig. 3(a) demonstrates the realized gain values of the two arrays in the azimuth plane at 1 GHz. Fig. 3(b) shows the corresponding phases of the radiated fields. As observed, the gain values are 2.64 dB and 2.4 dB for the common-mode and differential-mode arrays along the direction of maximum radiation (ϕ=90°), respectively. The phases of the radiated waves are 173° and 70° for the common-mode and differential-mode arrays along the direction of maximum radiation (ϕ=90°), respectively. Therefore, the needed amplification and phase shifter values are 0.24 dB and 103° to result in the radiation pattern shown in Fig. 3(a). As expected, this pattern has a maximum in one direction (ϕ=90°) and a deep null in the reverse direction (ϕ=270°) providing a high front-to-back ratio.

III. SIMULATION RESULTS AND DISCUSSION

Based on the simulated input impedance of the common- and the differential-mode arrays, the lowest frequencies of operation of these two arrays are respectively determined to be 575 and 680 MHz. Considering 680 MHz to be the lowest frequency of operation of the antenna, the antenna has electrical dimensions of $0.77\lambda_{min} \times 0.77\lambda_{min} \times 0.09\lambda_{min}$ at this frequency.

The feed network parameters (amplification and phase shift levels) can be chosen properly to create cardioid-shaped patterns. Since such patterns are desired over a large frequency band, these values must be determined to satisfy the two conditions described above over the entire bandwidth. Therefore, the same procedure is performed to choose the required feed network parameters at different frequencies. Since the values are frequency dependent, achieving deep nulls over the entire bandwidth requires using a rather complicated feed network capable of providing the desired amplitude and phase of excitation at each specific frequency. However, a good front-to-back ratio can still be achieved using a frequency-independent feed network. In this work, the averages of the required amplitudes and phases of the excitation coefficients are chosen for both amplification and phase shift values. These are respectively 2 dB and 90°. Fig. 4 shows the azimuthal radiation patterns of the antenna from 300 MHz to 1.8 GHz. As observed, over a 6:1 bandwidth, the antenna presents directional radiation patterns along the azimuth plane. However, at 300 MHz, the two arrays are highly-impedance mismatched and consequently, the realized gain of the antenna will be very small. As frequency increases beyond 600 MHz, the overall antenna efficiency and its realized gain increase considerably. Nonetheless, with the simple, frequency-independent feed network shown in Fig. 2, directional radiation patterns with front-to-back ratios exceeding 10 dB can be achieved over a 6:1 bandwidth.

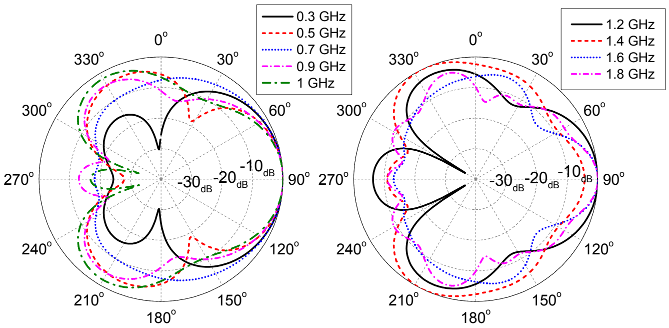

Fig. 4. Normalized radiation patterns of the antenna in the azimuth plane.

IV. CONCLUSION

A low profile and compact antenna demonstrating directional radiation patterns over a very large bandwidth is presented. This antenna has electrical dimensions of $0.77\lambda_{min} \times 0.77\lambda_{min} \times 0.09\lambda_{min}$ at its lowest frequency of operation and has an input VSWR better than 3:1 over almost a 4:1 bandwidth. It also shows directional radiation patterns over almost a 6:1 bandwidth.

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