A Uniplanar Dual-Polarized Miniaturized Antenna

Nader Behdad

School of Electrical Engineering and Computer Science,
University of Central Florida
4000 Central Florida Blvd, Orlando, FL 32816-2362, U.S.A.
Tel: (407) 823-3426, Fax: (407) 823-1488, email: behdad@mail.ucf.edu

Abstract

A new technique for designing dual-polarized miniaturized slot antennas is presented in this paper. The technique is based on the miniaturization of a crossed slot antenna fed with two coplanar waveguide feeds. Miniaturization is performed by terminating the slots with appropriate boundary conditions at their ends to ensure that the structure maintains resonance while the occupied area is considerably reduced. Using this technique, the occupied area of the antenna can be made as small as $0.085\lambda_0 \times 0.085\lambda_0$. The antennas designed using this technique utilize two coplanar waveguide feeds located on the same layer as the main radiating structure, thereby resulting in a uniplanar structure. In spite of the uniplanar nature of the structure, the antenna demonstrates a good isolation between the horizontal and vertical ports.

1. Introduction

The rapid development of communication technology and significant growth of consumer demands have brought about a new age in wireless communication industry. Smaller dimensions, increased functionality, and better performance are not only desired but also required in modern personal wireless communication devices. One of the challenges in reducing the size of any wireless communication device is the issue of antenna miniaturization. Antenna miniaturization is not a new topic and has been extensively studied over many decades. In particular, special attention has been paid to studying the fundamental limitations that govern the performance of electrically small antennas [1-4]. Also, numerous other studies have been performed to develop techniques that can be used to reduce the size of antennas and obtain electrically small antennas and a summary of successful and unsuccessful such attempts are provided in [5]. In a number of recent studies, new techniques for miniaturization and bandwidth enhancement of electrically small slot antennas were presented [6-7]. In a later study, it was demonstrated that electrically small slot antennas have a higher radiation efficiency compared to their dipole or wire counterparts that occupy the same aperture area [8]. This is mostly attributed to the reduced Ohmic losses in the radiating structure of a slot antenna compared to a dipole or printed wire structure.

In spite of the abundance of the literature discussing various antenna miniaturization techniques and the performance of such antennas, little attention has been devoted to the development of dual-polarized electrically small antennas. Dual-polarized antennas are a necessity in many applications ranging from polarization discrimination in radar systems to polarization diversity in wireless systems or Multiple Input Multiple Output (MIMO) communications systems. Furthermore, a dual-polarized antenna can be utilized to synthesize left or right-handed circular polarization, which will be beneficial in numerous other applications such as GPS or satellite communications. In this study, a new technique for designing ultra-miniature, dual-polarized slot antennas will be presented. The dual-polarized antenna studied in this work is in the form of a miniaturized slot antenna fed with co-planar waveguide (CPW) transmission lines. The special CPW feed topology used in this design results in a uniplanar structure and can be easily fabricated using standard printed circuit board fabrication techniques. The electrically small, dual-polarized antennas designed using this technique can be made to occupy areas as small as $0.085\lambda_0 \times 0.085\lambda_0$, where λ_0 is the free space wavelength. In the following sections, first the principles of operation of the proposed antenna as well as some design guidelines are presented in Section 2. In Section 3, experimental results of a fabricated antenna prototype are presented and discussed and finally the paper is concluded will a few concluding remarks in Section 4.

2. Principles of Operation and Antenna Design

The topology of the miniaturized dual-polarized slot antenna is shown in Fig. 1. The antenna is composed of a main crossed slot structure connected to two balanced spirals at the end of each slot. The principles of operation of the antenna can be understood by considering the magnetic current distribution of a regular crossed slot antenna. Fig. 2(a) shows the magnetic current distribution of a regular crossed slot antenna when the antenna is fed with a simple voltage source along the terminals **a** and **b**. The arrows show the direction of magnetic current in each slot. The magnitude of the magnetic current is zero at the slot edges and maximum at the center and resembles a half-wave sinusoidal distribution, similar to a half-wavelength dipole antenna. In the feeding arrangement shown in Fig. 2(a), the crossed slot's overall magnetic current is in the horizontal ($\hat{x}$) direction. Therefore, the antenna radiates a vertically polarized electric field (polarized along $\hat{y}$ direction) in its far field. Fig. 2(b) shows the magnetic current distribution of the same slot antenna when it is fed with the same voltage source along the terminals **c** and **d**. In this case, the crossed slot antenna will have a vertical overall effective magnetic current direction ($\hat{y}$ direction). Therefore, in this feeding arrangement, the antenna will radiate a horizontally polarized electric field in its far field (polarized along $\hat{x}$ direction).

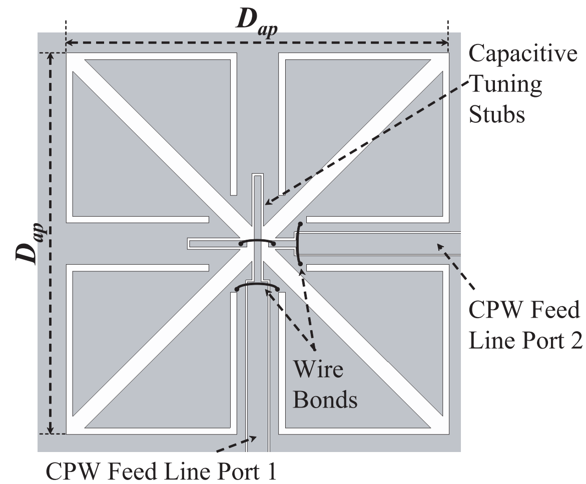


Fig. 1. Topology of the dual-polarized miniaturized slot antenna discussed in Section 2. The antenna is fed with two capacitively terminated coplanar waveguides.

At its normal mode of operation, each arm of the crossed slot is approximately $\lambda_g/2$ long, where λ_g is the guided wavelength along the slot. To reduce the size of this antenna, the approach depicted in Fig. 3 can be used. Fig. 3(a) shows the magnetic current distribution along only one arm of the crossed slot antenna. If the topology of this arm is modified as shown in Fig. 3(b), the effective electrical length of the antenna can be increased. In this case, two slanted slot sections are added at each end of the main slot and the overall electrical length of the antenna from one end of each slanted slot to the other end of the other slot is about $\lambda_{g2}/2$, where $\lambda_{g2} > \lambda_{g1}$. This increases the effective electrical length of the antenna or equivalently reduces its resonant frequency. This process can be further repeated as shown in Fig. 3(c), where the effective electrical length of the antenna is further increased by converting the simple slanted slots into triangular spirals. This will further reduce the resonant frequency of the antenna or equivalently reduces its occupied electrical dimensions. This process is applied to the original crossed slot antenna and the structure shown in Fig. 1 is obtained. The magnetic currents flowing in the two balanced spirals are oppositely directed to one another and they do not contribute to the far field radiation.

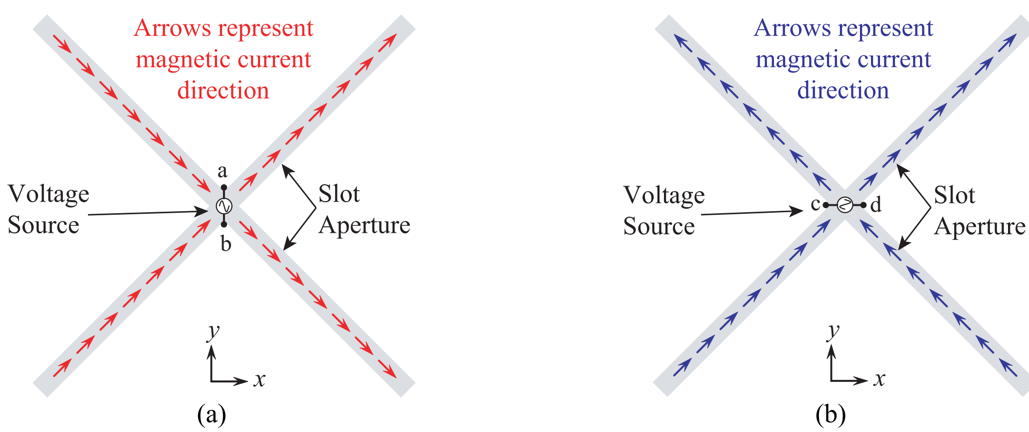


Fig. 2. Magnetic current distributions in a crossed slot antenna when fed with a voltage source. (a) Exciting the antenna at the a-b terminals results in a vertically polarized radiated E field (directed along y direction). (b) Exciting the antenna at the c-d terminals results in a horizontally polarized (x directed) radiated E field.

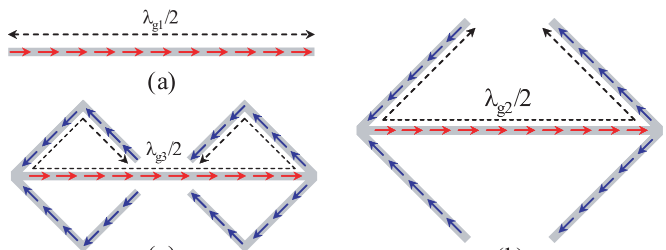


Fig. 3. Miniaturization procedure used to reduce the size (resonant frequency) of the crossed slot antenna. For simplicity, only one arm of the crossed slot is demonstrated.

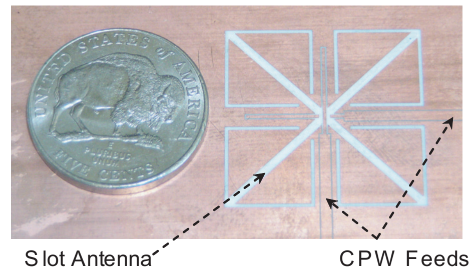


Fig. 4. Photograph of a fabricated prototype of the miniaturized crossed-slot antenna. The photo shows the antenna before wirebonding.

The electrically small dual-polarized antenna is fed with two capacitively terminated coplanar waveguide transmission lines as shown in Fig. 1. Each CPW line is composed of a main 50Ω section, which is transitioned to a compact 70 Ω line, which feeds the antenna. Since both feeds are on the same plane one CPW line is discontinuous to accommodate the other feed. To maintain electrical continuity, the two sections of the CPW line of the second port are wire bonded together. Moreover, since each CPW line presents a discontinuity in the electric current flowing on the ground plane around the slot, the equipotential condition on the CW grounds must be physically enforced. This is accomplished by wire bonding the two adjacent points on the CPW grounds as shown in Fig. 1. The input impedance of the antenna is matched to that of the feeding transmission lines (50Ω) by changing the length (value) of the capacitive termination.

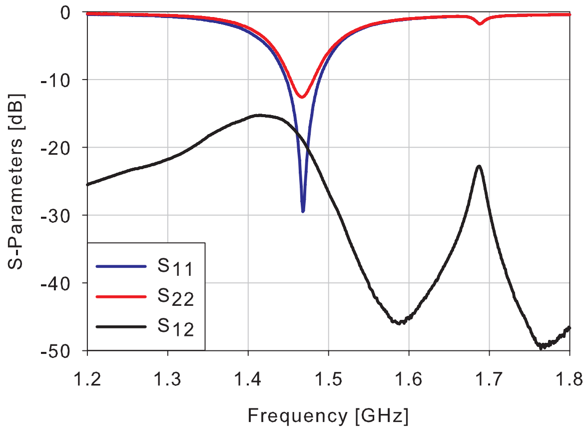
3. Measurement Results and Experimental Verification

A prototype of the dual-polarized miniaturized slot antenna similar to the one shown in Fig. 1 is designed and its geometrical parameters are optimized using full-wave EM simulations in IE3D (from Zeland Cop.). The antenna is designed to operate at 1.48 GHz and it has aperture dimensions of 23mm×23mm or equivalently $0.11\lambda_0 \times 0.11\lambda_0$. Impedance matching is performed by tuning the capacitive terminations at the end of CPW lines and optimizing them to achieve a good impedance match at the center frequency of operation. This ensures that the input impedance of the antenna is directly matched to 50Ω without using any external matching network. The prototype antenna is then fabricated on a 0.5mm thick RO4003 dielectric substrate (from Rogers Corp.) with the dielectric constant of ε_r=3.4 and loss tangent of tan(δ)=0.0022. Fabrication is performed using standard lithography techniques and a photograph of the fabricated prototype is shown in Fig. 4. The fabricated prototype has finite ground plane dimensions of 80 mm × 80 mm, which correspond to electrical dimensions of $0.4\lambda_0 \times 0.4\lambda_0$ at the center frequency of operation. The frequency response of the antenna is measured using a calibrated vector network analyzer. Fig. 5 shows the measured input reflection coefficient of the antenna at port 1 (S_{11}) and port 2 (S_{22}) as well as the measured isolation between the two ports (S_{12}). The antenna demonstrates a VSWR better than 2:1 at its both input ports and an isolation level better than 15 dB across its entire band of operation is achieved. The discrepancy observed between the measured S_{11} and S_{22} is caused by the presence of the discontinuity (wire bond) in the center conductor of CPW line feeding port 2, which is not present in the other CPW feed line. Nevertheless, both input ports have the same frequency range of operation and a good isolation level between the two ports is measured.

Table 1. Radiation parameters of the dual-polarized miniaturized slot antenna.

Parameter	Antenna Size	Ground Plane Size
Value	$0.11\lambda_0 \times 0.11\lambda_0$	$0.4\lambda_0 \times 0.4\lambda_0$
Parameter	Radiation Efficiency	Bandwidth
Value	91.8%	2.9%

Fig. 6 shows the radiation patterns of the antenna at its two principal planes of radiation for both excitations (ports 1 and 2). To decipher the data presented in Fig. 6, one must note that the y-z plane is the E-plane (with E_θ as the co-pol component and E_φ as the cross-pol component) and the x-z plane is the H-plane (with E_φ as the co-pol component and E_θ as the cross-pol component), when port 1 is excited and port 2 is terminated. When port 2 is excited and port 1 is terminated, the x-z plane will be the E-plane (with E_θ as the co-pol component and E_φ as the



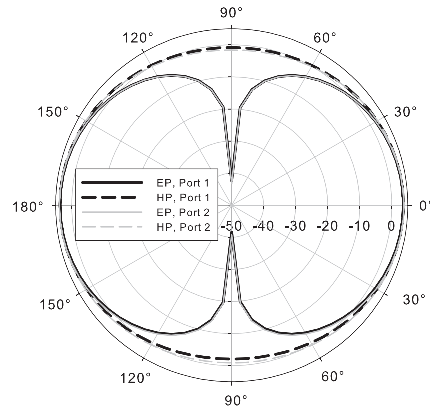


Fig. 5. Measured input reflection coefficients of the dual-polarized miniaturized slot antenna at ports 1 (S_{11}) and 2 (S_{22}) and the isolation between the two ports (S_{21}).

Fig. 6. The radiation patterns of the dual-polarized miniaturized slot antenna for both excitations at its two principal planes of radiation.

cross-pol component) and the y-z plane will be the H-plane (with E_φ as the co-pol component and E_θ as the cross-pol component). The antenna demonstrates similar radiation patterns for both excitations, as expected. The gain of the antenna is measured in the anechoic chamber of University of Central Florida and found to be 0.8 dBi. Gain measurement is performed using a double-ridge horn as the standard gain antenna. Using the measured gain value and calculated directivity value, the radiation efficiency of the antenna is then calculated and presented in Table 1. The dimensions of the proposed antenna can further be reduced by increasing the length of the balanced spirals used to satisfy the boundary conditions. This task is carried out and another antenna prototype with aperture dimensions of $0.085\lambda_0 \times 0.085\lambda_0$ is designed, fabricated, and tested; the measurement results of this antenna and other variants of the proposed dual-polarized miniaturized slot antenna will be presented and discussed in the symposium.

4. Conclusion

A new technique for designing miniaturized, dual-polarized slot antennas was presented in this paper. The proposed technique allows for designing electrically small dual-polarized antennas with extremely small aperture dimensions. Prototypes of such antennas with aperture dimensions of $0.11\lambda_0 \times 0.11\lambda_0$ and $0.085\lambda_0 \times 0.085\lambda_0$ are fabricated and tested in an anechoic chamber environment. Measurement results of one of these antennas was presented in this paper and the results of the other antenna and its variants will be presented and discussed in the 2008 URSI General Assembly.

5. References

1. L. J. Chu, "Physical limitations on omni-directional antennas," *J. Appl. Phys.*, **19**, Dec. 1948, pp. 1163–1175.
2. H. A. Wheeler, "Fundamental limitations of small antennas," in *Proc. IRE.*, **35**, Dec. 1947, pp. 1479–1484.
3. R. C. Hansen, "Fundamental limitations in antennas," *Proc. IEEE*, **69**, Feb. 1981, pp. 170–182.
4. J. S. McLean, "A re-examination of the fundamental limits on the radiation Q of electrically small antennas," *IEEE Trans. Antennas Propagat.*, **AP-44**, May 1996, pp. 672–676.
5. R. C. Hansen, *Electrically Small, Superdirective, and Superconducting Antenna, First Edition*, Wiley-Interscience, New York, NY, 2006.
6. N. Behdad and K. Sarabandi, "Bandwidth enhancement and further size reduction of a class of miniaturized slot antennas," *IEEE Trans. Antennas. and Prop.*, **AP-52**, Aug. 2004, pp. 1928-1935.
7. R. Azadegan and K. Sarabandi, "A novel approach for miniaturization of slot antennas," *IEEE Trans. Antennas and Prop.*, **AP-51**, Mar. 2003, pp. 421-429.
8. R. Azadegan and K. Sarabandi, "A compact planar folded-dipole antenna for wireless applications," *IEEE Internationa APS/URSI Symposium,* **3,** pp. 420-423, Columbus OH, 22-27 June 2003.