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Wideband Magnetic-Electric Antenna with Linear Single or Dual Polarization

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Abstract—A wideband antenna is designed based on the concept of equivalent magnetic dipole and electric dipole combinations with excellent radiation characteristics. Single linear polarization design with two different excitations achieves good radiation symmetry and low cross-polarization. The dual-polarization case has a 67% bandwidth and isolation better than 30 dB. The present design and construction of the antenna provides simple solutions compared with similar antennas in the literature. This design avoids loading the antenna with dielectric in the active region. The agreement between measured and simulated results is excellent. The suggested antenna construction is very simple and solves many of the problems related to the practical excitation of this antenna.

1. INTRODUCTION

USE of Huygens' source principal is used to design antennas that consist of electric- and magnetic-dipoles simultaneously. Such a combination provides symmetrical radiation patterns (equal E- and H-planes) [1]. The radiation patterns are the super-position of radiation pattern of the electric- and magnetic-dipoles. The radiation pattern shape of the electric-dipole is a figure-8 in the E-plane and figure-O in the H-plane, and it is a figure-O in the E-plane and figure-8 in the H-plane for the magnetic-dipole. With proper excitation of the electric- and magnetic-dipoles, the symmetry of the radiation pattern can be achieved. This idea was realized in 1974 [2]. The same concept of using a slot as a magnetic-dipole and a metallic split patch as an electric-dipole is suggested in [3–6]. However, these designs in [1–6] are either bulky or have narrow bandwidths. In [7], the parallel plate part of the antenna is corrugated to reduce the overall antenna height, which adds to the complexity of the structure.

In [8, 9], a wideband electric-magnetic antenna was designed. An air filled microstrip line fed this antenna. An air microstrip line is difficult to keep with a uniform height from its ground plane. We have found difficulty using an air microstrip line. We overcome this problem with the present design. The wideband characteristics are achieved with an antenna consisting of a planar dipole and a shorted patch antenna backed by a common ground plane. In addition, the radiation characteristics, such as low back radiation, stable antenna gain, and symmetric E- and H-plane radiation patterns, are achieved. A planar dipole acts as an electric-dipole, and a wide shorted patch is chosen as an equivalent magnetic-dipole. For further attempts to increase the bandwidth a bow-tie dipole is used instead of a rectangular one [10] with even more complicated feeding mechanism. However, the radiation characteristics are affected at the upper end of the band. Single polarized wideband antenna with a bow-tie dipole is also designed in [11]. This design is based on a planar printed structure.

Some of the above single polarized antennas are difficult to be extended for dual-polarization. A dual-polarized antenna is desired to double the number of channels. In addition, a dually polarized antenna enhances channel capacity by reducing the side effects of multipath fading.

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Here, a single-polarized wideband magnetic-electric antenna with excellent practical feeding mechanism with dual arms is used as proposed in [8], but we avoid air microstrip line feeding that had practical problems related to keeping the microstrip height constant from the ground plane. The dual-arm structure further increases the antenna bandwidth as well as provides a mean that helps in the design of the dual-polarized antenna with excellent isolation. A similar approach for dual-polarization is reported in [11, 12], but the bandwidth is reduced due to the dielectric material loading between the two vertical shorting walls (slot opening). In this paper, the proposed structure makes a dielectric substrate that supports the microstrip line outside the parallel plate region and behind the dipole. As such, the dielectric does not contribute to radiation of the antenna [13], which causes a reduction in the antenna bandwidth and efficiency. In addition, such a structure simplifies the excitation mechanism and at the same time retains excellent characteristics of the wideband complementary antenna element. A student with simple tools available to him constructs the prototypes of these antennas. With the limited construction accuracy, the antennas performances are verified through comparisons between measured and simulated results. The dually polarized antenna achieves an isolation level better than 30 dB within a bandwidth better than 44 %.

2. LINEARLY POLARIZED ANTENNA

2.1. Construction Description of the Antenna

The central frequency of the antenna is 2.5 GHz. Two different excitations are considered as shown in Fig. 1. The dimensions of the wideband patch antenna are adopted from the wideband unidirectional antenna element in [14]. The idea is simple. The structure is a combination of electric dipole that is parallel and above a ground plane by about a quarter of a wavelength, but for wideband purposes, the dipole should be thick, which is considered by a wide planar strip of half wavelength and width of also half a wavelength. Such a width accommodates an open-ended slot with length of a half wavelength. As the slot between is placed between two parallel plates and short ended with the ground plane, the parallel plate waveguide acts as a short-ended transmission line of quarter wavelength long. In order to keep the required balance between the electric and magnetic dipoles, both must be excited by the same source, which we bring to the top, and we provide a parameter to achieve the required match. The details of the design procedure are available in [15]. The antenna is composed of two horizontal rectangular wings with $W \times L = 60 \times 30\,\mathrm{mm}^2$ $(0.5 \times 0.25\lambda_0^2)$ forming the electric dipole (λ_0 refers to the center frequency of the operation in free space). The dipole is above a finite ground plane with $160 \times 160\,\mathrm{mm}^2$ $(1.33 \times 1.33\lambda_0^2)$. The equivalent magnetic dipole is presented by a slot located between the two dipole arms of width $S_1 = 17\,\mathrm{mm}$ and length equal to the dipole arm width. Here, the slot and dipole are both located on the same level above the ground plane. The slot is considered the aperture opening of a parallel plate waveguide that is shorted by the ground plane at a quarter-wavelength position. An L-shaped strip (probe) as shown in Fig. 1(a) excites both the slot and the dipole. The probe is excited by a microstrip line printed on a vertical dielectric substrate with dielectric constant of 2.94 and substrate thickness of 1.524 mm. The metallic strip extends through an opening (5 mm by 1 mm) where the vertical shorted wall and top horizontal patch meet. Also, a small rectangular hole in the ground plane of 5 mm by 1 mm is opened where the L-shaped probe connects to the microstrip feed line to avoid shorting the feed. The ground plane of the microstrip line forms one of the parallel plate waveguide walls. The horizontal part of the L-shaped probe has an inductive effect on the input impedance, and the vertical part has a capacitive effect [14]. So the two parts are optimized to achieve a wideband matching to the $50\,\Omega$ microstrip line [9].

The modified configuration with twin L-shaped probes is illustrated in Fig. 2. Twin-fed L-shaped probes are located parallel to each other with a separation of 39 mm $(0.33\lambda_o)$. A simple matching network, printed on the back of the same vertical substrate for a single L-shaped probe case, is used to excite the twin L-shaped metallic strips. The transmission line with a characteristic impedance of $50\,\Omega$ is connected to an SMA connector, which is located in the bottom of the substrate and branched into two $100\,\Omega$ transmission lines for exciting the L-shaped metallic strips. The aperture width (S) and metallic strip width (d) are changed from the configuration of the single L-shaped probe fed antenna to achieve the best bandwidth. The rest of the antenna dimensions are the same as that used in the single fed antenna.

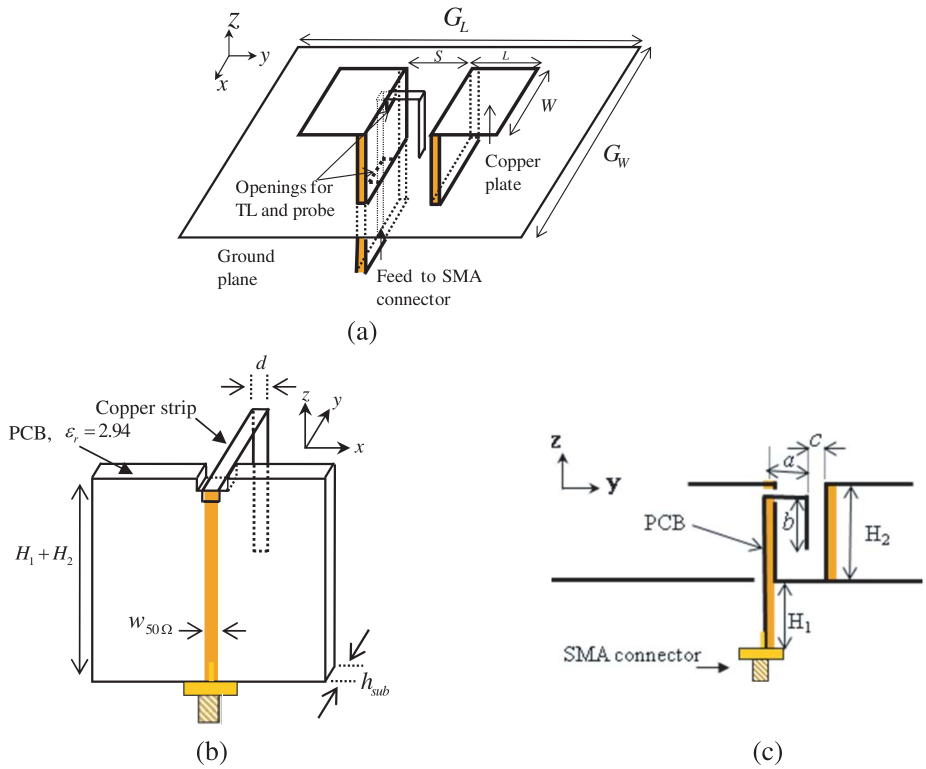


Figure 1. Sketch of the single-fed configuration of the linearly polarized wideband antenna. (a) 3D sketch of the single fed antenna. (b) Feeding part details (3D view). (c) Side view of the antenna.

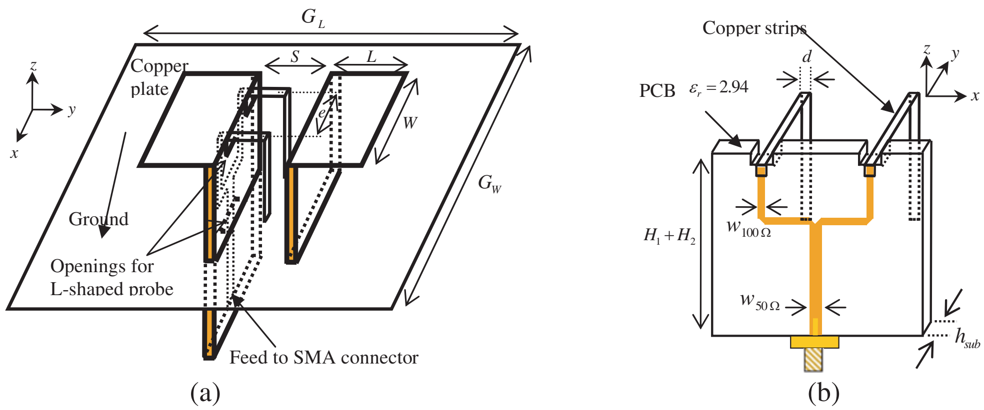


Figure 2. Sketch of the twin-fed configuration of the linearly polarized wideband antenna. (a) 3D sketch of the twin fed antenna. (b) Feeding details (3D).

2.2. Measured and Simulated Results

After reaching the proper dimensions using a full-wave EM simulator, Ansys HFSS, the two antennas with both excitations of single- and twin-fed L-shaped probes are constructed as illustrated above. Photos of the fabricated antenna are shown in Fig. 3. The measured results are in good agreement with the simulated ones. Fig. 4 shows the measured and simulated reflection coefficients of the proposed antenna with single and twin L-shaped probes, respectively. For the single L-shaped probe fed antenna, the measured impedance bandwidth with reflection coefficients better than −10 dB is 53% (1.74–3.00 GHz), which is wider than those in [8]; meanwhile, wider measured impedance bandwidth of 72% (1.50–3.20 GHz) is obtained for the twin L-shaped probe fed antenna. This is almost 40%

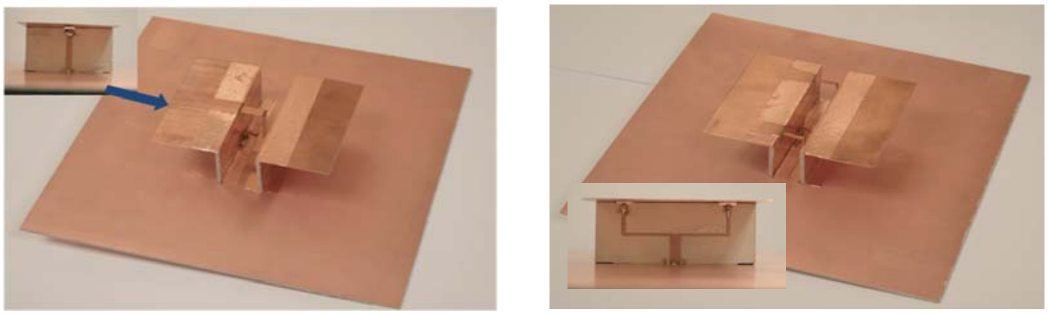
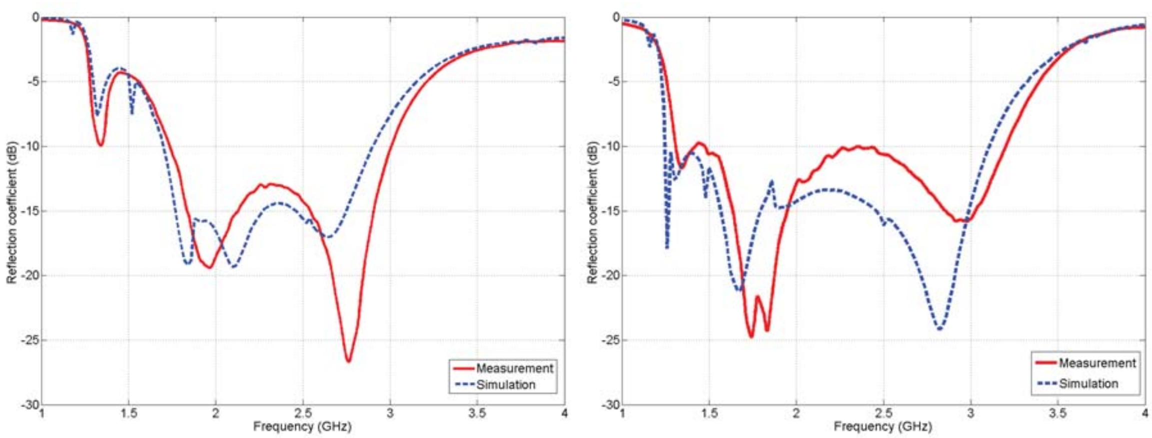


Figure 3. Photos for single and twin-fed L-shaped antenna.



(a) Single (b) Twin

Figure 4. Measured and simulated reflection coefficients of antenna with (a) a single-fed probe, and (b) a twin-fed probe.

wider bandwidth than the single fed case. In addition, the twin-fed case is the one most suitable for the dually polarized antenna. It is observed that the simulation results show some sharp variations indicating possible resonances. Some of these resonances are observed in the measurements, but some are not shown out of the matching bandwidth. We could not determine the reason for that, but it could be related to the difference in frequency steps, which are very small in the simulation. As shown in Fig. 5, the comparisons between measured and simulated radiation patterns at the center frequency of 2.5 GHz are in good agreement with each other. The measured radiation patterns at frequencies of 1.75, 2.50, and 3.00 GHz for a single L-shaped probe, and 1.55, 2.50, and 3.20 GHz for twin L-shaped probes are shown in Fig. 6. It can be seen that the antenna provides symmetrical radiation patterns (equal E- and H-planes patterns). The radiation patterns are also stable over the entire frequency band. In addition, the cross-polarization levels and back lobes are low. At lower frequencies, relatively higher back-lobe radiations are observed due to the size of the ground plane. In [15], the back radiation of this antenna has been further reduced by surrounding the ground plane by a vertical rim. These results have been removed for brevity.

3. DUAL POLARIZED ANTENNA

3.1. Construction of Dually Polarized Antenna

The previously twin-fed single polarized antennas is extended for a dual-polarized antenna by splitting the single-polarized antenna to orthogonally insert another split single polarized antenna as shown in the photo in Fig. 7. The sketch showing the construction details is given in Fig. 8. The antenna dimensions

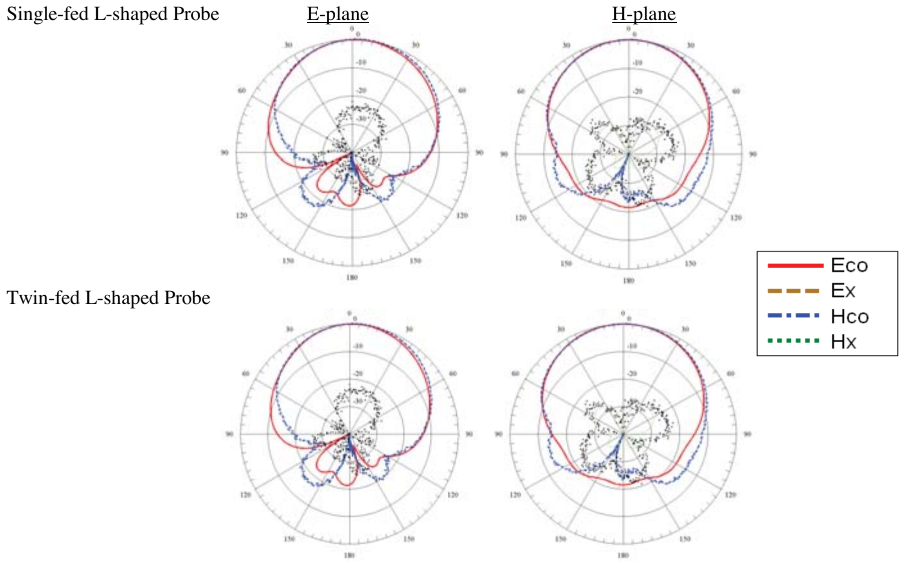


Figure 5. Measured and simulated radiation patterns of the antennas with single and twin L-shaped probes at center frequency of 2.5 GHz.

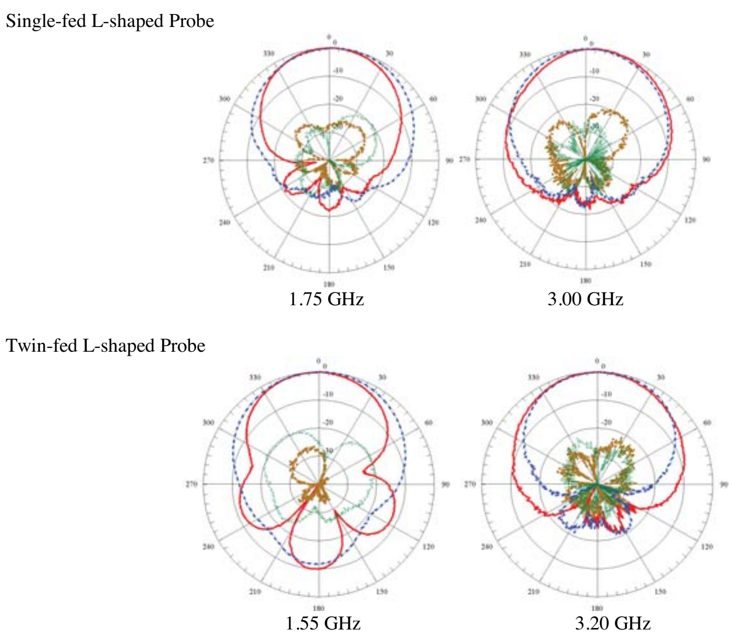


Figure 6. Measured radiation patterns of the antennas with single and twin L-shaped probes: Top for single L-shaped probe at 1.75, 2.50 and 3.00 GHz, and bottom for twin hook-shaped probes at 1.55, 2.50 and 3.20 GHz. Legends are the same as Fig. 5.

are given in Table 1 for all the antenna parameters.

The final geometry can be described as an antenna consisting of four horizontal square patches above the finite ground plane by about a quarter-wavelength and two vertical feeding substrates. Each patch with dimensions $P \times P = 30 \times 30\,\text{mm}^2$. The patches are connected to the ground plane by vertical feeding substrates. The same size of the ground plane as that for the linearly polarized patch antenna is used for the dual-polarized case with $G_W \times G_L = 160\,\text{mm}^2$ $(1.33 \times 1.33\lambda_0^2)$. The separation between patches, aperture width (S_3), is 13 mm. Details of the two vertical feeding substrates with dielectric

Table 1. Dimensions of the parameters of antenna with single and twin L-shaped probes in Figs. 1 and 2.

Parameter	a	B	c	d_1	d_2	W_{50}	W_{100}	S_1	S_2	W	L	H	G_W	G_L
Value/mm	12	22	5.48	4.91	1.61	3.88	1.04	17	13	60	30	30	160	160
Value/λ_o	0.10	0.18	0.05	0.04	0.01	0.06	0.01	0.14	0.11	0.50	0.25	0.25	1.33	1.33

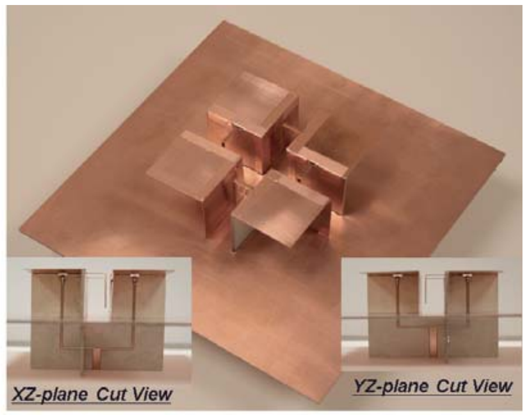
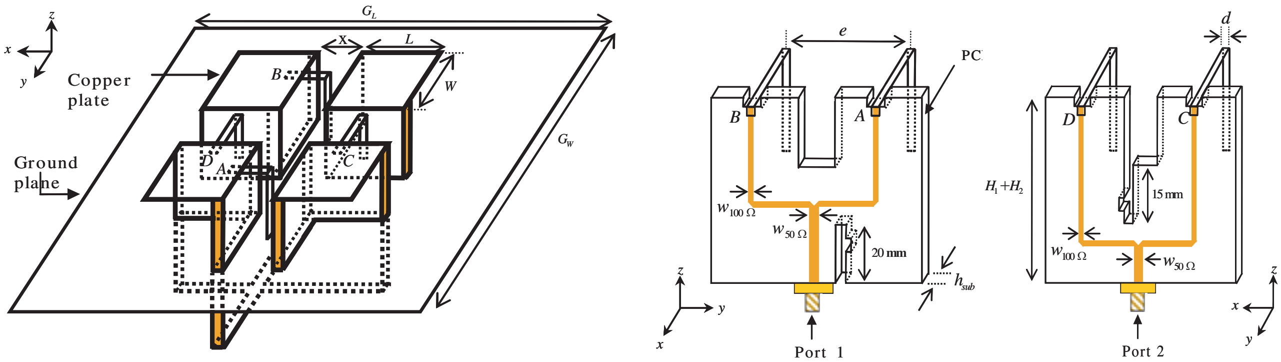


Figure 7. Photo of a dual-polarized wideband antenna.



(a) (b)

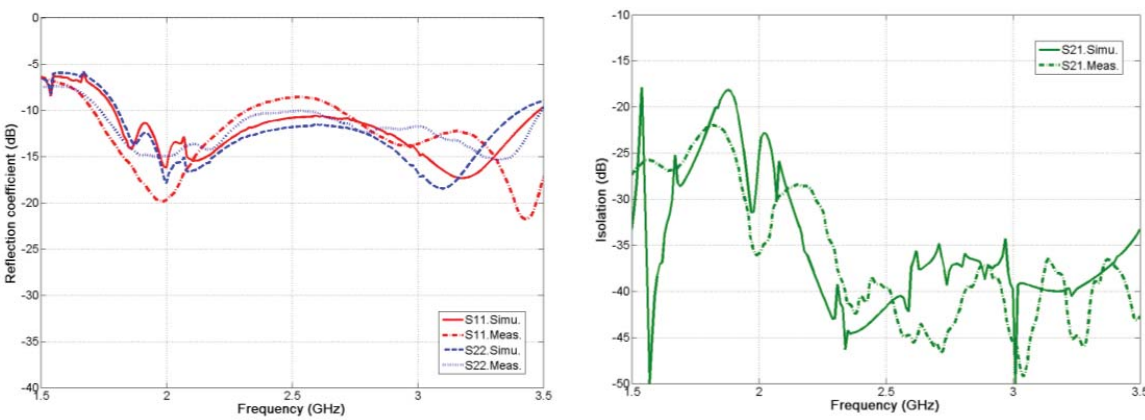
Figure 8. Configuration of a dual-polarized wideband antenna. (a) 3D view. (b) Feeding network.

constant of 2.94 and thickness of 1.524 mm are also shown in Fig. 8. One substrate is oriented in the YZ-plane and the other in the XZ-plane. As illustrated in Fig. 8(b), both substrates are orthogonally arranged to each other.

A simple in-phase power divider to split the power equally in the two arms is employed for each polarization to excite the dual-polarized patch antenna. The twin L-shaped probes have the same phase excitation of the feeding network, which connect to port 1. Similarly, the twin L-shaped probes for the other polarization with the same phase excitation connect to port 2.

3.2. Measured and Simulated Results

The measured and simulated reflection coefficients as well as the isolation between the two ports are shown in Figs. 9(a) and 9(b), respectively. The simulated reflection coefficients bandwidths of the antenna for better than -10 dB are 64% (1.79–3.49 GHz) and 61% (1.81–3.41 GHz) for ports 1 and 2, respectively. As explained before, the sharp variations in the simulated results of S_{21} are mainly because frequency steps in the simulation are much smaller than the measurements, and as the signal is very weak, any small change may show large difference in dB. From the measurement results of the reflection coefficients, the antenna operates from 1.71 GHz to 3.59 GHz with a bandwidth of $\sim 71\%$ from 1.74 to 3.50 GHz and with a bandwidth of 67% for ports 1 and 2, respectively. Compared with the simulated result, the measured reflection coefficients at port 1 show that the antenna performance is slightly deteriorated by about 2 dB difference at the center frequency to be -8.5 dB. This is probably due to the inaccuracy for the L-shaped probe alignment. Both simulated and measured isolations between the two input ports are shown in Fig. 10. Isolation levels are kept below -35 dB starting from 2.18 GHz in the simulation and starting from 2.29 GHz in the measurement. At the lower ends of the bandwidth, both simulated and measured results show relatively low isolation levels up to -18 dB and -22 dB in simulation and measurement, respectively. It is observed that the measured isolation level is better than -30 dB for the operating frequency band better than 2.22 GHz.



(a) (b)

Figure 9. Measured and simulated isolation for a wideband dual-polarized antenna. (a) Reflection coefficients. (b) Coupling coefficients.

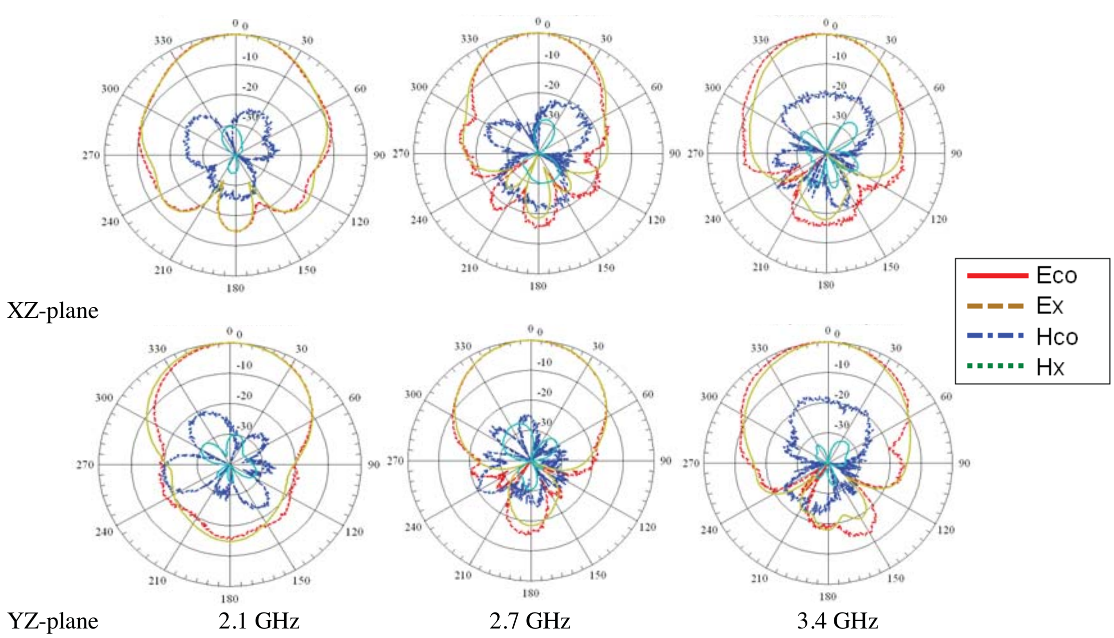


Figure 10. Measured and simulated radiation patterns of the dual-polarized antenna at 2.1, 2.7 and 3.4 GHz for port 1.

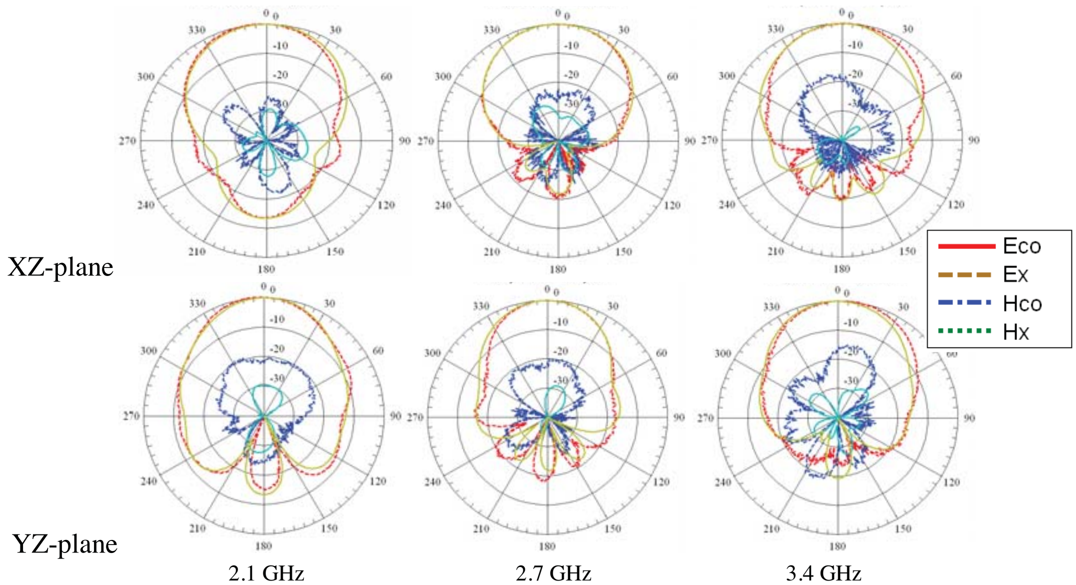


Figure 11. Measured and simulated radiation patterns of the dual-polarized antenna at 2.1, 2.7 and 3.4 GHz for port 2.

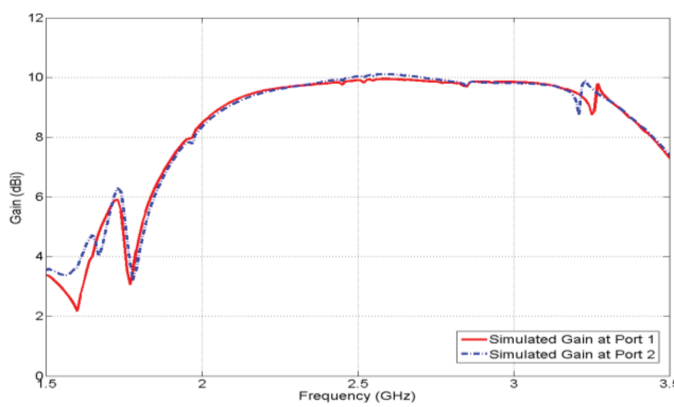


Figure 12. Simulated gain of the wideband dually polarized antenna.

The measured and simulated radiations at 2.1, 2.7, and 3.4 GHz patterns from port 1 and port 2 are plotted in Figs. 10 and 11, respectively. The measured co-polarization radiation patterns are in good agreement with the simulated results. It is observed that both the XZ-plane and YZ-plane radiation patterns are stable over the entire operating frequency band and symmetrical in the broadside direction. The back radiations at lower frequency, which are relatively high compared with those at other frequencies, are about -14 dB for both ports 1 and 2. The radiation patterns at that frequency slightly deteriorate because of the relatively small electrical size of the ground plane at that frequency. From the simulation results using HFSS, the cross-polarization levels of the radiation patterns are better than -26 dB. The measured ones are as high as -15 dB at the upper frequency. The cross-polarization levels at the lower and center frequencies are less than -20 dB, but only those at the upper frequency are relatively high to about -17 dB.

Figure 12 illustrates the simulated gain of the designed antenna over the operating frequency range. The maximum gain of the antenna is about 10.1 dB, and the 3-dB gain bandwidth ranges from 1.89 to 3.50 GHz, which covers almost the entire common reflection coefficients bandwidth, corresponding to a range of 1.81 to 3.41 GHz in simulation. It is worthwhile to comment that this antenna has excellent stable gain over the entire bandwidth.

4. CONCLUSIONS

A wideband linearly polarized antenna based on the principle of Huygens' source has been designed and tested. Single and dual polarizations have been realized in a simple construction. The antennas for linear single and dual polarizations have provided excellent characteristics. The co-polar radiation patterns are symmetrical, and the cross-polarization levels (better than -17 dB) and back radiations are low. To increase the bandwidth of the antenna, the dielectric substrate has been shielded from the radiating region and twin L-shaped probe feeds have been used. The measured bandwidth of the dually polarized antenna is about 67% (1.74 to 3.50 GHz). The measured isolations between the two ports are better than -30 dB within 45% (2.22 to 3.50 GHz).

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