Progress In Electromagnetics Research Letters, Vol. 71, 15–22, 2017

Antenna at S-Band as Ground for Array at X-Band in Dual Frequency Antenna at S/X-Bands

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Abstract—In this paper, a novel configuration for linearly polarised Dual Frequency Microstrip Antenna at S- and X-bands is presented. The proposed configuration utilises the frequency ratio of 1 : 3.3 between the two bands to its advantage by saving space. It uses the antenna at S-band as ground plane for a 2×2 antenna array at X-band without any additional requirement of separate space and ground plane. The patches are electromagnetically coupled to give measured bandwidth ($|S_{11}| < -10\,\text{dB}$) of 13% at S-band and 6.2% at X-band. It gives isolation better than 38 dB over the entire bandwidth of the two frequency bands. The measured antenna gain is 7.5 dBi at S-band and 10.5 dBi at X-band.

1. INTRODUCTION

Dual-frequency antennas find applications in many areas such as satellite and wireless communication, mobile communications, space borne Synthetic Aperture Radar (SAR) systems and Radio Frequency Identification Systems (RFID). The antennas for such applications should be small and light with more capabilities such as handling high data rate, low power budget, and reduced system volume [1]. The motivation to design a dual-frequency antenna is to provide communication in a concurrent and non-interfering manner in the two bands. It minimizes the space and weight requirement of two separate antennas.

Dual-frequency antennas can be designed by using a variety of techniques, such as stub loading [2, 3], multi-patch antenna [4], cutting slots [5], orthogonal feed to an antenna [6], perforated microstrip antennas [7–10], and combination of dipoles and square patches [11]. Each of the techniques mentioned above has certain disadvantages. The stub loading technique makes the antenna narrow band, and the technique of cutting slots degrades the radiation pattern. The technique of two orthogonal feeds to a rectangular microstrip antenna makes the antenna operate at two bands, but each band has orthogonal polarization. In [7–9], perforated dual-band stacked antenna geometry has been reported to give simulated bandwidth of 6.4% at L-band and 8.8% at X-band, 9.5% at S-band and 25% at X-band, and 1.8% at L-band and 7.8% at C-band, respectively, but these antennas would give less gain due to perforated configuration. In [10], a combination of stacked microstrip dipoles and square patches gives bandwidth of 8.9% at S-band and 17% at X-band but has multiple input ports, and the feed network has not been designed. In [11], two notches and stacking technique is used to design a dual-wideband antenna with broad bandwidth of 26.6% at 1.04 GHz and 31.7% at 2.4 GHz, and gain of 9 dB; however, it is reported for the two bands having low frequency ratio. In [12], a dual-frequency antenna is realised by arranging two triangular stacked patches with bandwidth of 9% and gain of 8.7 dB at 1.8 GHz and bandwidth of 11% and gain of 8.9 dB at 3.5 GHz but has a large size of 210 mm × 180 mm. In [13], a dual-band stacked antennas is designed using a stub-loaded parasitic patch and fractal-shaped radiating

Received 7 August 2017, Accepted 17 September 2017, Scheduled 6 October 2017

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edge microstrip antenna to give bandwidth of 12% and gain of 8.6 dB at 1.6 GHz and bandwidth of 5% and gain of 8.5 dB at 2.2 GHz but has a low frequency ratio of 1.37. In [14], a perforated patch and annular rings are used in stacked configuration with shorting posts to give the bandwidth of 1.6% with gain of 0.5 dB at 1.8 GHz and bandwidth of 2.0% with gain of −0.1 dB at 2.6 GHz. In [15], a dual-frequency stacked annular ring microstrip antenna is reported which demonstrates the use of air gap to control the separation of the two frequency bands.

In this paper, a novel configuration of a linearly polarised dual-frequency microstrip antenna (MSA) is reported for high frequency ratio of 1 : 3.3. The antenna at S-band is used as ground plane for a stacked 2×2 antenna array at X-band without any additional requirement of separate space and ground plane and affecting the antenna performance. Due to difference in frequencies of the two bands having the frequency ratio of 1 : 3.3, a 2×2 antenna array (instead of a single patch) at X-band has been accommodated within the size of antenna at S-band as a ground plane. It achieves better bandwidth and gain with reasonable size of the antenna, operates without interference at each of the two bands, and achieves high isolation between the two bands with radiation pattern stability over the required bandwidth. This antenna can be used to perform search and rescue services in meteorological satellites. The design of the antenna is described in Section 2. The concept can be used to design antenna for any frequency ratio $f_1 : f_2$ (1 : 1.5, 1 : 2, 1 : 2.5, 1 : 3). The measured and simulated results are discussed in Section 3.

2. DESIGN OF DUAL FREQUENCY ANTENNA AT S/X-BANDS

A linearly polarised dual-frequency antenna is designed at S- and X-bands. A 2×2 antenna array is designed for higher gain at X-band utilising the patch antenna at S-band as a ground plane. This is possible due to high frequency ratio of 1 : 3.3 between S- and X-bands (2.5 and 8.25 GHz).

Antenna is designed using substrate $\epsilon_r = 2.55$, thickness = 1.6 mm and $\tan\delta = 0.001$ at S-band and $\epsilon_r = 2.2$, thickness = 0.8 mm and $\tan\delta = 0.001$ at X-band. It is simulated using IE3D which is based on Methods of Moments [18]. Air is used in the design and can be replaced by foam to provide mechanical support. Section 2.1 explains the design of the antenna at S-band. Section 2.2 describes the design of 2×2 antenna array at X-band, and Section 2.3 discusses the antennas at two bands combined to operate as dual-frequency antenna.

2.1. Design of Antenna at S-Band

This section discusses the electromagnetically coupled microstrip antenna at S-band. This antenna uses inverted configuration of the patch and open-circuit microstrip line to feed the patch antenna [19] to obtain larger bandwidth as shown in Fig. 1(a). An air gap of 3.5 mm is introduced to improve bandwidth, and the patch in inverted configuration is designed on RT 5880 having $\epsilon_r = 2.2$, $h = 0.8$ mm and $\tan\delta = 0.001$. The square patch has each side of 45.5 mm. The feedline offset (x) from the center of the patch is 1.2 mm. Figs. 1(b)–1(c) show the simulated results which give bandwidth ($|S_{11}| < -10$ dB) of 10% from 2.35–2.59 GHz and has the maximum gain of 8.2 dBi.

2.2. Design of 2×2 Antenna Array at X-Band

Figure 2(a) shows the antenna array at X-band and its side view. The gain of the antenna at X-band is increased by designing a 2×2 antenna array instead of a single patch. Each square patch has side of 11.6 mm. It is fed using a microstrip line which feeds the patch at an offset of 2.45 mm from the center of the patch using a $\lambda/4$ transformer for impedance matching. The antenna array is fed with a corporate feed network so that the power received by each patch is equal. There is an air gap of 0.4 mm above the first substrate, and the square patch array is placed on top of the second substrate. The spacing between the patches is 20 mm ($0.55\lambda_o$ at 8.25 GHz).

Figure 2 shows the 2×2 microstrip antenna array with feed network at X-band and its simulated results. It gives bandwidth ($|S_{11}| < -10$ dB) of 12.1% from 7.7–8.7 GHz and a peak gain of 12.1 dBi.

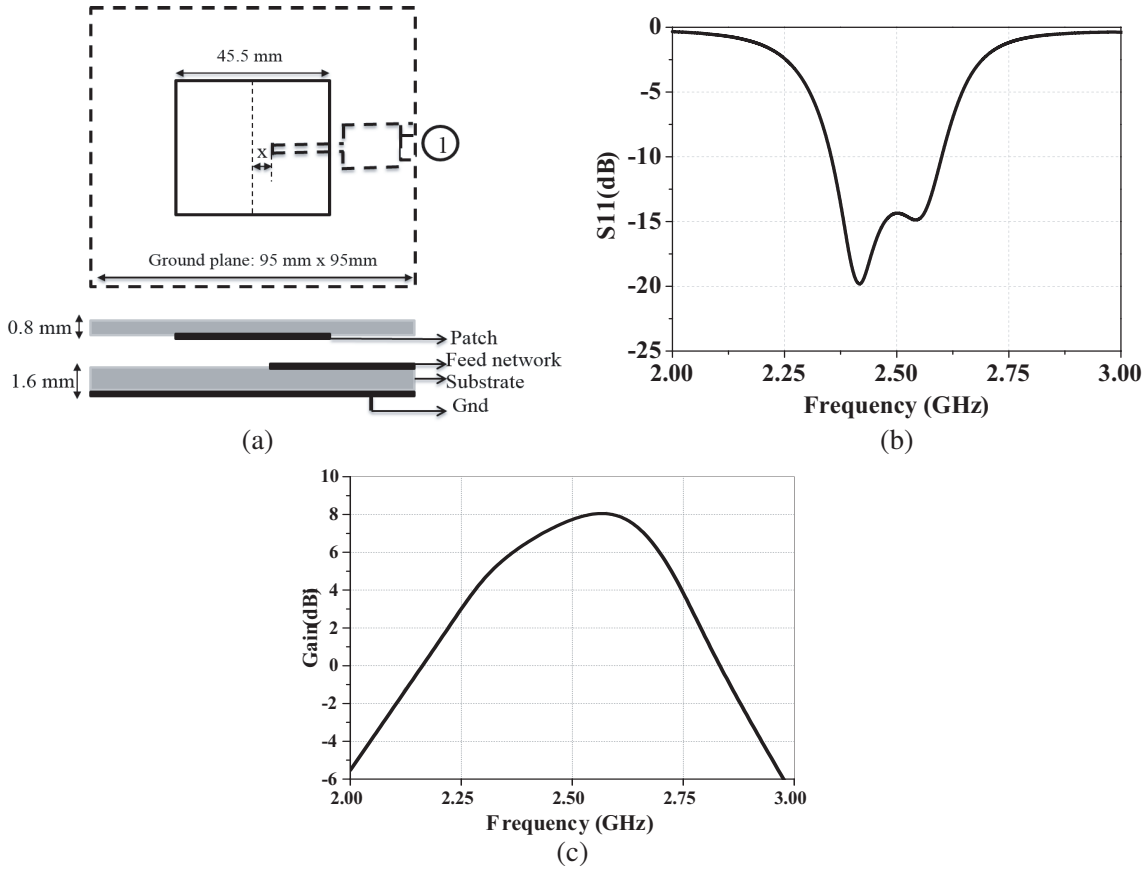

Figure 1. (a) Electromagnetically coupled antenna at S-band and its simulated (b) S-parameter and (c) gain vs frequency plot.

2.3. Design of Dual-Frequency Antenna

The antenna at S-band and the 2×2 antenna array at X-band are stacked together to design a dual-frequency antenna. The 2×2 antenna array at X-band is accommodated within the size of the larger patch at S-band. The patch antenna at S-band acts as a ground plane for the 2×2 antenna array at X-band. The dimension of the patches at S-band and X-band remains the same as the individual antennas discussed in Sections 2.1 and 2.2.

Figure 3 shows the electromagnetically coupled inverted patch antenna at S-band with microstrip feedline on finite ground plane and 2×2 array of the antenna with its feed network at X-band, stacked on top of each other having five layers. The first layer (L1) has a microstrip feed line which electromagnetically couples the patch at S-band in inverted configuration through air gap of 3.5 mm. The microstrip feed line to the patch consists of a feed line and a transformer having lengths of 21 mm and 17.8 mm, respectively. The microstrip feed line has an offset of 6 mm from the center of the patch and is open circuit towards the center of the patch. It is connected to 50 Ω line through transformer. The ground plane has size of 95 mm $\times$ 95 mm. The second layer (L2) has an air gap of 3.2 mm. The third layer (L3) has a square patch of 45.5 mm at S-band designed on the bottom of the substrate, i.e., inverted configuration.

The third layer (L3) can be divided in two parts: bottom and top. The bottom of layer (L3) has a square patch of 45.5 mm at S-band in inverted configuration. The top of the third layer (L3) has the feed network of a 2×2 array at X-band. This feed network also electromagnetically couples the patches at X-band. The distance between two adjacent patches of of 2×2 array at X-band is 20 mm ($0.55\lambda_o$). The center of the feed network is fed with an SMA-type coaxial connector having diameter of 1.2 mm which uses the bottom of L3 (patch at S-band) as its ground plane. It does not affect the antenna

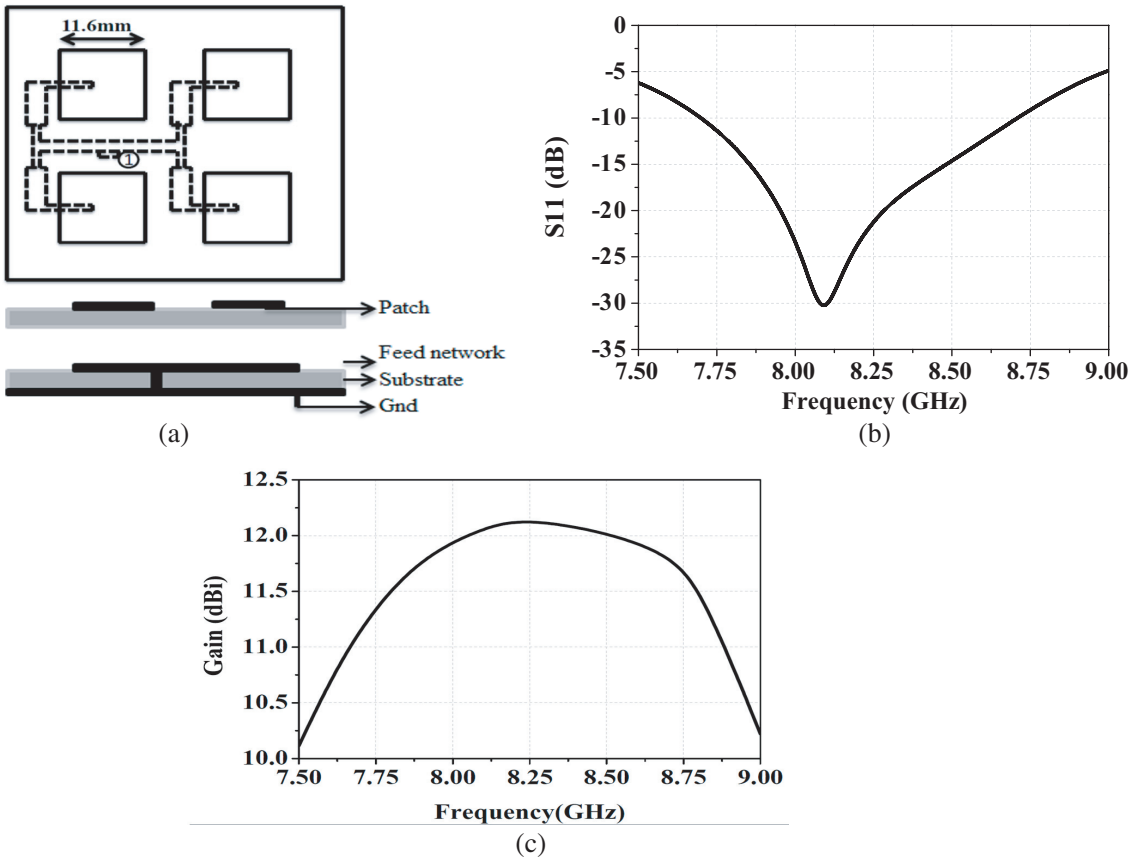

Figure 2. (a) Top and side views of 2×2 antenna array at X-band and its simulated (b) S-parameter and (c) gain vs frequency plot.

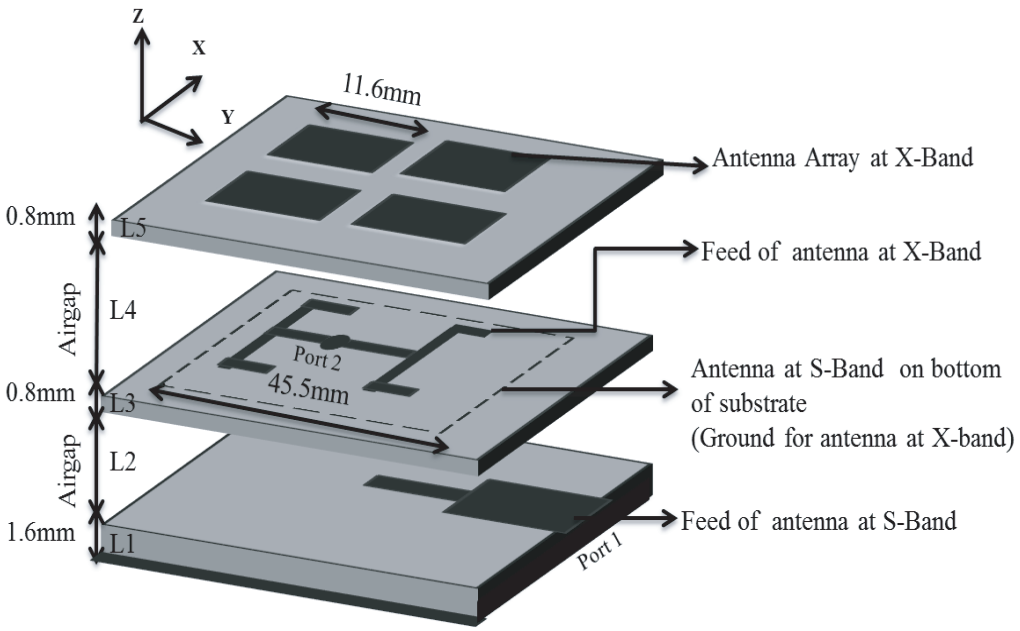

Figure 3. Electromagnetically coupled patch at S-band with microstrip feedline on finite ground plane (Layers 1, 2 and 3) and 2×2 array of the antenna with its feed network at X-band (Layers 3, 4 and 5) of five layered dual frequency microstrip antenna.

performance at S-band as the feed point is at the voltage null of the patch at S-band. The fourth layer (L4) is an air gap of 0.8 mm. The 2×2 array of patch is placed on the top of the substrate of the fifth layer (L5). Each square patch at the top has side of 11.6 mm.

3. SIMULATED AND MEASURED RESULTS

Figure 4 shows the simulated results of the dual-frequency antenna at S- and X-bands. Fig. 4(a) shows the simulated gain at S- and X-bands for two separate feeds of the antenna. Maximum gain is 8.4 dBi at 2.5 GHz and 11.15 dBi at 8.2 GHz. Figs. 4(b)–4(c) show the radiation pattern of the dual-frequency antenna at S- and X-bands. E-plane is observed by varying θ at $\phi = 90$ plane, and H-plane is observed by varying θ at $\phi = 0$. Radiation pattern at S-band has cross-polarised component less than -35 dB and front to back ratio of 20 dB. Radiation pattern at X-band has higher cross-polarised component of around -12 dB due to coaxial feed which acts as a monopole antenna and front to back ratio of 20 dB.

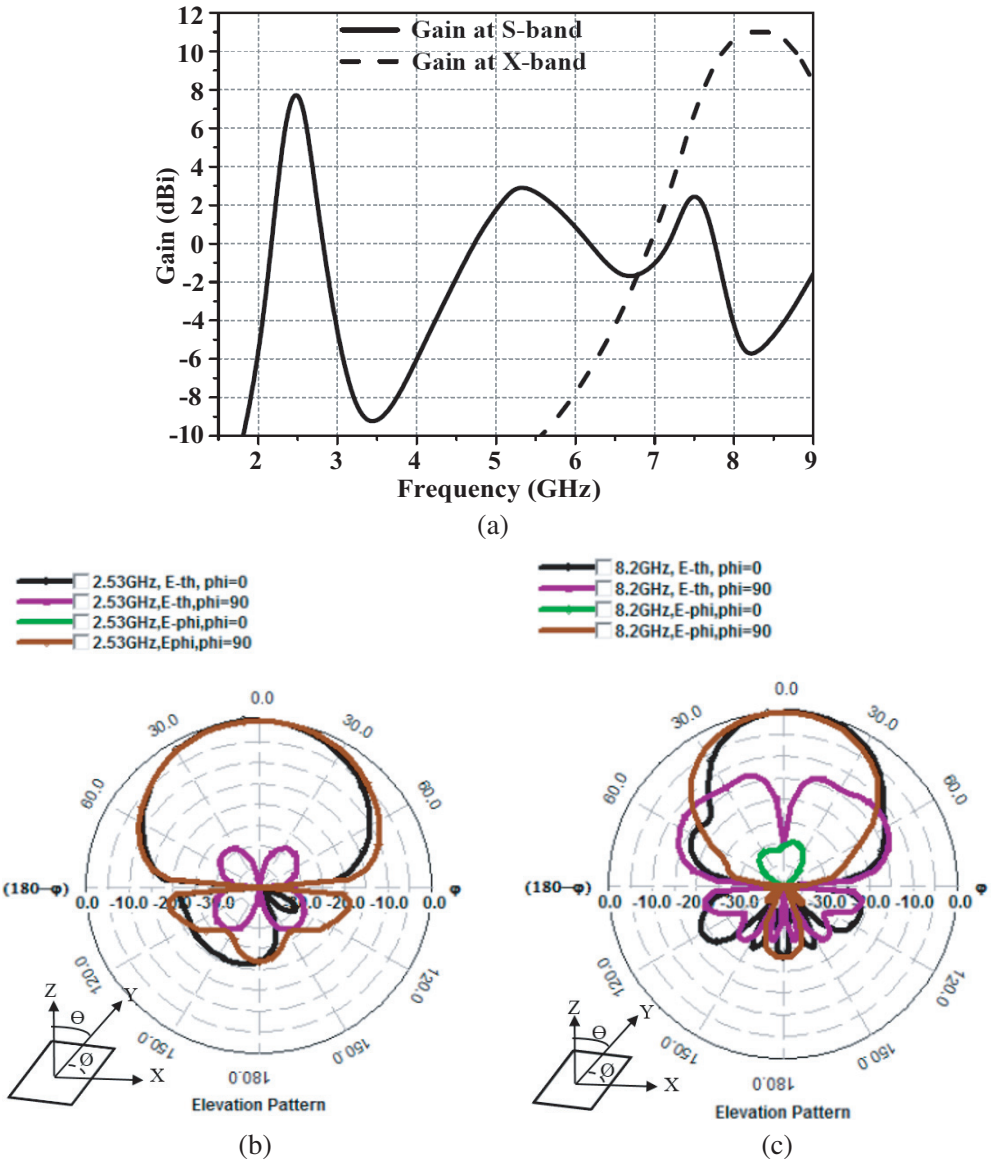

Figure 4. (a) Gain vs frequency variation at S- and X-band from 2 to 9 GHz and radiation pattern at (b) 2.5 GHz and (c) 8.2 GHz of dual frequency antenna.

The radiation pattern is stable over the entire bandwidth of the two frequency bands (S- and X-bands) as the antenna radiates due to fundamental modes generated in it. Fig. 5(c) shows the simulated and measured passive S-parameters of the antenna. The simulated bandwidth of 9% from 2.4–2.63 GHz is achieved at S-band and 9.8% from 7.7–8.5 GHz at X-band. Simulated isolation better than 28 dB is achieved at each frequency band. Good isolation is achieved because there is negligible interference between the higher order modes of patches at lower frequency and higher frequency.

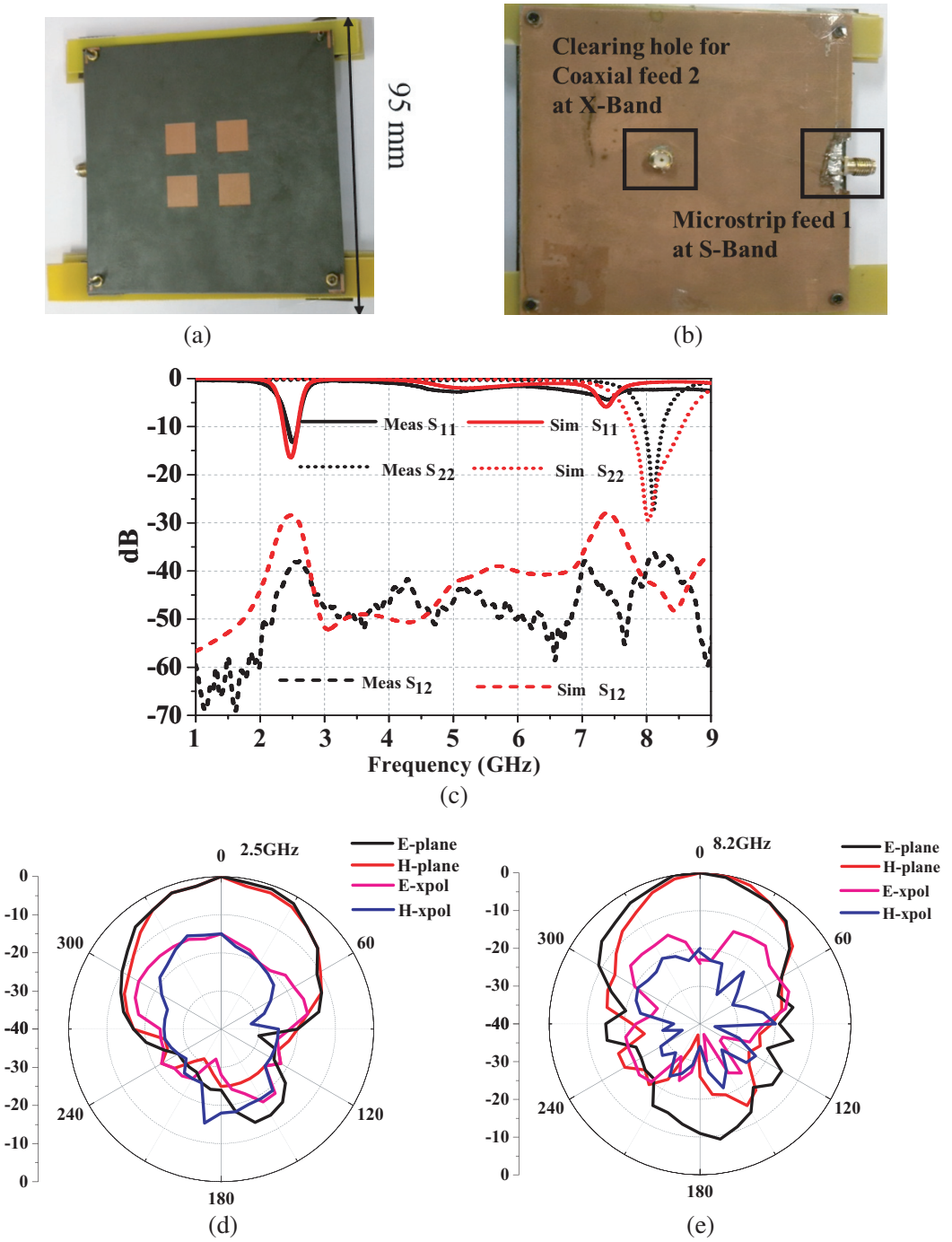

Figure 5. (a) Top and (b) bottom views of fabricated dual frequency antenna at S- and X-bands and its measured (c) S-parameters and radiation pattern at (d) 2.5 GHz and (e) 8.2 GHz.

Figure 5 shows the top and bottom views of the fabricated antenna, its measured S-parameters and measured radiation pattern. The substrates have been stacked on each other with air gap in between with the help of clamps at four corners of the substrate of the antenna. A clearing hole is made on the first substrate (L1) for feed 2 at X-band. Antenna has size of 95 mm × 95 mm × 64 mm. The measurements of S-parameters (S_{12}) are done using a two-port VNA (N9918A) with both the ports connected to the proposed antenna. The measurement of S_{11} and S_{22} is done using only one port of VNA connected to antenna and the other port of antenna terminated with matched impedance. The measured bandwidth is 13.3% from 2.3–2.63 GHz at S-band and 6.2% from 7.8–8.3 GHz at X-band. Bandwidth at X-band is shrunk because of shift in the input impedance plot to lower impedance value due to fabrication error. However, the bandwidths of the antennas in references [8] and [10] are better at the two bands, but they have multiple coaxial feeds, and no feed network has been designed. Measured isolation of the proposed antenna is better than 38 dB at S- and X-bands. There is change in measured isolation (S_{12}) due to the deviation in simulated and measured (S_{11}) at Port 1. The difference appears large in dB scale, but numeric value difference is small.

The radiation pattern is measured in an anechoic chamber using reference antenna as double-ridge horn antenna having gain (G_r) of 12 dBi at S-band and 18 dBi at X-band, respectively. The reference antenna and test/proposed antenna are kept at a distance (R) of 300 cm. The transmitted power (P_t) is 0 dBm. The received power (P_r) is −30.5 dBm at S-band and −37.5 dBm at X-band. The gain of the antenna under test (G_t) is calculated using Friis transmission equation as follows:

$$P_r = P_t G_t G_r \left(\frac{\lambda}{4\pi R}\right)^2 \tag{1}$$

The measured gain of the antenna is 7.5 dBi at 2.5 GHz and 10.5 dBi at 8.2 GHz. The radiation pattern of the antenna is found to be stable over the entire bandwidth of the two frequency bands. Figs. 5(d)–5(e) show the measured radiation patterns at the two frequencies. The cross-polarized component at S-band is better than −15 dB, and front to back ratio is 20 dB. The cross-polarised component at X-band is better than −15 dB, and front to back ratio is 20 dB. Thus, the simulated and measured results are in reasonable agreement. The antenna can be extended to design a dual-polarised dual-frequency antenna by introducing orthogonal feed network and can be used for Telemetery, Tracking and Control applications.

4. CONCLUSIONS

A novel configuration for a dual-frequency antenna having a high frequency ratio (1 : 3.3) is proposed in this paper. A 2 × 2 antenna array at higher frequency (X-band) is used instead of single patch to achieve high gain. This configuration uses the antenna at lower frequency (S-band) as ground plane for antenna array at higher frequency (X-band) and saves space. It achieves bandwidth of 13.3% at S-band and 6.2% at X-band without any interference between the two bands. It gives gain of 7.5 dBi at 2.5 GHz and 10.5 dBi at 8.2 GHz. It has high isolation of better than 38 dB between the two bands, and the radiation pattern is stable over the bandwidth of the two frequency bands. The antenna is fabricated and tested, and measured results are in reasonable agreement with the simulated ones.

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