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Design of Asymmetric Wideband Printed Dipole Antenna Using Inset Feeding Technique

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Abstract—In this paper, the design of an asymmetric wideband printed dipole antenna is presented along with measured results. The wide bandwidth covering 0.8–4 GHz is achieved using inset feeding technique. This paper also presents the techniques for achieving good omnidirectional radiation patterns over the wide frequency band with deviation from omni-directionality within ± 2.5 dB. This design offers more than $5:1$ impedance bandwidth (for VSWR $\leq 2.2:1$), with good radiation efficiency and omni-directionality. The comparison study of symmetrical and asymmetrical printed dipole antennas with and without inset feed is presented in this paper. Thus, the proposed antenna finds a wide range of applications in trans-receive modes in today's wireless devices.

1. INTRODUCTION

Printed antennas are one of the favourite choices among antenna designers. These antennas have also won wide acceptability and demand from system designers owing to their low profile, low cost, ease of fabrication, and compatibility with microwave integrated circuit technology [1]. For implementing the printed antenna on the same PCB as the circuitry, practically no additional cost is needed. For a system which requires an omnidirectional radiation pattern, as in a broadcasting system or a communication system, a monopole or dipole is a good choice. Printed monopole antennas are generally easy to design, and impedance matching can be achieved for a frequency range $3:1$ bandwidth as reported in [2, 3]. Recently, printed monopole antennas have been widely adopted in wireless communication systems [4]. However, these antennas require a finite ground plane, defeating the desired properties of low profile and conformal nature of a printed antenna [5]. A tapered feed printed strip dipole with parasitic metal strip near the feed point to achieve wide bandwidth is reported by Behera and Harish [6]. Here the bandwidth is limited to 66% with return loss (S_{11}) ≤ -10 dB.

Achieving wide impedance matching without compromising the pattern bandwidth is not possible as reported in [7] where the omni-directionality suffered. There is always a trade-off between impedance and pattern bandwidth, and in some applications, relatively high VSWR over the pattern bandwidth may be preferred.

In this paper, a printed dipole antenna is presented covering a wide frequency band from 0.8 to 4 GHz without degrading its overall radiation efficiency and omni-directionality. Thus the proposed antenna covers the EM spectrum for GSM-900 (890–960 MHz), GSM-1800 (1710–1880 MHz) band, Industrial Scientific and Medical band of 2.45 GHz, and fixed wireless access band (FWA) of (3.4–3.8 GHz). Moreover, this paper also addresses the issue of bandwidth enhancement techniques for a conventional narrowband printed dipole antenna.

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2. DESIGN APPROACH

Conventional wire monopole/dipole antennas are narrowband antenna configurations with bandwidth of the order of 5–10% of its centre frequency. This is not sufficient for high data transfer rate for wireless networks. Much research work has been carried out in order to broaden the bandwidth of these antennas, and several different approaches have been proposed [8]. The bandwidth of these antennas can be improved by applying the following techniques as reported in [9],

i) Lowering the λ/D (i.e, wavelength to diameter ratio).
ii) Use of angle concept (Rumsey's criteria).
iii) Using loading, impedance matching, or tuning circuits [10].

By lowering wavelength to diameter ratio or in other words thickening the radiating elements, the impedance bandwidth can be improved up to certain extent. Further thickening will result in distorted radiation patterns. Again, the Rumsey's principle for a frequency independent antenna can give wide bandwidth provided that the antenna dimension is infinite [11]. Even though a finite structure can perform similarly to that of an infinite structure after a couple of wavelengths, the dimension will still be very large for wireless applications. [12].

Finally, loading techniques or impedance matching circuits introduce losses in the antenna system, thereby lowering the efficiency of the antenna system. This may not be acceptable in applications where the overall system performance critically depends on the efficiency of the antenna. In this paper, the first two techniques will be exploited along with inset feeding technique to achieve wideband operation.

For a conventional wire dipole antenna design, the dipole length is taken as half of its wavelength. To compensate the inductive reactance, it is required to reduce the dipole length to less than half a wavelength long ($\sim$ 0.47 of its wavelength) [13]. However, for the proposed wideband printed dipole antenna shown in Figure 1, the above design flow is not completely applicable.

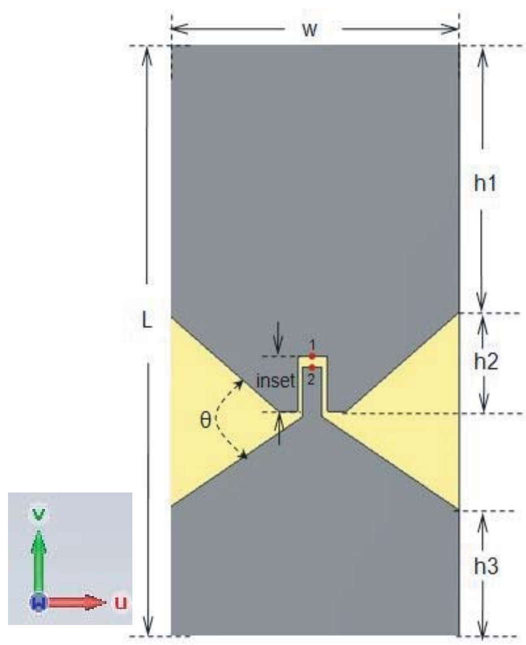


Figure 1. Sketch of the wideband printed dipole antenna.

The length of the wideband dipole antenna is decided by its highest operating frequency in order to avoid pattern split or nulls. For a thin wire antenna, to avoid the pattern split, the overall length of the dipole must be lower than 1.1 times of the wavelength [14]. The pattern control in the proposed printed dipole antenna is accomplished by optimization of its various parameters such as length, width, flare angle, and inset feed depth. The antenna is optimized for good performance using CST Microwave

Studio$^{\mathrm{TM}}$ [15]. The proposed antenna is printed on one side of the RT Duriod 5880$^{\mathrm{TM}}$ substrate with dielectric $\varepsilon_r = 2.2$ and thickness $t = 1.6$ mm.

The overall antenna design steps are shown below:

Step 1: Designing the antenna at its centre frequency,

Operating Frequency, (F_1, F_2): 0.8 GHz to 4 GHz,

Centre Frequency F_c: Sqrt($F_1 \times F_2$) = 1.79 GHz,

Wavelength, λ_c (at F_c): 167.5 mm,

***Step 2*:** Wavelength at highest frequency,

$\lambda_{\mathrm{at\,4\,GHz}} = 75$ mm,

$1.1 \times \lambda_{\mathrm{at\,4\,GHz}} = 82.5$ mm.

This is the maximum length that can be taken for a thin wire dipole to avoid elevation pattern split at 4 GHz. For a fat dipole the overall length could be further increased depending on the wavelength/diameter ratio.

***Step 3*:** The proposed antenna is a variant of a fat dipole with width = W. Thus the length of the printed dipole is optimized between 82.5 mm and 167.5 mm. Since the antenna is printed on only one side of the substrate, the effect of dielectric on antenna performance is minimal.

***Step 4*:** The antenna impedance is matched to 50 ohms over the wideband frequency using two techniques, i.e., (i) Inset feed and (ii) Flare angle.

***Step 5*:** For the proposed antenna to have good gain and omnidirectional pattern, the two elements of the dipole are asymmetrically designed [16].

Step 6: To suppress unbalanced current and improve radiation patterns, a choke type balun is designed and integrated with the antenna.

The final optimized design parameters of the printed dipole antenna are shown in Table 1. The antenna is fed using a 0.141” coaxial cable. The critical parameters of the antenna are varied, and the antenna response is discussed in the next section.

Table 1. Optimized design parameters of asymmetric printed dipole antenna.

Parameter	Optimized Value	Description
L	110 mm	*Overall length*
W	60 mm	*Width*
$h1$	50 mm	*Upper section of top element*
$h2$	18 mm	*Lower section of top element*
$h3$	24 mm	*Lower section of bottom element*
inset	10 mm	*Inset feed depth*
Flare angle, θ	69.3°	*Flaring angle between the top and bottom element*

3. RESULTS AND DISCUSSION

The asymmetrical printed dipole antenna is first designed using EM simulation software, CST microwave studio$^{\mathrm{TM}}$. The simulated results are presented along with measured ones.

3.1. Simulated Results

The following simulation studies are carried out before arriving at the final configuration of the antenna.

I. Parametric study of inset feed depths with respect to VSWR is shown in Figure 2. The depth of the inset is varied from 2 mm to 20 mm. From the figure, near optimal impedance matching is achieved between inset depths of 10 mm and 14 mm.

II. Parametric study of flare angle with respect to VSWR, keeping inset depth = 10 mm is shown in Figure 3. The flare angle is varied from 24.7° to 98.5°. From the figure, near optimal impedance matching is obtained at 69.3°.

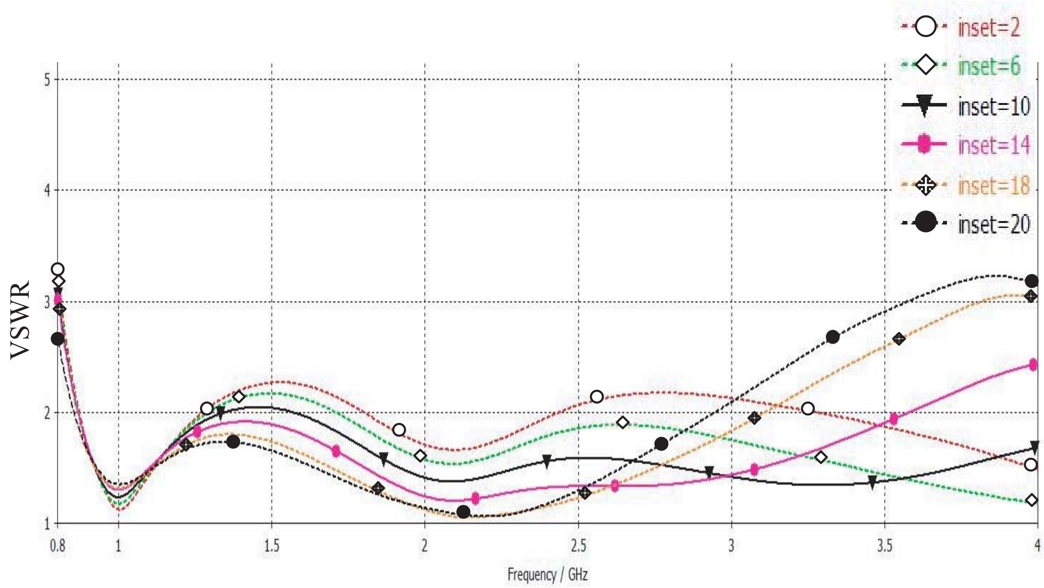


Figure 2. Parametric study of inset feed depth with respect to VSWR.

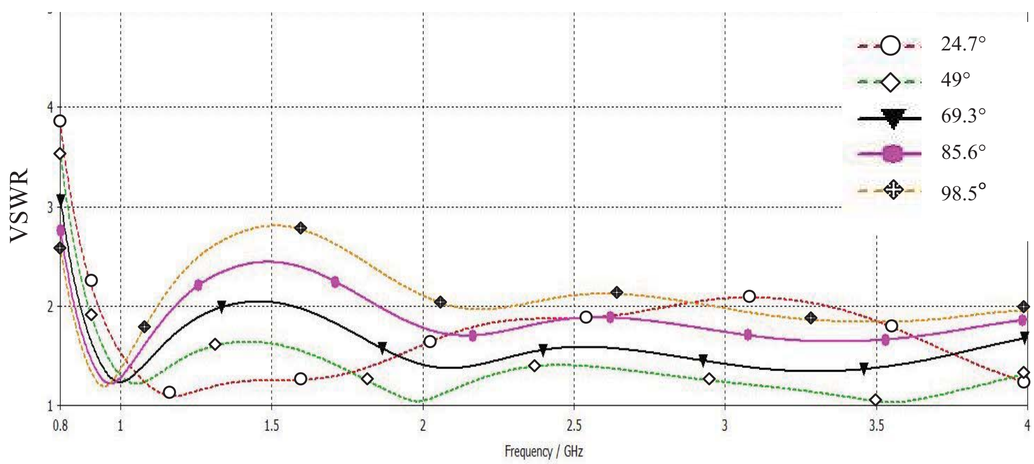


Figure 3. Parametric study of flare angle with respect to VSWR.

From the above two studies, it can be concluded that the impedance matching is controlled by the inset feed depth and flare angle.

III. The configuration of a fat symmetrical printed dipole antenna without inset feed is shown in Figure 4(a). This antenna configuration is studied for VSWR and radiation pattern characteristics. Figure 4(b) shows the VSWR comparison plots of a symmetric printed dipole antenna with and without inset feed.

From the results, it is seen that without inset feed, the impedance is not properly matched to 50 ohms.

The radiation patterns of symmetrical printed dipole antenna behave well with figure of eight in E-plane and omni-directionality in H-plane. However, the radiation patterns deteriorate at higher frequencies as shown in Figure 4(c).

IV. The asymmetrical printed dipole antenna without inset feed as shown in Figure 5(a) is studied for VSWR and radiation pattern. Figure 5(b) shows the VSWR comparison of the asymmetric printed

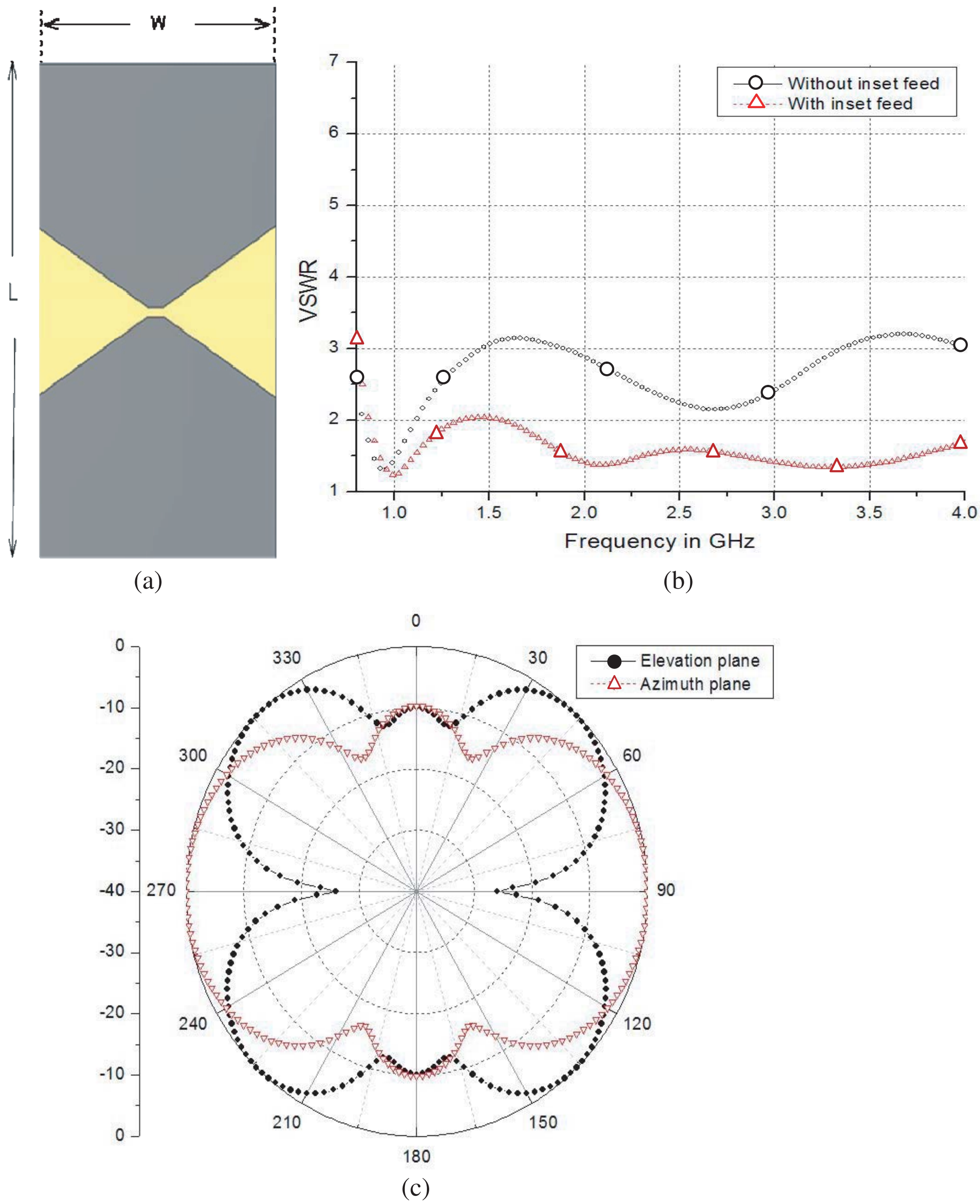


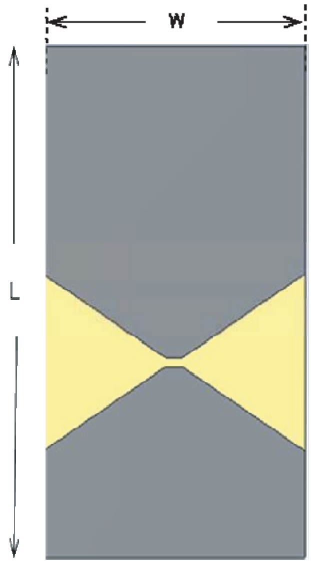
Figure 4. (a) Symmetrical printed dipole antenna. (b) VSWR comparison plot of symmetrical printed dipole antenna. (c) Radiation pattern of symmetrical printed dipole antenna at 4 GHz.

dipole antennas with and without inset feed. It is seen that without inset feeding, the antenna impedance is not properly matched to 50 ohms.

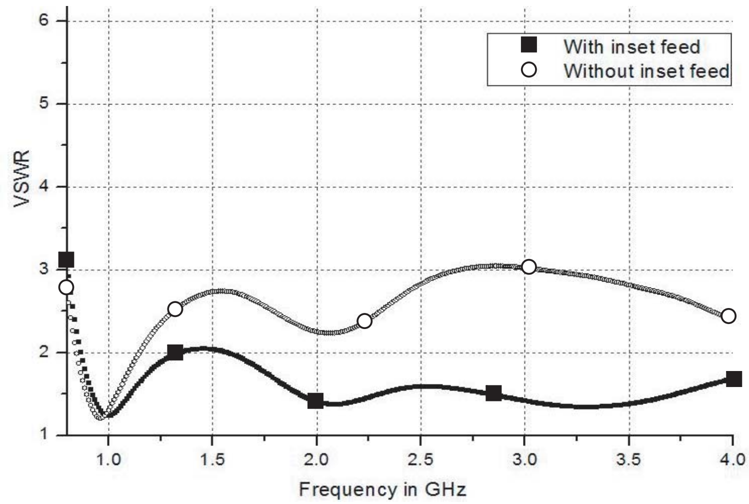
Figure 5(c) shows the radiation patterns of the asymmetrical printed dipole antenna at 4 GHz. It is found that the deterioration in radiation pattern characteristics at higher frequencies is reduced compared to symmetrical printed dipole antenna of Figure 4(c).

From the above simulation studies it is concluded that an asymmetrical printed dipole antenna with inset feed is an optimum broadband antenna configuration.

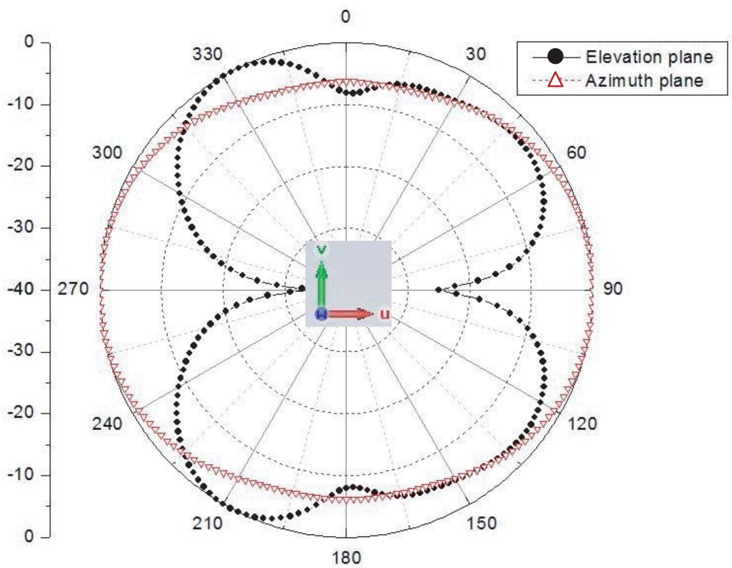
The asymmetrical printed dipole antenna with optimized antenna dimensions (taken from Table 1)



(a)



(b)



(c)

Figure 5. (a) Asymmetrical printed dipole antenna. (b) VSWR of asymmetrical printed dipole antenna with and without inset feed. (c) Radiation pattern of asymmetrical printed dipole antenna at 4 GHz.

is simulated for its radiation pattern at 0.8 GHz, 2 GHz, 3.5 GHz, and 4 GHz, respectively. The normalized radiation patterns are shown in Figures 6(a), (b), and (c). The results indicate good omnidirectional characteristics with omni-variation within ± 2 dB.

3.2. Measured Results

The final optimized antenna is printed on RT Duriod 5880$^{\mathrm{TM}}$. Figure 7 shows a photograph of the asymmetric printed dipole antenna. The overall dimension of the printed antenna is 110 mm $\times$ 60 mm excluding feed cable. Using Agilent's E5071C ENA series, VSWR is measured with and without a ferrite choke balun, and comparison is shown in Figure 8. Using a ferrite balun, the VSWR ripples at lower frequencies are suppressed. The measured VSWR is less than 2.2 : 1 over the band, and there is good agreement between the simulated and measured results.

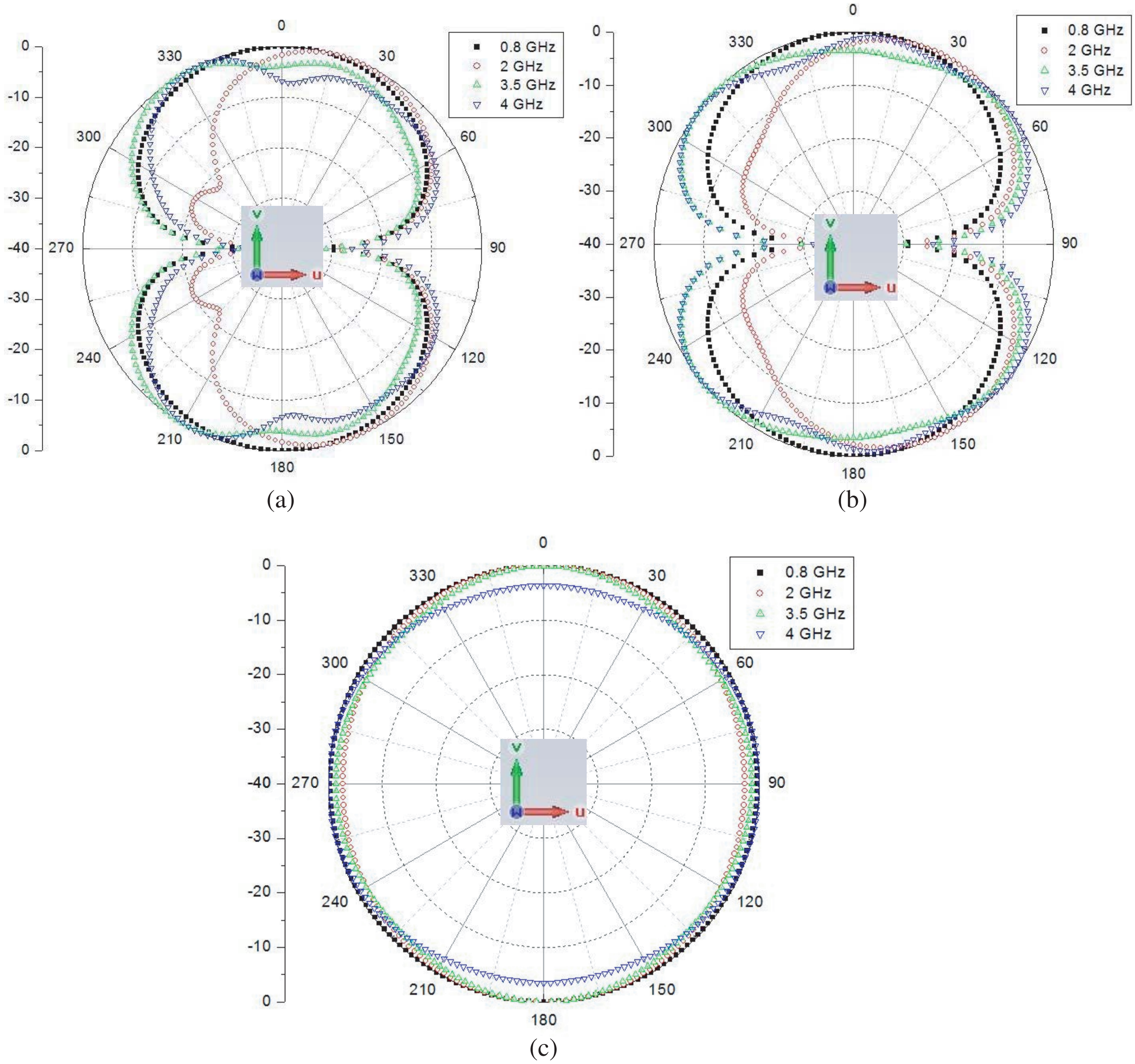


Figure 6. (a) Radiation pattern of proposed printed dipole antenna in VW-plane. (b) Radiation pattern of proposed printed dipole antenna in UV-plane. (c) Radiation pattern of proposed printed dipole antenna in UW-plane.

The antenna far field radiation patterns are measured inside a rectangular anechoic chamber using a PNA based antenna measurement system. Figures 9(a) and 9(b) show the measured elevation patterns, and 9(c) shows azimuth plane patterns.

From the figures, it is seen that the antenna exhibits good radiation patterns with maximum omnidirectional variation within ± 2.5 dB.

The antenna also exhibits good radiation efficiency. Figure 10 shows the measured gain plot of the antenna, and the gain varies from 1dBi to 4.1 dBi over the band.

Figure 7. Photograph of proposed printed dipole antenna.

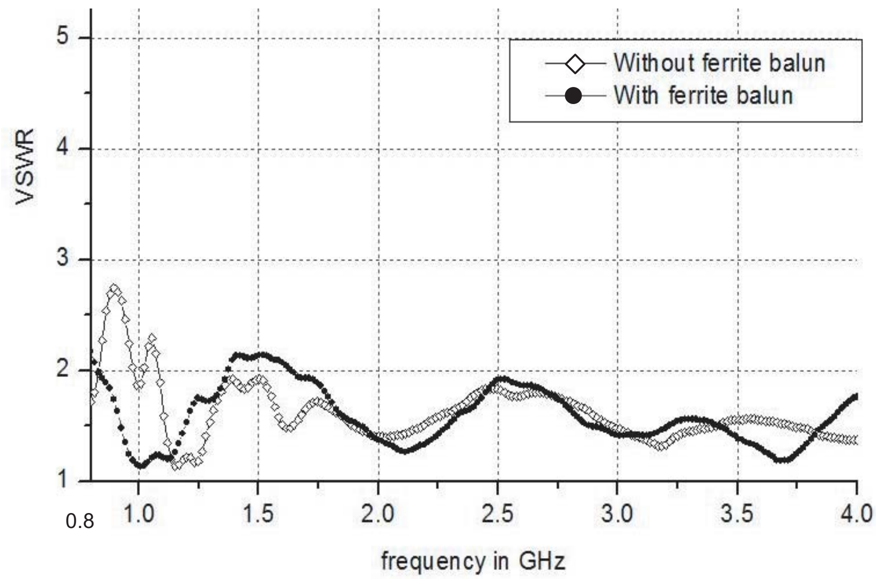
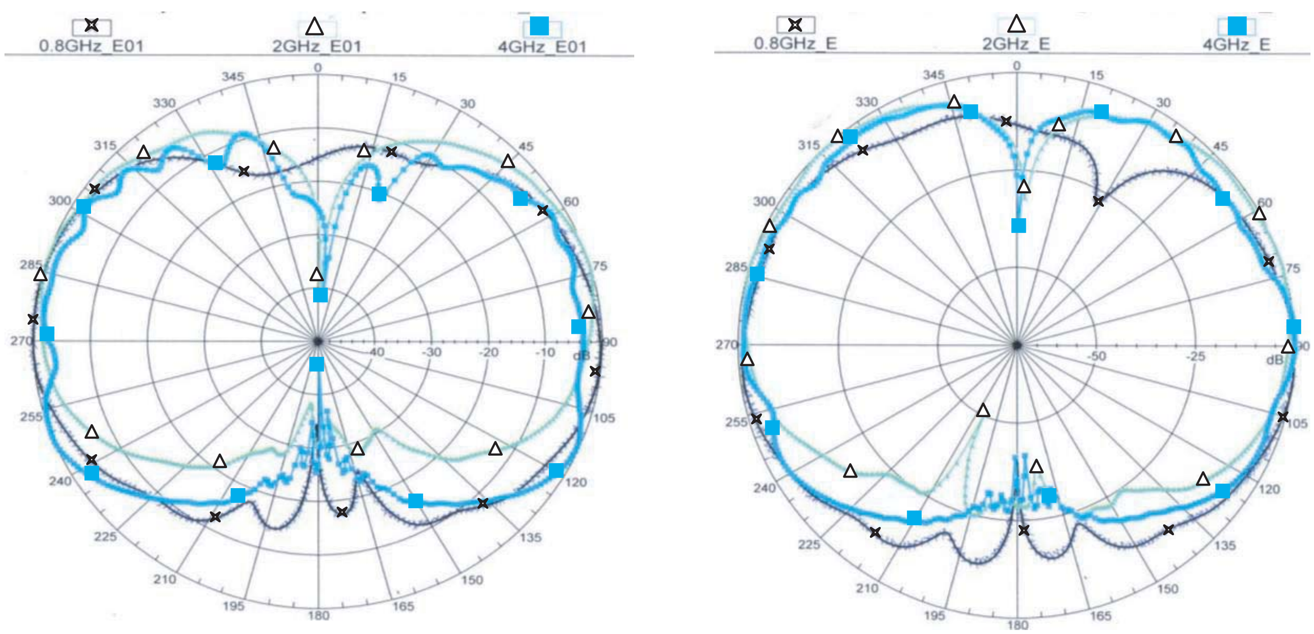
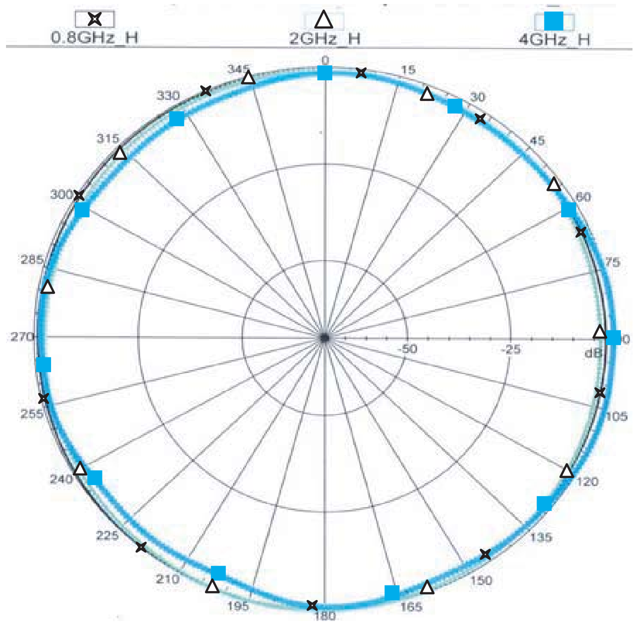


Figure 8. Measured VSWR of asymmetrical wideband printed dipole antenna.



(a) (b)



(c)

Figure 9. (a) Measured radiation patterns of printed dipole antenna in VW-plane. (b) Measured radiation patterns of printed dipole antenna in UV-plane. (c) Measured radiation patterns of Printed dipole antenna in UW-plane.

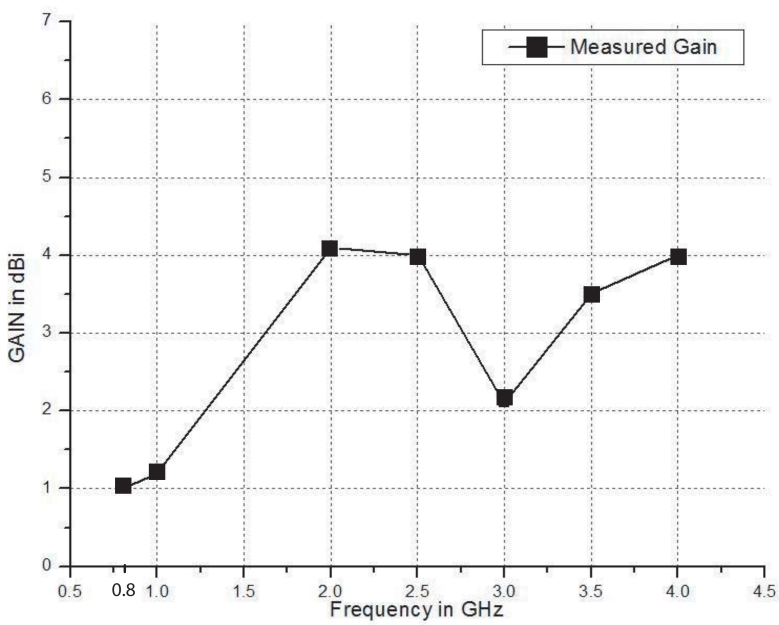


Figure 10. Measured gain of the wideband printed dipole antenna.

4. CONCLUSIONS

The design of a printed dipole antenna is discussed, and the optimum antenna configuration is found to be that of an asymmetric wideband printed dipole antenna given in Table 1. The antenna parameters for achieving wide bandwidth have been studied and optimised. This antenna shows good VSWR, gain, and radiation patterns over the frequency band 0.8–4 GHz. By varying the inset feed depth and flare angle, an optimum impedance matching can be accomplished. Using asymmetry in the antenna structure, the radiation pattern split can be avoided. The antenna performance is further enhanced by using a ferrite choke type balun, which improves the impedance match as well as radiation characteristics. Thus, the proposed compact wide band printed dipole antenna is envisaged to have wide range of applications in wireless communication systems, spectrum monitoring and military systems.

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