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An Experimental Study of the Printed-Circuit Elliptic Dipole Antenna with 1.5-16 GHz Bandwidth

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Abstract

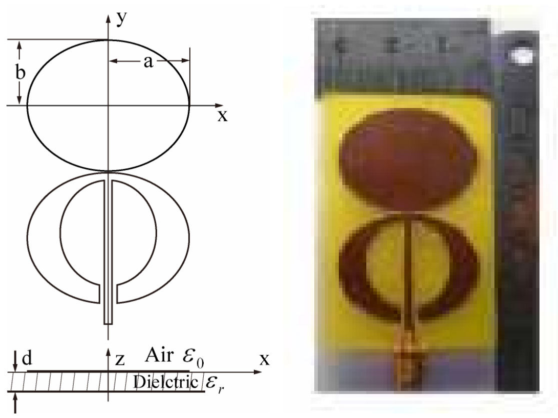
Printed-circuit board (PCB) elliptic antennas with useful bandwidth exceeding 10:1 ratio are suitable for wideband radar, wireless ultra wideband (UWB) and other wireless communication applications. We present wideband PCB elliptic dipole antennas which are capable of achieving the bandwidth requirements for all the applications. A set of elliptic dipole antennas with varying eccentricities have been fabricated for demonstration. We find one specific size (specific eccentricity) dipole that can yield an impressive 1.5-16 bandwidth exceeding the currently available. A couple of elliptic dipole antennas suitable for UWB application have been presented. We have measured swept frequency response, impedance and radiation patterns of all dipoles. An empirical formula is given for calculating the starting resonant frequency within the operating band. The calculated values are found in good agreement with measured results.

Keywords: Elliptic Dipole Antenna, Wideband Radar Antenna, Printed-Circuit Board (PCB), Ultra Wideband (UWB)

1. Introduction

The printed-circuit elliptical antenna has proven to be an efficient and effective radiator with broadband performance. In its simplest configuration, circular or elliptical antenna can be designed to produce a broad beamwidth as well as broadband with linear polarization and a radiation pattern having a broadside maximum. The most direct approach to provide a broad beamwidth and broadband performance from such an antenna is to use a printed-circuit dipole with the upper and lower radiation elements having a circular or elliptical shape. The antenna dipole could be fed with a 50 ohm microstripe line, extending into the dipole center (the point where the two adjacent circular or elliptical radiators join). It was found that the current on the radiator at all frequencies is largely concentrated on the peripheral edge with very low current density approaching inward towards the center. For elliptic (circular) dipoles, one can picture that numerous semi-elliptic thin-line dipoles of varying lengths are effectively formed to excite multilinear modes hence resulting in a wide bandwidth with linear polarization.

Several methods have been proposed to study the impedance of elliptical printed-circuit antennas [1–3]. A printed crescent patch antenna [4] and a bottom fed elliptical antenna [5] were investigated experimentally to provide broadband performance with linear polarization without added complexities inherent in the feed circuit.



(a) **(b)**

Figure 1. (a) Geometry of an elliptical printed-circuit dipole antenna. (b) An elliptical dipole antenna etched on PCB with dielectric constant ε_r =4.2.

Broadband printed-circuit elliptical dipole antennas covering 750 MHz to 6.0 GHz for WLAN and WiMax applications have been fabricated and tested [6]. Recently, Powell [7] has shown that broadband linear polarization could also be achieved by two differential crescent patches fed at the dipole center of the two adjacent elliptic elements. They achieve a broadband performance covering the 3.1-10.6 GHz ultra wideband (UWB) spectrum with a swept frequency return loss of about 11dB.

In this paper, experiments are carried out to investigate the impedance bandwidth and swept frequency measurement for several elliptic dipole radiators using various eccentricities (equivalently, various b/a ratios, see Figure 1). The radiation patterns are also measured.

The rest of the paper is organized as follows. Section 2 presents experimental results of the bandwidth performance for a set of elliptic dipoles of various sizes (various eccentricities) by measuring the frequency return loss. An optimum dipole size is found to yield widest bandwidth among all. Section 3 discusses the starting resonant frequency. Section 4 discusses the antenna products for UWB application. Then, Section 5 measures the radiation patterns of the optimum dipole. Finally, Section 6 concludes the paper.

2. Experimental Results of Bandwidth Performance

The geometry of a printed-circuit elliptic antenna dipole is shown in Figure 1(a). A photograph of an elliptical dipole antenna etched on PCB with dielectric constant of 4.2 is shown in Figure 1(b). In the lower elliptic radiator, portion of the area is cut off in the shape of an ellipse to accommodate the 50 ohm micro stripe feed line. The first part of our experiment study is to investigate the broadband properties. A set of dipoles with varying *b/a* ratios were etched on the printed-circuit board (PCB). We varied the *b/a* ratio progressively from 1.00 (a circle), 0.945, 0.897, 0.852 to 0.813. The minor diameter 2*b* was held constant at 26 mm, while the major diameter 2*a* was progressively increased from 26 mm to 32 mm. Thus, five different size dipoles are etched on microwave printed-circuit boards (PCBs) using 41.2 mm×88.1 mm to 38.1 mm×53.4 mm FR4 with thickness *d* = 0.762 mm and dielectric constant 4.2.

The swept frequency return loss for an elliptic dipole with 2*a*=32 mm and 2*b*=26 mm *(b/a* = 0.813) is first measured using a network analyzer. We can see from Figure 2 that, in the 1.5 GHz to 16 GHz range (bandwidth ratio 10.66:1), the return losses are all better than -10 dB. This is an impressive broadband result as the bandwidth has exceeded the 10:1 ratio. Next, Figure 3 presents the swept frequency measurement of this particular dipole in Smith chart format. Then, a plot of the real and imaginary parts of the input impedance against frequency is given in Figure 4. From this figure, we can see multiple resonance peaks indicating that the radiator effectively consists of multi-elliptically-shaped thin-line dipoles of various lengths exciting many linear modes thus resulting in a broad bandwidth with linear polarization.

Next, we vary 2*a* from 26.0, 27.5, 29.0, and 30.5 mm while holding 2*b* constant at 26 mm (*b/a* ratios of 1.000, 0.945, 0.897, and 0.852) and repeat the experiment. For these *b/a* ratios, the measured swept frequency return losses are compared and results are presented in Figure 5. Typical swept frequency input impedance derived from corresponding Smith chart measurements are given in Figure 6 and Figure 7. The first dipole with 2*a*=32mm outperforms all. Then, we have also fabricated elliptic dipoles with reducing *b/a* ratios of 0.800 and 0.750 (increasing 2*a* beyond 32mm) and found that the performance also starts to fall.

The bandwidth performance (bandwidth is defined here as the frequency range with return loss better than

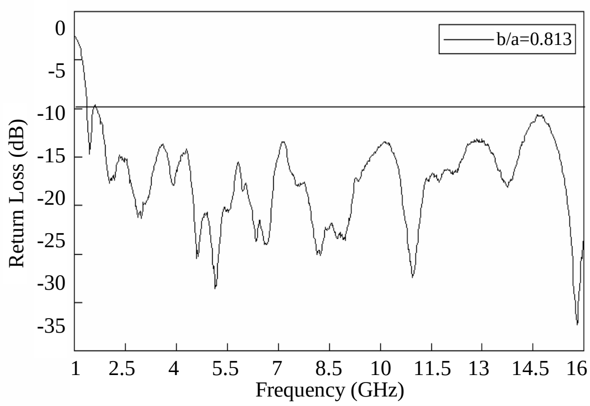


Figure 2. Measured return loss for elliptic dipole with 32 mm × 26 mm, *b/a* = 0.813.

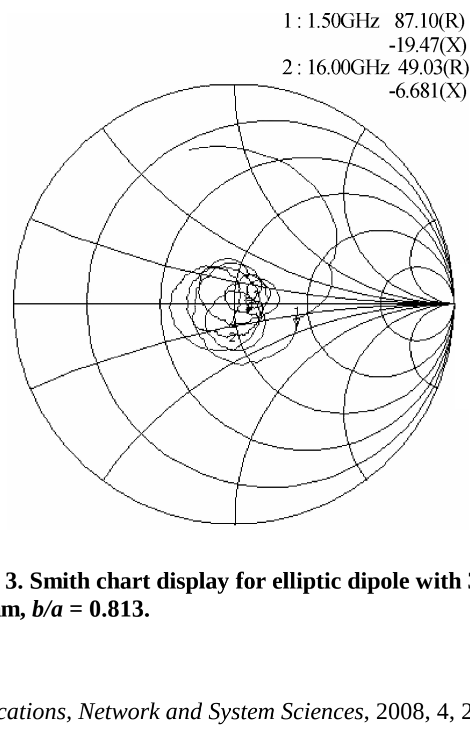


Figure 3. Smith chart display for elliptic dipole with 32 mm × 26 mm, *b/a* = 0.813.

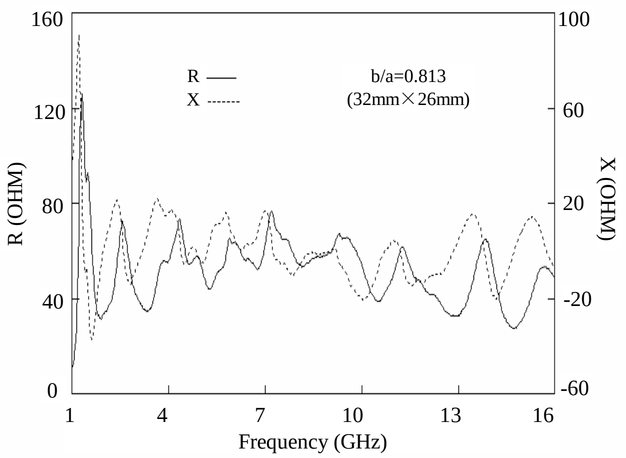


Figure 4. Impedance vs. frequency for elliptic dipole with 32 mm × 26 mm, *b/a* = 0.813.

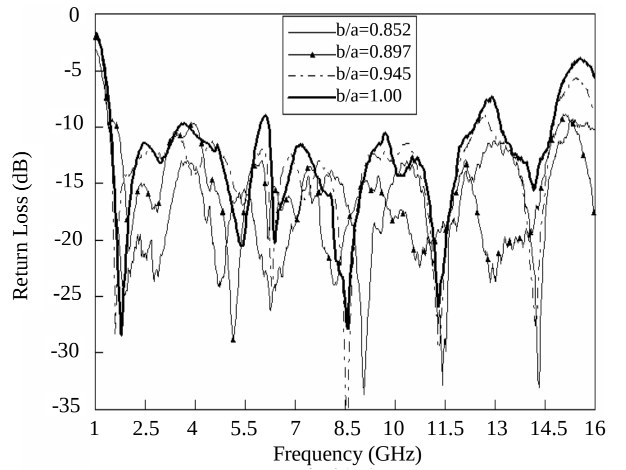


Figure 5. Comparison of measured return loss between elliptic dipoles (*b/a* = 0.852, 0.897, 0.945, and 1.000).

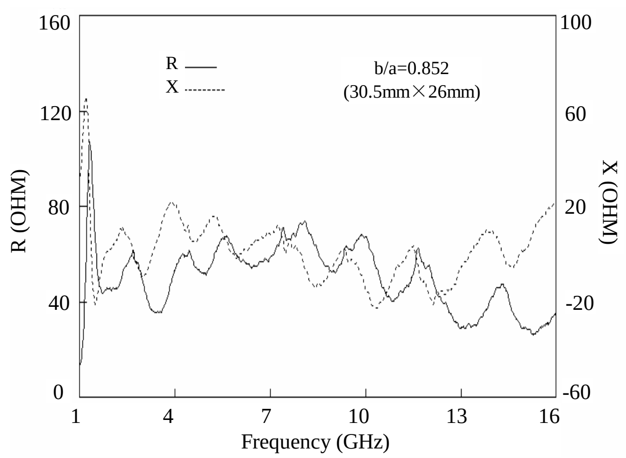


Figure 6. Impedance vs. frequency for elliptic dipole with 30.5 mm × 26 mm, *b/a* = 0.852.

-10 dB) versus *b/a* ratio for the above five dipoles is given in Figure 8. It is observed that as the radiator shape becomes less elliptical, the number of effective semi-elliptical-shaped thin-line dipoles of various lengths appears to decrease resulting in a narrower bandwidth.

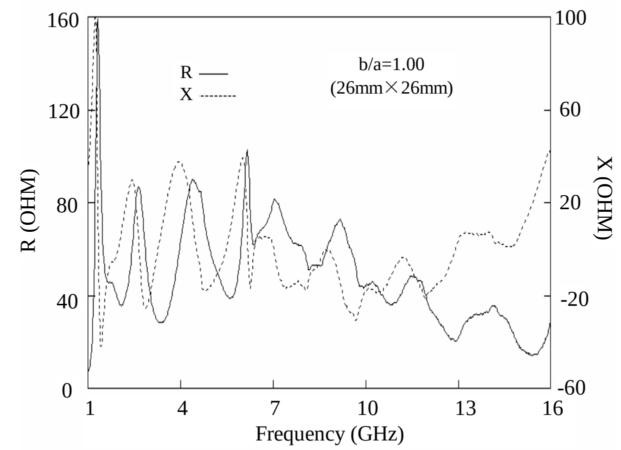


Figure 7. Impedance vs. frequency for elliptic dipole with 26 mm × 26 mm, *b/a* = 1.000.

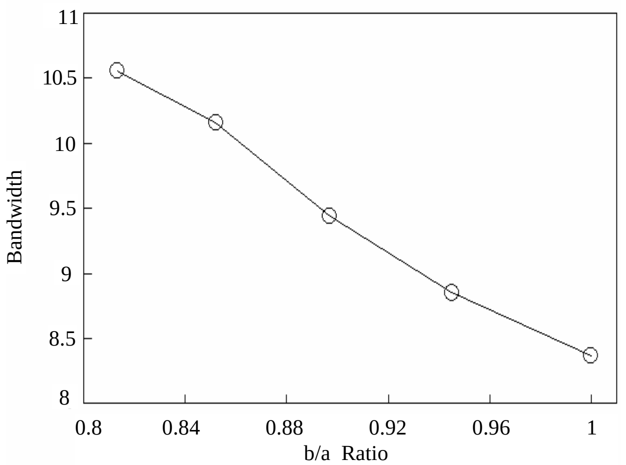


Figure 8. Bandwidth vs. *b/a* ratio for elliptic dipoles with minor diameter 26mm.

3. The Starting Frequency

The second part of our study is to investigate the starting frequency in the operating band of the elliptic dipole. It is well-known that the minor diameter 2*b* of a dipole radiator determines the resonant frequency. To investigate the resonant frequency of the elliptic dipole experimentally, we vary 2*b* from 27.0, 28.0, 29.0, and 31.0 mm while holding 2*a* constant at 32 mm (*b/a* ratios of 0.844, 0.875, 0.906, and 0.969) and repeat the experiment. For these *b/a* ratios, the swept frequency Smith charts are measured and the typical input impedances derived from the corresponding Smith charts are given in Figures 9 through 12.

For a PCB material of dielectric constant ε_r and a given 2*b* (mm), we found an empirical formula for calculating the starting resonant frequency (defined for return loss < -10 dB) in GHz as

$$f_s = \frac{40.8}{b\sqrt{\varepsilon_r}} \quad \textbf{(1)}$$

For elliptic antenna dipoles with 2*b* varied from 26.0, 27.0, 28.0, 29.0, and 31.0 mm and with 2*a* held constant at 32 mm, using (1), the calculated values of corresponding starting resonant frequencies are respectively about 1.53, 1.47, 1.42, 1.37, and 1.28 GHz. These calculated frequencies are found in good agreement with the measured frequencies (at frequencies, the impedance values correspond to better than 10 dB return loss) as shown in Figure 4 and Figures 9 through 12. Thus, (1) proves to be quite useful and handy.

4. Products for UWB Application

Utilizing Equation (1) in Section 3, printed-circuit elliptical dipole antennas for 3.1-10.6 GHz UWB applications have been fabricated and tested [8]. Figure 13 shows a photograph of elliptical dipole antennas etched on PCB with dielectric constant of 4.2 and 10.2, respectively.

To achieve the required 3.42:1.00 UWB impedance bandwidth properties, low eccentricity elliptic dipole radiators were first etched on FR4 PCB with an overall size of 24 mm × 46 mm. The measured return loss, as shown in Figure 14, in the 3.1 GHz to 10.6 GHz range is generally better than -12.6 dB. Figure 15 presents the swept frequency measurement in Smith chart format. Next, to reduce he size of the product, an elliptical dipole antenna of the same design is etched on a flexible laminate PCB with a thickness d=0.635 mm and ε_r =10.2. With an overall PCB size of 15 mm × 28 mm, this elliptic dipole provides suitable impedance properties across major portions of the frequency spectrum. The swept frequency return loss of this elliptic dipole fabricated on the flexible laminate PCB is presented in Figure 16. Due to the non-uniform properties of the flexible laminate PCB, this antenna can only achieve close to -10 dB return loss performance in the specified 3.1 GHz to 10.6 GHz frequency band.

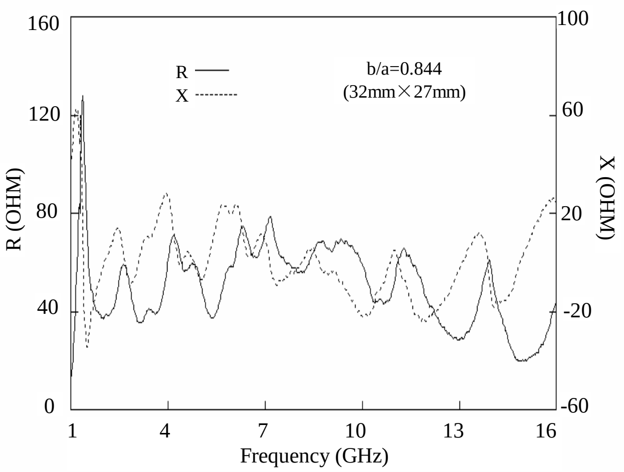


Figure 9. Impedance vs. frequency for elliptic dipole with 32 mm × 27 mm, *b/a* = 0.844.

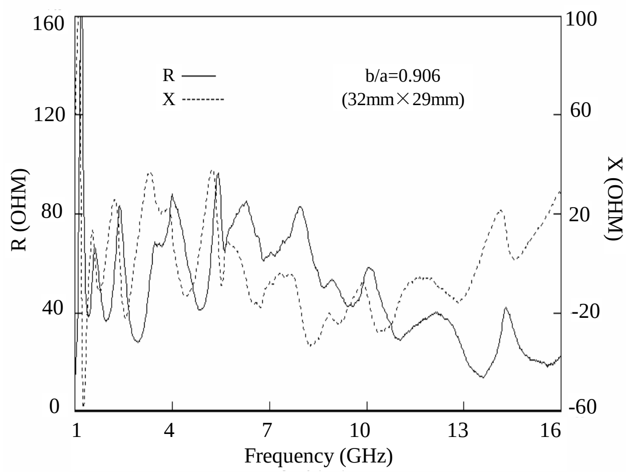


Figure 11. Impedance vs. frequency for elliptic dipole with 32 mm × 29 mm, *b/a* = 0.906.

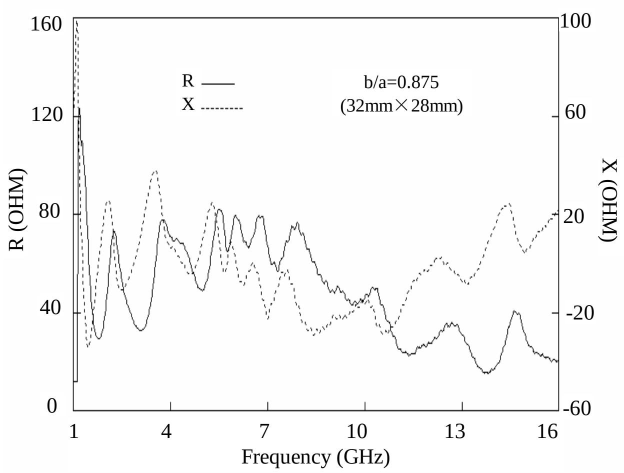


Figure 10. Impedance vs. frequency for elliptic dipole with 32 mm × 28 mm, *b/a* = 0.875.

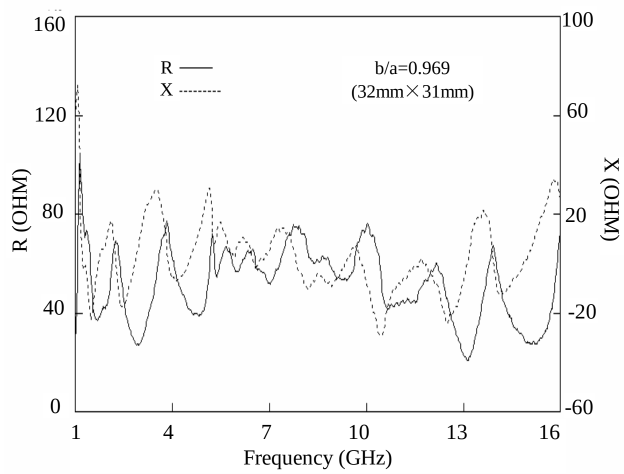


Figure 12. Impedance vs. frequency for elliptic dipole with 32 mm × 31 mm, *b/a* = 0.969.

Different from in wideband radar applications, for UWB impulse radio application, antenna requires sufficient impedance matching, linear ungroup phase response or near constant group delay throughout the entire 3.1 to 10.6 GHz band. As shown in Figure 13, the presented antennas are small, compact, and should exhibit fixed phase center property. Owing to that, this antenna tends to radiate a mostly non-dispersive waveform which cause less pulse shape distortion to the transmitted waveform and provides suitable frequency domain characteristics and performance. For UWB applications, we are preparing equipment to perform the time domain transmission tests required to assess the impulse response and fidelity characteristics of these antennas.

5. Radiation Patterns

The third part of our experiment is to investigate the radiation patterns of the 1.5-16 GHz elliptic dipole. For demonstration purpose, we only present the measurements for our optimum dipole (32 mm × 26 mm, b/a = 0.813). The radiation patterns on the x-z, x-y, and y-z planes of the optimum elliptic dipole at 2.0, 4.0, 10.0, and 14.0 GHz are measured in an anechoic chamber and shown in Figure 17, Figure 18, and Figure 19 respectively. Results indicate reasonable omnidirectional radiation patterns on all the three planes. Consistency of the patterns, similar to a typical dipole radiation pattern, can be observed across major portions of the frequency band. The measured gain is about 2 dBi.

6. Conclusions

For elliptic dipole antennas with 2*b* varied from 26.0, 27.0, 28.0, 29.0, and 31.0 mm and with 2*a* held constant at 32 mm, we found an optimum size 32 mm × 26 mm, *b/a* = 0.813 can yield a maximum bandwidth performance in the 1.5-16 GHz range. Thus, we have shown that, with a proper choice of minor to major axis ratio, a printed-circuit elliptic dipole antenna using a

Figure 13. Elliptical dipole antennas etched on PCB with dielectric constant ε_r = 4.2 (Left) and 10.2 (Right).

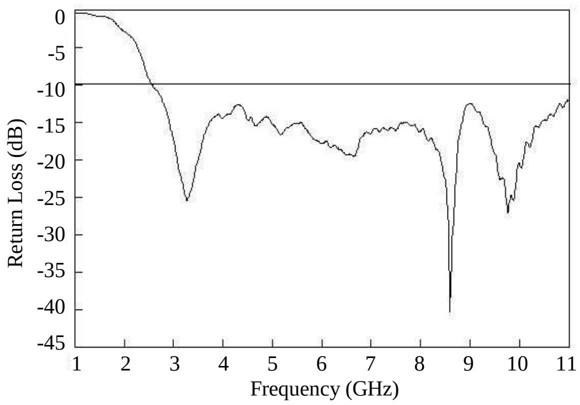


Figure 14. Measured return loss of the (24 mm × 46 mm) elliptic dipole etched on FR4 with ε_r = 4.2.

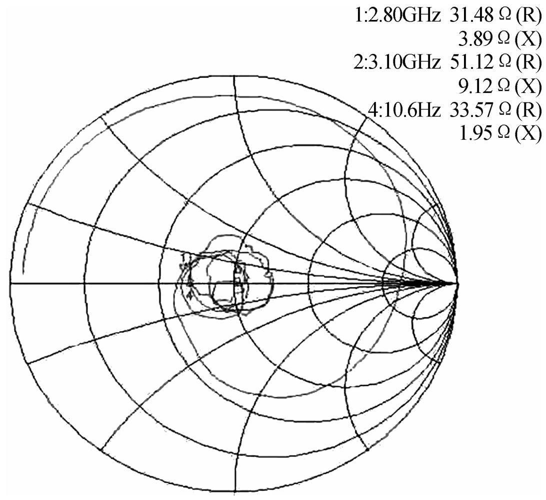


Figure 15. Smith chart display of the (24 mm × 46 mm) elliptic dipole etched on FR4 with ε_r = 4.2.

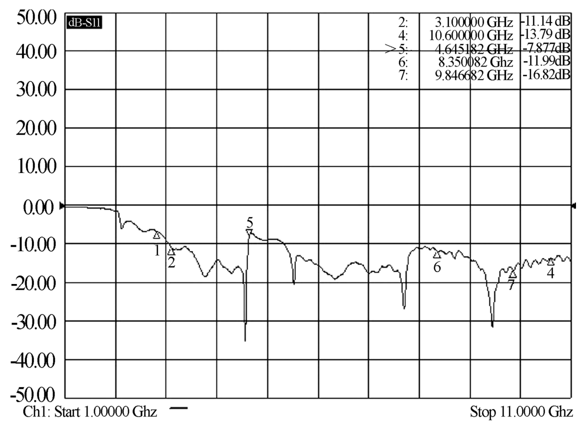


Figure 16. Measured return loss of the (15 mm × 28 mm) elliptic dipole etched on a flexible laminate PCB with ε_r = 10.2.

simple single-feed network can provide a useful operating bandwidth exceeding the 10:1 ratio. Aside from swept frequency and impedance measurements for elliptic dipoles of various *b/a* ratios, the radiation patterns for the optimum dipole are measured and found to be in consistency with typical dipole radiation patterns. By properly choosing the minor diameter for the dipole made of PCB of known dielectric constant, the starting operating frequency can be easily calculated using an empirical formula for system design. A couple of elliptic dipole antennas for 3.1-10.6 GHz (3.42:1 bandwidth ratio) UWB application have been presented to demonstrate that these dipole antennas can be designed for other fixed operating frequency bandwidth ratio.

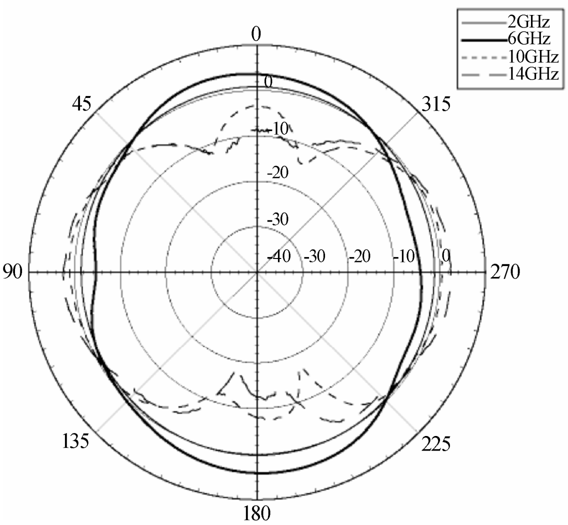


Figure 17. Measured radiation pattern on x-z plane of antenna (32 mm × 26 mm, *b/a* = 0.813).

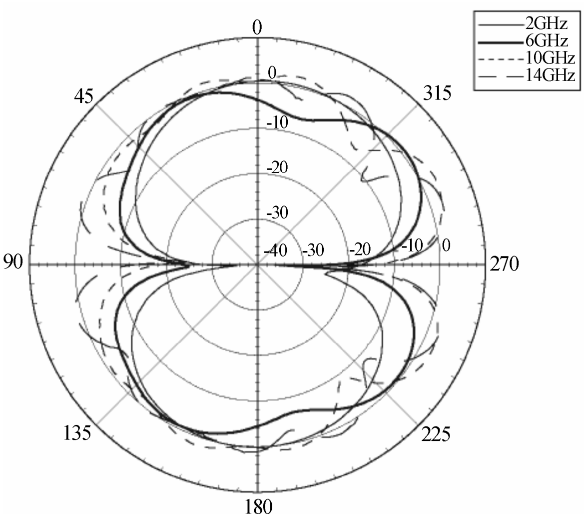


Figure 18. Measured radiation pattern on x-y plane of antenna (32 mm × 26 mm, *b/a* = 0.813).

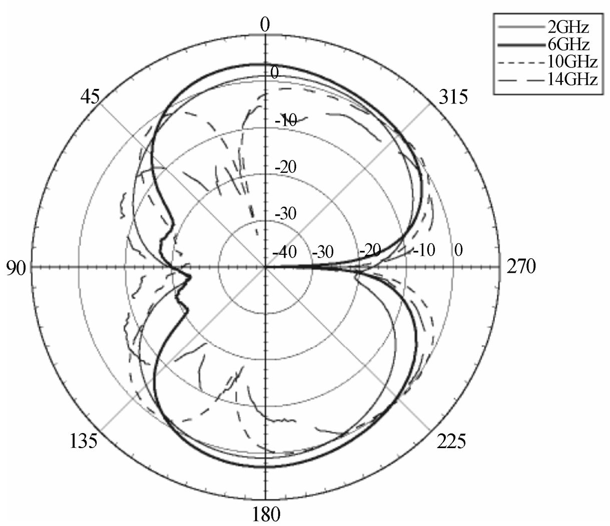


Figure 19. Measured radiation pattern on y-z plane of antenna (32 mm × 26 mm, *b/a* = 0.813).

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