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Performance Analysis of Different Ultra Wideband Planar Monopole Antennas as EMI sensors

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Abstract

The electromagnetic interference (EMI) has become an important issue in the performance of modern high frequency electronic equipment. This requires the detection of unwanted electromagnetic radiation from an equipment using suitably calibrated EMI sensor. The performance of the sensors is studied in terms of the antenna factor – which is the ratio of the incident electric field on the antenna surface to the received voltage at the load end. The planar monopole antennas are widely used for ultra wideband communication. However, the performance of these antennas has not been studied earlier as EMI sensors. This paper presents an initial investigation on the performance of different planar e.g. circular, annular circular, elliptical, triangular, truncated triangular monopole antennas as EMI sensors over the ultra wideband (UWB) frequency range (3.1 – 10.6 GHz). The antenna factors of these antennas are evaluated using electromagnetic simulation software CST Microwave Studio. The performance of these antennas are also studied in terms of the reception of the cross polarized component of incident electric field. The simulated result for return loss of a band notched circular ring monopole antenna is verified with the measured data for the prototype antenna over the UWB range. The circular monopole antenna is found as the most suitable EMI sensor.

Keywords: Antenna factor, computational electromagnetics, electromagnetic interference sensor, method of moments, planar monopole antenna.

Introduction

In recent years, the electromagnetic interference (EMI) has become a crucial issue in the performance of modern high frequency electronic equipment. This requires stringent electromagnetic compatibility (EMC) testing of the electronic devices which involves the measurement of radiated electromagnetic field from the equipment. Accurate measurement in the field requires accurately calibrated equipment. When measuring radiated signals, the front end of the measurement system is the sensor which is actually an antenna in receiving mode. The wideband EMI sensor is preferred for this purpose due to its large frequency coverage. Wideband antennas e.g. hybrid monopole / dielectric resonator antenna and loaded wire antennas (e.g. inverted L, T, I and C antennas) and broadband dipole have been studied as EMI sensors [1 – 3]. Different planar monopole antennas e.g., circular and elliptical disc, annular ring and triangular plates have found wide application as ultra wideband antennas [4 – 10]. However, no literature is found on the planar monopole antennas as EMI sensors. In this paper, an initial investigation has been performed to study the performance of these planar monopole antennas as EMI sensors. The square or rectangular monopole is not chosen due to its narrow bandwidth. The design guidelines are followed from literature [4 – 10]. The performance of a sensor depends on its antenna factor, which is the ratio of the incident electric field on the antenna surface to the received voltage at the load end [11]. The results are simulated using the electromagnetic simulator Computer Simulation Software (CST) Microwave Studio [12]. The measured data for return loss versus frequency of a band notched circular ring monopole antenna is presented for the sake of validation of the simulation result [13].

Antenna Configurations

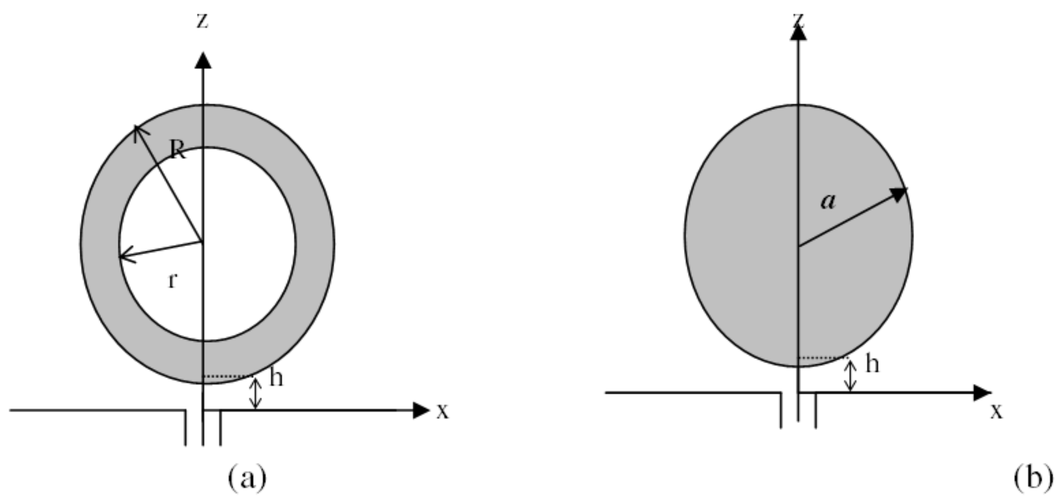
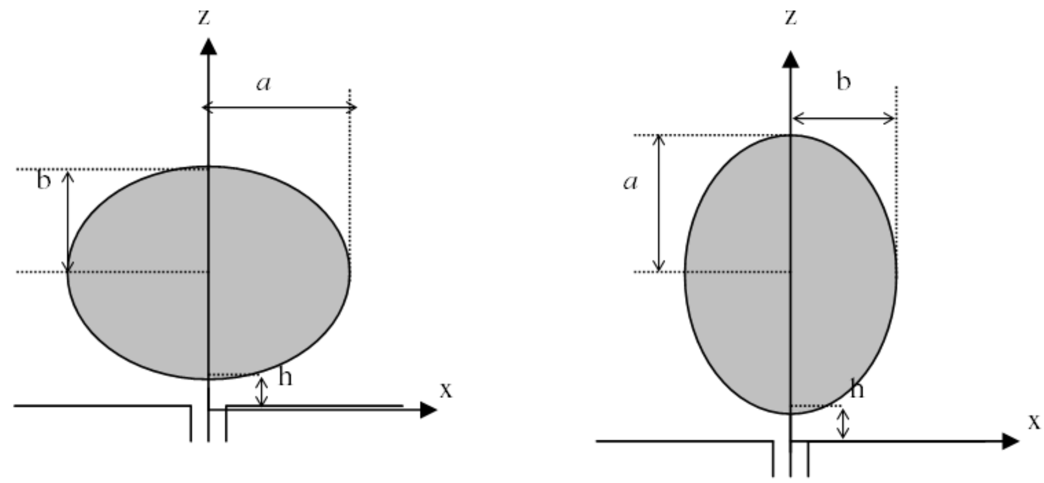


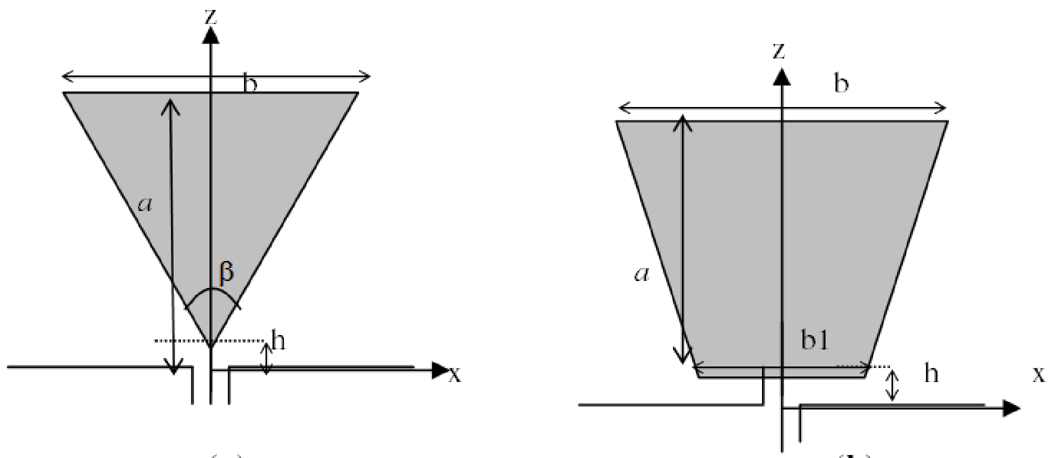
Figure 1: a) Configuration of annular circular monopole, b) circular disc monopole.



(a) (b)

Figure 2: a) Elliptical disc monopole fed along minor axis, b) elliptical disc monopole fed along major axis.

The planar monopole antennas yield large impedance bandwidth. In this paper, planar monopole antennas of different shapes e.g. circular, annular circular, elliptical, triangular etc. are considered (Fig. 1). The plates of different geometries are placed vertically above a finite sized rectangular ground plane. A coaxial probe excites the bottom of the plate through the ground plane via a connector. The bandwidth of the antenna mainly depends on the size and thickness of the plate and length of the feeding probe.



(a) (b)

Figure 3: a) Configuration of planar triangular monopole antenna, b) Configuration of truncated equilateral triangular monopole antenna.

Design formulations

The antennas are designed according to the formulations achieved in the literatures [4 – 10]. The frequency corresponding to the lower edge of the bandwidth of the circular monopole antennas is approximately determined by equating the area of the planar disc to that of a cylindrical wire of height *l*(which is same as that of the planar disc height) with equivalent radius *r*. The length of monopole for real input impedance is given as follows [14]

$$l = 0.24 \times \lambda \times F \tag{1}$$

Here

$$F = (l/r)/(1 + l/r) \tag{2}$$

From the above equations, the resonant frequency is achieved as follows [4]

$$f = c/\lambda = (30 \times 0.24)/(l + r)\,\text{GHz} \tag{3}$$

Here *l* and *r* are in centimeters.

However, considering the effect of the probe length of the monopole, equation (3) is modified as follows

$$f = (30 \times 0.24)/(l + r + h)\,\text{GHz} \tag{4}$$

Here h is the height of the monopole in centimeter.

The wind loading and weight of the antenna can be reduced by using the annular circular monopole [9 – 10]. For this configuration, the outer radius is kept same as that of the circular monopole. However, with the increase in the inner circle diameter, the lower resonant frequency reduces [9].

The elliptical planar monopole antennas are used as ultra wideband antennas due to their wide impedance bandwidth. The elliptical disc antennas with different elliptic ratios are considered by keeping the area same. For calculating the lower frequency for the elliptical antenna, the *l* and r of the effective monopole are determined by equating its area as follows

$$2\pi rl = \pi ab \tag{5}$$

For elliptical disc fed along minor axis, *l*= 2b and r = a/4, and for the disc fed along major axis, *l*= 2a and r = b/4.

Later the triangular monopole fed at the vertex and truncated triangular monopole antennas are considered. For calculating the lower edge frequency value by using equation (4), the values of *l* and r of the effective cylindrical monopole are determined as follows [4]:

$$l = \sqrt{3}W/2 \tag{6}$$

$$r = W/(4\pi) \tag{7}$$

Here W is the side length of the equilateral triangle.

The dimensions of different planar antennas are chosen according to the above design formulations. The ground plane for all the antenna configuration is considered to be a square of area 15 cm x 15 cm and the feed gap is considered as 1 mm. The other dimensions are presented in Table 1.

Table 1: Dimensions of different planar monopole antennas in mm.

Configuration	R	r	*a*	b	b1	β
Annular circular disc (Fig. 1(a))	25	15	-	-	-	-
Circular disc (Fig. 1(b))	-	-	25	-	-	-
Elliptical disc fed along minor axis (Fig. 2(a))	-	-	26	24	-	-
Elliptical disc fed along major axis (Fig. 2(b))	-	-	29	21	-	-
Equilateral triangular disc (Fig. 3(a))						
Truncated triangular disc (Fig. 3(b))	-	-	60	69.3	-	60°
	-	-	45	69.3	17.3	

Antenna factor

The most common performance descriptor of a sensor is the antenna factor. For EMI measurement, the sensor is illuminated by the incident plane wave. A receiver such as a spectrum analyzer is attached to the terminals of the sensor. The voltage measured by this instrument is denoted as Vrec. The incident electric field is related to the received voltage by the antenna factor. The ratio of the incident electric field on the surface of the sensor to the received voltage at the antenna terminal when terminated with 50 ohms load is known as the antenna factor [11]. In equation form, the antenna factor is written as follows

$$Antenna\ \ factor = \frac{Incident\,electric\ field\,(E_i)}{\mathrm{Re}\,ceived\,voltage\,(V_{rec})} \tag{8}$$

$$Antenna\ \ factor\Big|_{dB} = 20\ \log_{10}\left[\frac{Incident\,electric\ field\,(E_i)}{\mathrm{Re}\,ceived\,voltage\,(V_{rec})}\right] \tag{9}$$

Generally, the impedance of the receiver (e.g. spectrum analyzer) is taken as 50 Ω and the polarization of the antenna is parallel to the incident electric field.

Accordingly, the Thevenin's equivalent circuit diagram of an EMI sensor is presented in Fig. 3. The sensor is replaced by an equivalent open circuit voltage *Voc* at the two terminals of the antenna and its impedance.

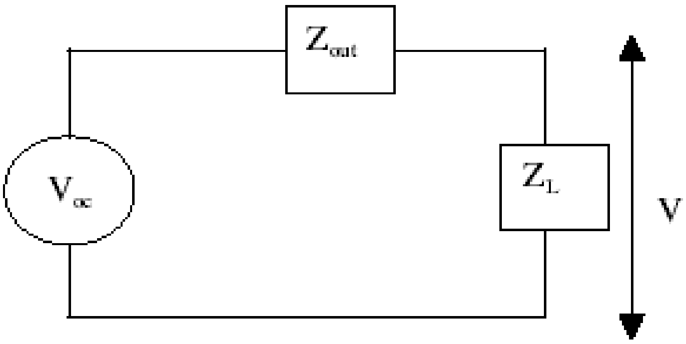


Figure 3: Equivalent circuit diagram of an antenna used as EMI sensor [3].

Cross polarization pick up

Due to the planar structure of the different ultra wideband monopoles discussed above, the antennas have sufficient cross polarization pick up. This requires the study of the reception of these monopoles for cross polarized incident field also. Here, the incident plane wave with z-directed electric field is considered as the desired polarization. The plane wave with x-directed incident field is considered as the cross polarized incident field.

Results

The results are achieved using electromagnetic simulator CST Microwave Studio. For the simulation in transmitting mode, the antenna is considered to be excited by a waveguide port. When the same antenna is studied as EMI sensor, the antenna connected with a lumped element of impedance 50 Ω at the gap, is considered to be illuminated by a plane wave with z-directed electric field of magnitude 1 volt / m for the desired polarization. For the simulation of cross polarization, the electric field is taken along x direction (Fig. 1 – 3). The measured result for the return loss of a band notched ring monopole antenna with stub is presented in Fig. 4 for the sake of comparison and validation of the simulated results. The dimension of the antenna structure is taken from the literature [13]. The return loss versus frequency plot for different planar monopole antennas are shown in Fig. 5. Later the antenna factor plots of different planar monopole antennas are presented in Fig. 6 – 11. The antenna factor versus frequency plot for all the antennas are presented in Fig. 12 for comparative study. The dimensions of the antennas are presented in Table 1.

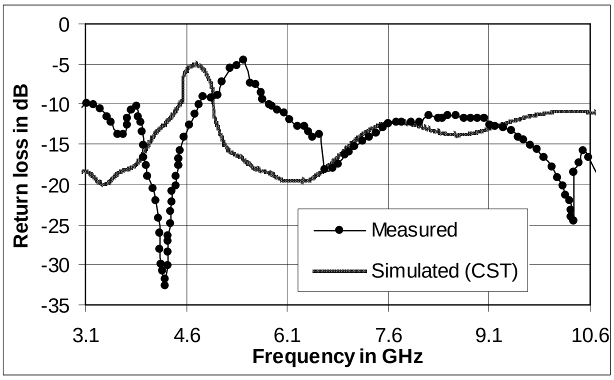


Figure 4: Plot of return loss versus frequency of band-notched circular ring monopole antenna with stub [12].

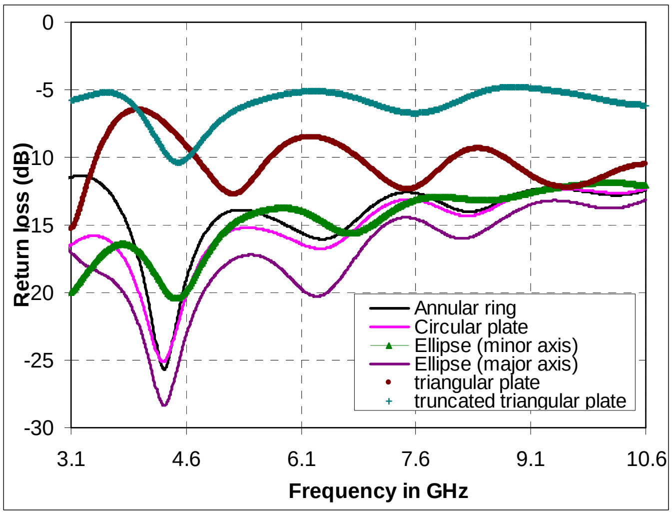


Figure 5: Plot of return loss versus frequency of different planar monopole antennas.

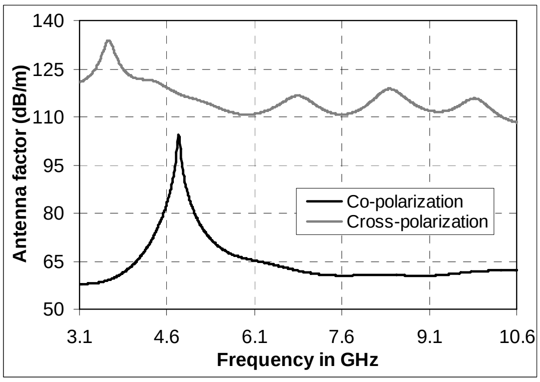


Figure 6: Plot of antenna factor versus frequency of annular circular monopole antenna.

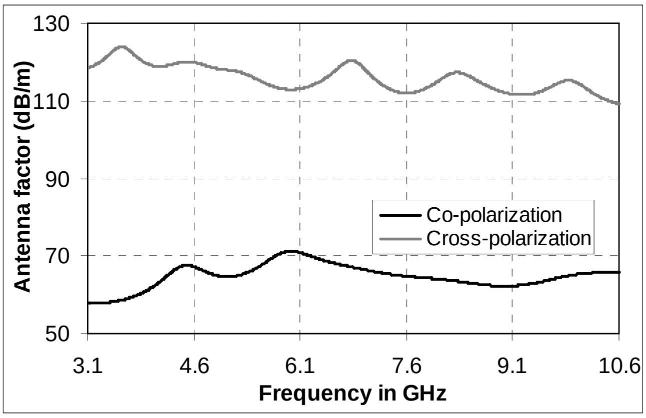


Figure 7: Plot of antenna factor versus frequency of circular monopole antenna.

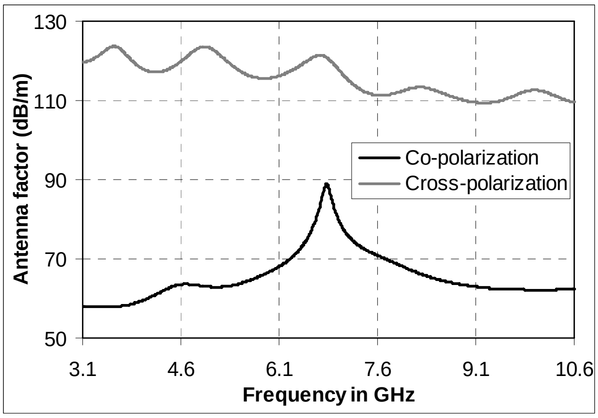


Figure 8: Plot of antenna factor versus frequency of elliptical disc monopole antenna fed along minor axis.

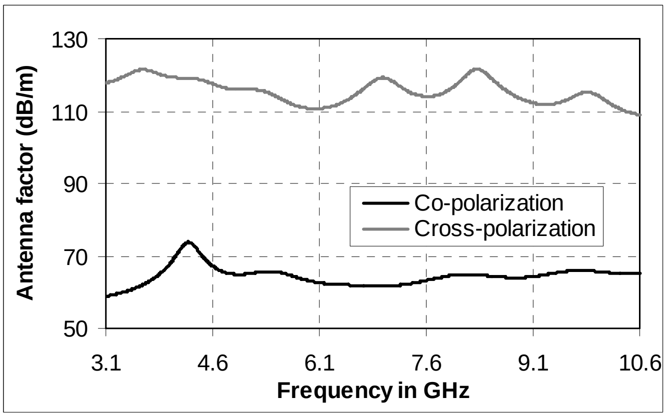


Figure 9: Plot of antenna factor versus frequency of elliptical disc monopole antenna fed along major axis.

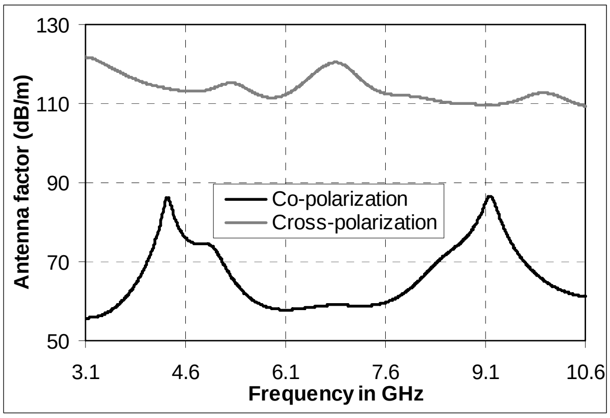


Figure 10: Plot of antenna factor versus frequency of triangular monopole antenna.

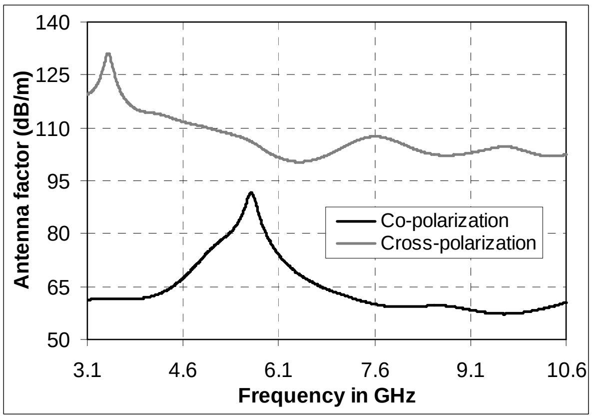


Figure 11: Plot of antenna factor versus frequency of truncated triangular monopole antenna.

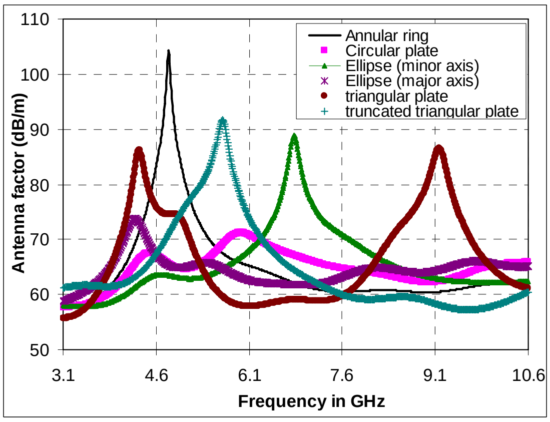


Figure 12: Plot of antenna factor versus frequency of different planar monopole antennas.

Discussions

The return loss data simulated using CST for the band notched ring monopole antenna shows same bandwidth as the measured result for prototype antenna (Fig. 4). The return loss versus frequency plots (Fig. 5) show that the desired return loss<10 dB is achieved for the circular, annular ring and elliptical monopole over the ultra wideband frequency range. However, the triangular and truncated triangular plate shows narrow bandwidth. The plots of antenna factor of the planar monopoles (Fig. 6 – 11) for the desired polarization show that the circular monopole maintains almost constant and low antenna factor (57 – 71 dB/m) over the UWB frequency range. However, for other antennas, the antenna factor becomes higher at certain frequency points (e.g. 104 dB/m at 4.8 GHz for annular disc) over the UWB frequency range. Since an antenna with lesser antenna factor behaves as a better receiver / sensor, the circular monopole may be considered as the best sensor compared to the others discussed here. However, for the planar monopoles, the cross polarization pick up characteristics becomes an important factor. For a good sensor, the cross polarization pick up is expected to be minimum. Hence the greater the value of cross polarization isolation, the better is the performance of the antenna as sensor. The plot of Fig. 6 shows that the cross polarization isolation for annular ring is better than 13 dB/m. The cross polarization isolation for circular plate is better than 41 dB/m (Fig. 7). Fig. 8 – 9 show that the cross polarization isolation for ellipse fed along minor and major axis is better than 33 dB/m and 46 dB/m respectively. Fig. 10 – 11 show that the cross polarization isolation for triangular and truncated triangular is better than 23 dB/m and 14 dB/m respectively. Since an antenna with lesser antenna factor and higher cross polarization isolation shows a better performance as EMI sensor, it is noticed that the circular disc antenna behaves as the best sensor among these planar monopoles.

Conclusion

This paper presents the initial investigation of different planar monopole antennas e.g. annular circular, circular and elliptical disc, triangular and truncated triangular monopoles as EMI sensors. It can be concluded from the work that the circular disc is found to be the best sensor among the other shapes. Later this study can be extended for extending the bandwidth of square monopole antennas by appropriate loading.

Acknowledgment

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