Analysis of different sensors for electric field measurements

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ABSTRACT

This paper deals with the performance of different loaded (e.g. inverted L, T, I and C-shaped antennas, monopole antenna loaded with dielectric resonator antenna) and unloaded wire antennas as electromagnetic interference (EMI) sensors. To determine electromagnetic radiation from an electronic component, it is required to evaluate the field strength at a certain distance from it using the sensor. The most common performance descriptor of a sensor is its antenna factor. The ratio of incident electric field at the surface of receiving antenna to the received voltage at the antenna terminal when terminated in 50 ohms load is known as the antenna factor. Here, the Method of Moments with Pulse basis function and Point-matching technique is used to evaluate the current distribution on the antenna surface and hence the antenna factor. The monopole antenna loaded with dielectric resonator is recently used as transmit antenna for ultra wideband application. In this paper, the performance of this antenna as EMI sensor is studied. For the simulation the electromagnetic software WIPL-D Pro v5.1 is used.

Keywords: Electromagnetic interference, sensors, loaded wire antenna, dielectric resonator antenna, antenna factor.

1. INTRODUCTION

The increased use of electronic equipment in modern day technologies causes electromagnetic interference (EMI) with each other. To avoid this interference episode different regulatory committees in different countries had set some standards of electromagnetic emission. All the electronic devices must conform to these standards. By measuring the radiated electric field due to that equipment, the compliance of the devices conforming to the standards of interference is tested. The measurement is performed inside an anechoic chamber, GTEM Cell, shielded chamber or in Open Area Test Site (OATS) which are made free from other electromagnetic radiation by putting the receiver at a specific distance from the device under test. The EMI sensors in common use are dipoles or loop antennas (e.g. Anritsu dipole MP651A / B). Wire antennas are widely used as transmitting antenna and as sensor for electromagnetic interference (EMI) measurements. The term “wire” refers to metallic, highly conducting wire or wire-like structures. For EMI measurement it is required to determine the field strength at the point of measurement using the sensor. To use these sensors for this purpose, a calibration data is required relating the electric field at the aperture of the receiving antenna to the voltage at the 50 ohms matched detector. The ratio of incident electric field at the surface of the sensor to the received voltage at the antenna terminal is known as the antenna factor [1]. So for EMI measurements it is of utmost importance to know the antenna factor of the sensor at the frequency of measurement. In this paper, a theoretical method based on numerical technique of Method of Moments has been evolved to predict the antenna factor of different wire antennas. The studies of different types of transmitting and receiving wire antennas have occupied the interests of numerous researchers for decades [2-8]. At low frequencies, the electrical length of the antenna to achieve self-resonance becomes very large. For this case, proper loading of the antenna is employed to reduce the resonant length of the antenna. The loaded antennas (e.g. inverted L, T, I and C-shaped antennas) are widely used for low frequency communication [2]. However, the extra loading is likely to introduce the reception of cross-polarized component of incident electric field that may degrade the performance of the sensor. Hence, while using these loaded systems as sensors, the cross-polarization characteristics must be known. In this paper, the authors concentrated on the characterization of the loaded antennas as EMI sensors in terms of the antenna factor for the desired and cross-polarized incident electric field. The results are compared with the data available in literature, wherever possible [3]. The hybrid monopole/dielectric resonator antenna (DRA) has become attractive to antenna designers due to its broadband characteristics along with the advantages of the DRA [9-10]. In this paper, this hybrid antenna is chosen as a broadband EMI sensor because of its compact size and broadband characteristics. The result for antenna factor of this antenna is presented using the electromagnetic software WIPL-D Pro v5.1 [11].

2. ANTENNA CONFIGURATION

The antennas are shown in Fig.1. The length of the load arms and main arms of the loaded antennas are chosen considering the resonance in transmitting mode. The dimensions of the DRA-loaded monopole antenna are chosen from the literature [9-10]. The hybrid antenna consists of a thin monopole and an annular DRA, both sharing the same axial reference and mounted on a finite ground plane. The quarter-wave monopole is designed to have a resonance at the lower end of the frequency band, while the DRA is designed to have a resonance near the upper end of the desired spectrum range. The dimensions of the hybrid antenna are considered as follows: L=15 mm, d=1.3 mm, a=4.5 mm, b=1.2 mm, h=7.2 mm, Ground plane radius= 40 mm, DRA: ε_r= 20 [9].

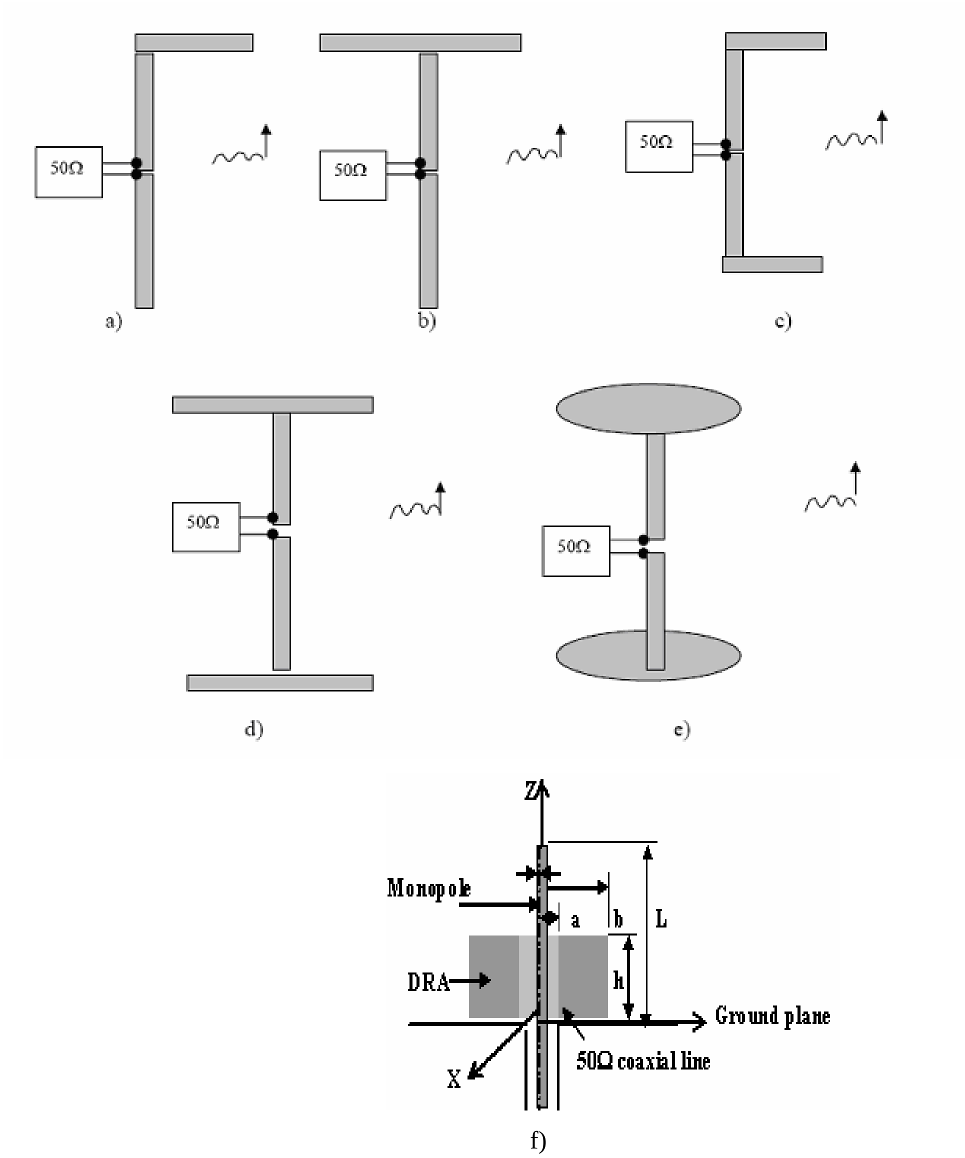

Fig. 1. Different EMI sensors; a) Inverted L antenna; b) T-antenna; c) C-antenna; d) I-antenna; e) Broadband dipole antenna-loaded with circular disc; f) DRA-loaded monopole.

3. ANALYSIS

For the analysis of the loaded and unloaded wire antennas the method of moments with pulse basis function and point matching is used [12]. The boundary conditions for the electric field are satisfied on the surface of the wires. The expressions for scattered electric field are simplified using the approximation of thin perfectly conducting wire. Applying the boundary conditions on the surfaces of the wires, an integral equation is achieved involving the unknowns used to describe the current distribution on the surface of the wires and the known incident electric field on the other side of the equation. A simple solution to the integral equation is obtained by approximating the integral as the sum of integrals over a number of small segments. The current density is considered as constant throughout a particular segment. Using the method of moments with pulse basis function and point matching the integral equation is converted to matrix equation and the solution is obtained using simple matrix formulation.

For the simulation of the DRA loaded monopole, the electromagnetic software WIPL-D Pro v5.1 is used [11].

3.1 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 by 50 ohms load is known as antenna factor [1].

$$Antenna\ Factor = \frac{Incident\ \ electric\ field(E_i)}{Received\ \ voltage(V)} \tag{1}$$

The Thevenin's equivalent circuit diagram of an EMI sensor is shown in Fig. 2. The receive antenna is replaced by an equivalent open-circuit voltage (V_{OC}) at the two terminals of the antenna and its impedance (Z_{OUT}). Generally the receiver (e.g. spectrum analyzer) impedance is considered as 50 ohm. The open circuit voltage V_{oc} at the gap of the antenna is related to the incident electric field on the antenna surface.

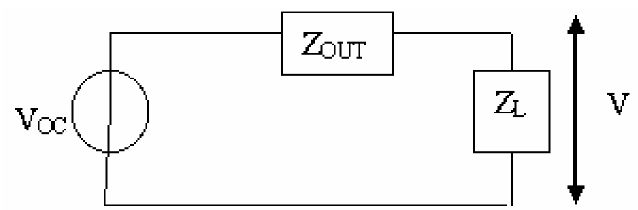

Fig. 2. Thevenin's equivalent circuit diagram of a sensor.

3.2 Cross polarization effect

Due to the presence of the top and bottom loading, loaded sensors are likely to suffer from cross polarization pick-up. Hence, while dealing with loaded antennas, the cross polarization characteristics of the antennas should be known. Here these studies are performed in terms of the antenna factor of these antennas for the desired and cross-polarized electric field (Fig. 3).

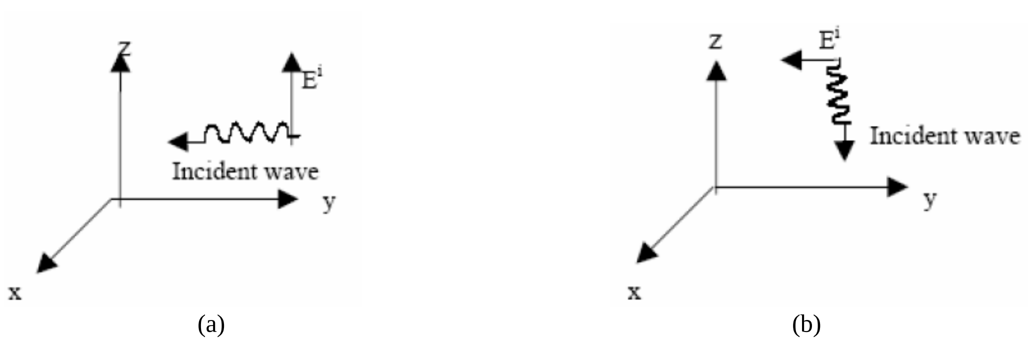

Fig. 3. Desired polarization of incident field; b) Cross polarization of incident field.

4. RESULTS

The antenna factor versus L/λ graph for a wire antenna is shown in Fig. 4. Also the antenna factor data supplied by the manufacturer for an Anritsu dipole (MP651A) antenna is compared with the theoretical antenna factor (Fig. 5). Investigations are extended for loaded wire antennas. Fig. 6-7 show the load arm lengths for various main arm lengths to obtain the resonant effect and corresponding resonance resistance of inverted L, T, I and C-antenna. The results are achieved as the output of huge computation time and efforts. These data for the main arm length and the corresponding load arm length to achieve resonance in the transmitting mode are used to study the antenna factor of these antennas in receiving mode. The antenna factor of different loaded sensors for the desired and also for the cross-polarized incident electric field is shown in Figs 8-11. The theory is verified with the experimental result (Fig.12) for the broadband dipole available in literature [7]. The dimensions of different parts of the antenna are given below:

Length of the central part of broadband dipole antenna = 0.54 m; radius of the central part of the dipole = 2.244 cm; radius of the capacitive hats = 8.9 cm; number of wires used to represent each circular disc = 12.

Next, the simulated result of VSWR and antenna factor versus frequency of a DRA-loaded monopole antenna is presented in Figs 13-14. For the simulation, the electromagnetic software WIPL-D is used [11].

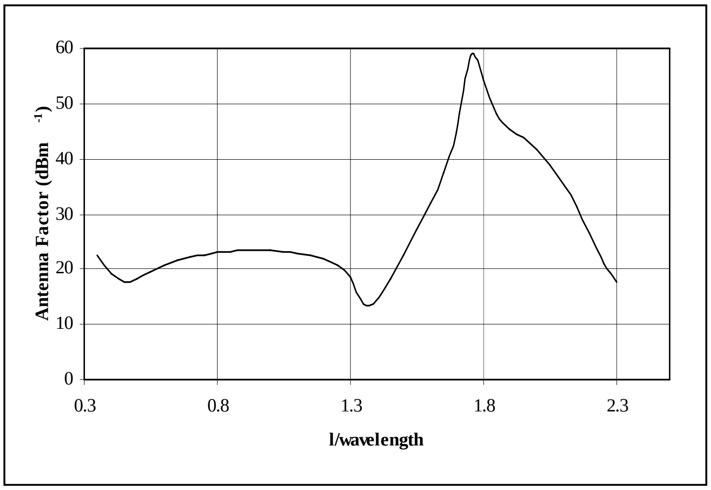

Fig. 4. Plot of antenna factor versus L/λ with radius=0.004λ.

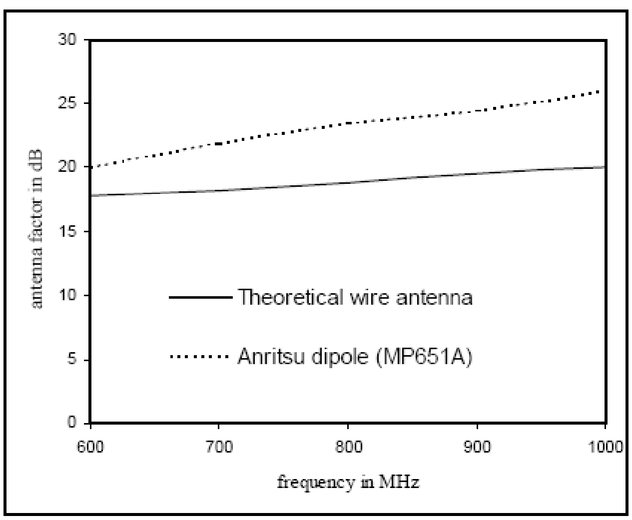

Fig. 5. Comparison of antenna factor of theoretical wire antenna with the Anritsu dipole MP651A antenna.

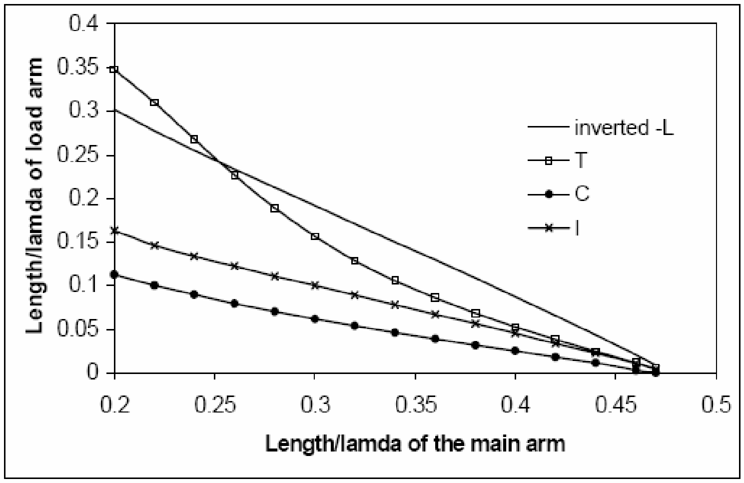

Fig. 6. Length in wavelength of the load arms versus corresponding length of main arms of loaded antennas.

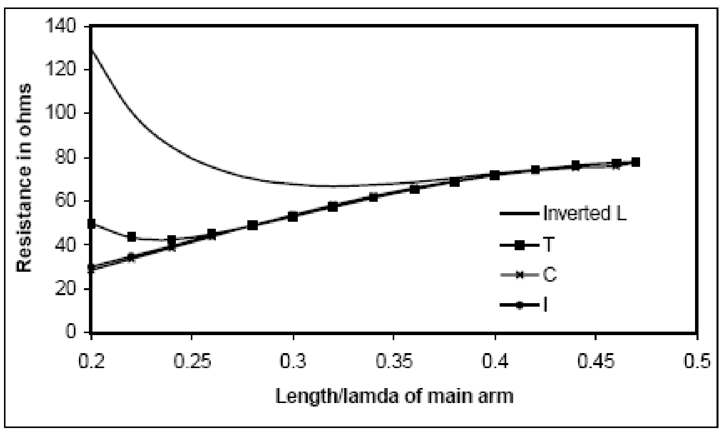

Fig. 7. Resonance resistance in ohm versus corresponding length of the main arms of loaded antennas.

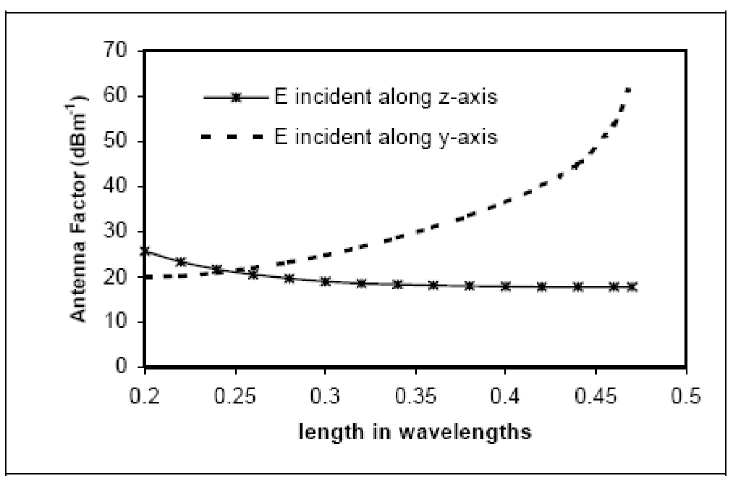

Fig. 8. Antenna factor versus resonant length of inverted L shaped antenna.

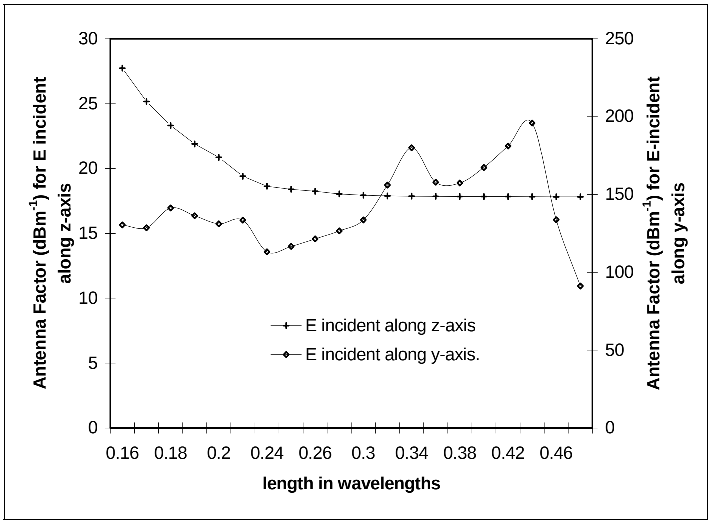

Fig. 9. Antenna factor (dBm^{-1}) vs. length in wavelengths of T-shaped antenna.

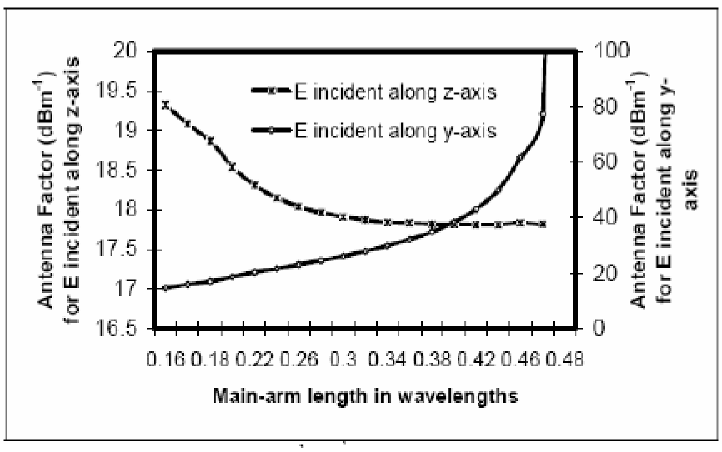

Fig.10. Antenna factor (dBm^{-1}) versus length in wavelength of C-shaped antenna.

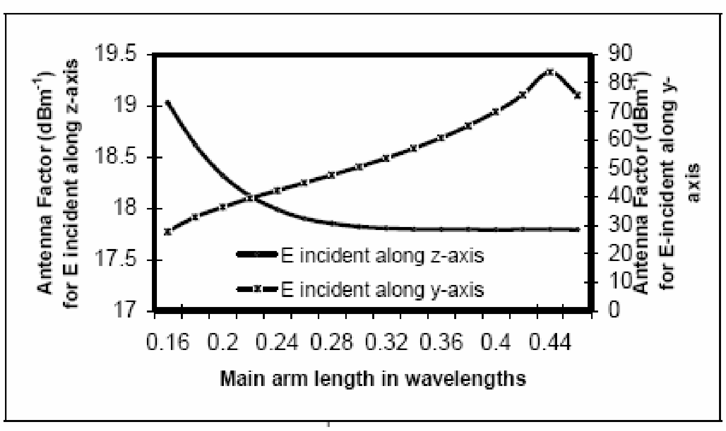

Fig. 11. Antenna factor (dBm^{-1}) versus length in wavelengths of I-shaped antenna.

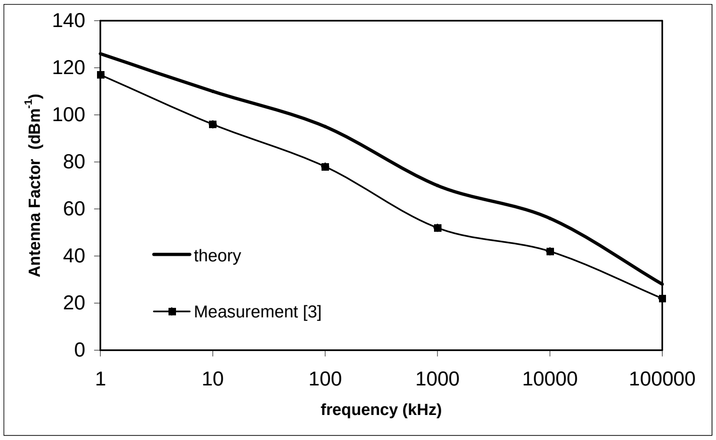

Fig. 12. Antenna factor (dBm^{-1}) versus frequency plot of a broadband dipole.

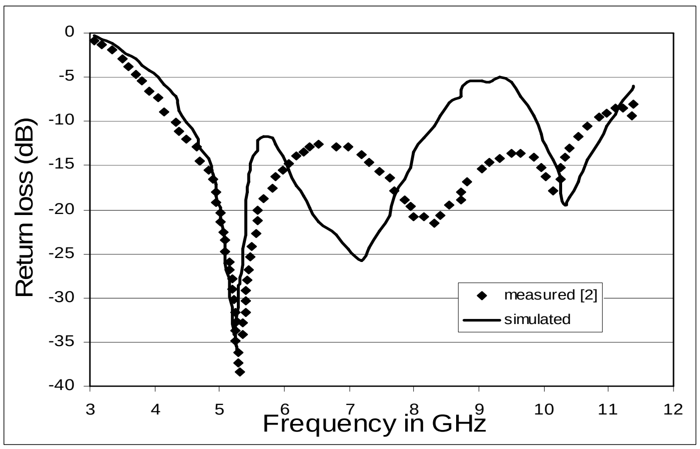

Fig. 13. Return loss (dB) versus frequency plot of a broadband dipole.

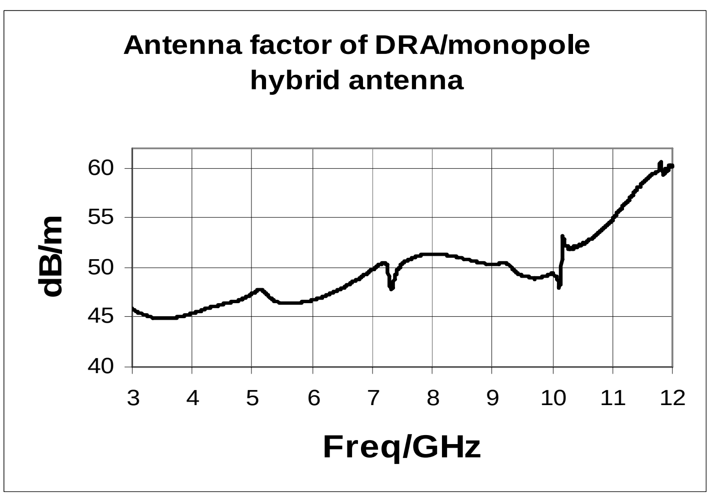

Fig. 14. Antenna factor (dBm^{-1}) versus frequency plot of a broadband dipole.

5. DISCUSSION

In this paper, extensive analysis has been performed on different loaded and unloaded wire antennas in receiving mode as EMI sensors. The antenna factor is the ratio of incident electric field on the surface of the antenna to the received voltage at the antenna terminal. An antenna with lesser antenna factor behaves as a better receiver. From the plot of antenna factor vs. L/λ (Fig. 4) it is seen that the antenna acts as a good receiver when its length is between 0.35λ - 1.35λ. The theoretical value of antenna factor is compared with the chart supplied by the manufacturer of an Anritsu Dipole MP651A (Fig. 5). The length of the Anritsu dipole arms and the diameter was measured for different frequencies. The same value of length and diameter is incorporated in the software programs for numerical evaluation of antenna factor. The plot of antenna factor versus frequency shows the same trend. The same method with suitable boundary condition is extended for loaded wire antennas (e.g. inverted L, T, I and C-antennas). Studies show that the antenna factor for the desired polarization for all these reduced height sensors do not show significant change from the corresponding antenna factor of unloaded dipole of resonant length (which is usually higher in length than the loaded length). The advantage is achieved in terms of the reduction of main arm. From the study of the cross polarization pick up and cross polarization isolation the following points are noticed:-

The plot of antenna factor of the inverted L-shaped antenna (Fig. 8) shows a cross polarization isolation of better than 0.8 dBm^{-1}; for T-shaped antenna (Fig. 9) better than 73.4 dBm^{-1}; for I shaped (Fig.10) is better than 21.3 dBm^{-1} and for C-shaped antenna (Fig.11) is found as better than 0.22 dBm^{-1}.

For a good receiver the cross polarization pick up of the antenna is expected to be minimum. Hence the greater the value of cross polarization isolation, the better is the performance of the antenna as sensor. From the study of different loaded antennas it is seen that the cross polarization isolation of a T-shaped antenna is maximum i.e. the T-shaped resonant antenna is found as a better receiver /sensor or sensors. Also the correctness of the theory for the loaded sensor has been proved from the well-matching of the theoretical results to available experimental data (Fig. 12).

The results for the return loss of DRA-loaded monopole shows good matching with the experimental data (Fig. 13). The antenna factor versus frequency plot shows wideband characteristics (Fig. 14).

6. CONCLUSION

It can be concluded from this work that the height of the sensors can be appreciably reduced by the introduction of the load arms without making any major compromise in the performance in terms of cross polarization isolation. The inclusion of the DRA increases the bandwidth of a simple monopole.

7. ACKNOWLEDGMENT

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