An RF Anechoic Box System Development for Shielding Effectiveness Measurements

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Abstract

Shielding effectiveness is a term that defines the electromagnetic shielding property of a material. The demand of using wireless technologies and higher frequencies in new devices also bring the need to shield the unwanted electromagnetic fields. Therefore determining the shielding effectiveness of materials becomes an important concept. In this study a compact, low-cost RF anechoic box system for shielding effectiveness is explained. The design and construction of the anechoic box is given as well as the designed printed log-periodic antennas specifically for the measurement system that operates in the frequency band of 750-3000 MHz. The simulation and measurement results of the antennas given. Also, the performance of the whole system is investigated by measuring the shielding effectiveness of an absorber used in the anechoic box with another reference antenna. Open area measurements are compared to the measurements taken in the anechoic box.

Keywords – shielding effectiveness, printed log-periodic antenna, RF anechoic box

1. Introduction

The rapid developments in the equipment that use high frequency and the tendency to operate devices in higher frequencies [1-4] have brought the need to prevent unwanted electromagnetic signals for both proper operation of devices and human health concerns. Especially the frequency band from 750 MHz to 3 GHz is occupied by many RF devices. However the research and study of the effects of exposure to electromagnetic signals still continue [5-7], researchers have discovered some effects on genes that control early development in zebrafish that have homologs in human [8]. The World Health Organization (WHO) underlines that the electromagnetic fields produced by cell phones are classified as possibly carcinogenic to humans by the International Agency for Research on Cancer [9].These findings lead researchers to implement techniques to shield unwanted electromagnetic fields suitable to be used houses, offices or even in nursery rooms such as drapery, curtains etc. Thus, measuring electromagnetic shielding effectiveness (EMSE) of such materials becomes an important issue as well as the medium the measurements are held.

The EMSE is a term that relates the incident electromagnetic power or field to the transmitted electromagnetic power or field. It is defined as [10]:

$$SE_{db} = 10\log\frac{P_i}{P_t} \tag{1}$$

where P_i is the incident field on a planar material and P_t is the transmitted power. There are a couple of methods to measure the shielding effectiveness. For planar materials, ASTM D4935-10 is a widely used standard which suggest using large coaxial specimen holder [11]. But the proposed method is valid for the frequency range of 30 MHz to 1.5 GHz which doesn't cover many ISM bands such as 3G and Wi-Fi. Reverberation chamber and anechoic chambers are also used for measuring shielding effectiveness [12-15]. However these rooms are very large and expensive structures. When frequency of interest can be narrowed to certain bandwidth, anechoic boxes can be built and used for measuring the shielding effectiveness of materials.

In this study the design of an RF anechoic chamber box and the measurement of the designed and fabricated printed log periodic dipole antenna arrays used in the RF chamber are explained and their validity are discussed by measuring the shielding effectiveness of an absorber which is also used in the RF chamber. The constructed chamber has a volume of 1mx1mx1.5m and it is designed to operate from 0.75 GHz to 3 GHz, which is suitable for GSM (900 MHz), PCS (1800 MHz), Wi-Fi (2400 MHz), 3G (2100 MHz) and LTE (2600 MHz) wireless systems as well as the log-periodic antennas. Therefore, the characteristics of materials are analyzed and measured within these mentioned frequency bands.

2. RF Chamber Design and Construction

Shielding effectiveness is determined by dividing the incident electromagnetic power over the transmitted electromagnetic power through the material under test (MUT). It is required to measure these powers using a transmitter and a receiver antenna. If this measurement is held without an anechoic chamber, the received power is prone to errors due to multipath and multi-reflections from the environment (Fig. 1.).

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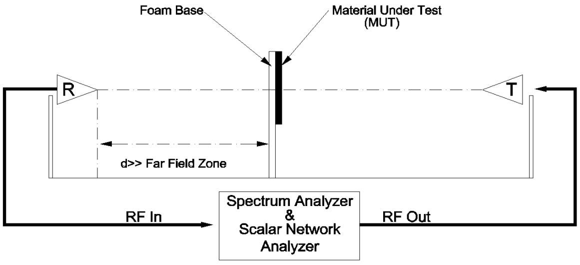


Fig. 1. Shielding effectiveness free space measurement set up

An RF anechoic chamber is a small anechoic room in terms of its size. The dimensions of the chamber depend on the frequency band of interest as well as the dimensions of the antennas. The frequency band and the dimensions of the antennas determine the far-field. The material under test should be placed in the middle of chamber. Thus the distance between two antennas must be at least two times of the far-field of the antennas (Fig. 2).

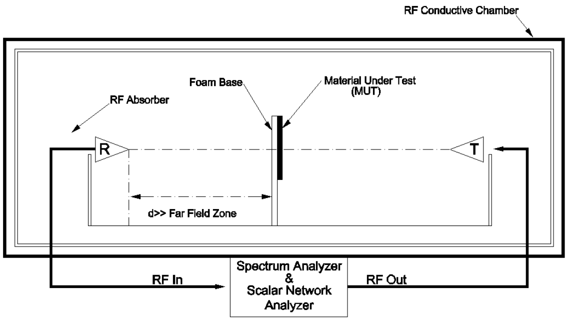


Fig. 2. Shielding effectiveness measurement set-up with the RF anechoic chamber

The designed RF anechoic box has the dimensions of 1m x 1m x 1.5m. The outer conductor of the chamber is stainless steel (Fig. 3.). The chamber is coated with RF absorbers inside. The two antennas can be connected to a spectrum analyzer or network analyzer which can be calibrated with transmission measurement option. The system is calibrated without any materials inside the box which takes the free space and cable losses into consideration and transmits uniform power through the frequency band of interest. Therefore, the received power from the receiver antenna is only due to the shielding behavior of the MUT (Fig. 4).

Fig. 3. The anechoic box closed view

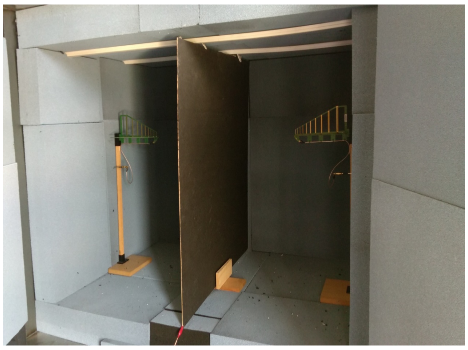


Fig. 4. Inside the anechoic box

3. Antenna Design and Implementation

One of the realizable solution for the antenna used in these measurements is microstrip antenna. This is because they are cheap, robust and also used in many communication systems. However, they have narrow bandwidth which is one of the disadvantages. Due to the fact that many devices such as cellular phone and tablets need to be operate different frequency bands, the antennas used in these devices should be either wideband or multi-band. At this study, the solution is concentrated on the design of a wideband antenna. Many printed log periodic dipole array antennas have been proposed until now for different frequency bandwidth [16, 17].

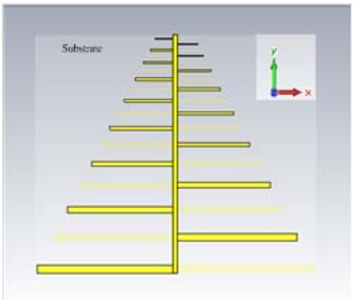
In this study, wideband antenna operating within the frequency band of 0.75 GHz – 3 GHz are designed and modified to use it in the measurement of the characteristics of the materials. The antenna is designed by the help of standard log periodic dipole array antenna formulations [18, 19].

3.1. The Design and Performances of the Antenna

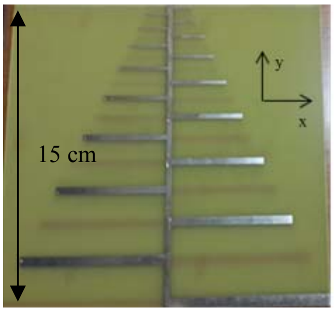
The log-periodic dipole antenna is realized on FR4 substrate whose simulated and manufactured views are shown in Fig. 5. While designing the antenna; practical design procedure proposed by Carrel [18] is used with some modifications firstly. After these mathematical calculations, antenna parameters summarized in Table 1 are obtained where , ε_{eff} is effective dielectric permittivity, τ is the periodic relationship between dimensions σ is spacing factor, 2α is the aperture angle, B_{ar} is bandwidth of the active region, B_s is designed bandwidth, N is number of dipoles, L is length of the structure, Z_a is average characteristic impedance of the elements, Z_0 is characteristic impedance of the feeder line, R_{in} is input impedance (real) and W is width of the characteristic impedance of feed line [17-20]

Table 1. Antenna Design Parameters

ε_{eff}	τ	σ	2α	B_{ar}	B_s
2.2	0.88	0.055	31°	1.28	5.12
N	***L (mm)***	Z_a **(Ω)**	Z_0 **(Ω)**	R_{in} **(Ω)**	***W* (mm)**
17	145	158.6	50	50	3



(a)



(b)

Fig. 5. Printed Log Periodic Dipole Array Antenna. (a) Modelled in CST Microwave Studio (b) Realization of the antenna

The designed antenna has 17 printed dipoles. Dipoles are printed both side of the dielectric substrate with symmetrically. The biggest dipole with the length L_1 and width W_1 is designed for the minimum working frequency which is 0.75 GHz, and the shortest dipole with the length L_{17} and width W_{17} is designed for the maximum working frequency of 3 GHz. The dipoles in the antenna are excited by a traditional stripline, which is printed on the both sides of the dielectric material. The lengths (l_n's), spacing (R_n's), diameters (d_n's), and even gap spacing at dipole centers (s_n's) of the log-periodic array increase logarithmically as defined by the inverse of the geometric ratio tau (τ) [19]. The optimal behavior of the log-periodic antenna is achieved when the periodic relationship between dimensions is τ = 0.88 [16, 21]. Therefore, in our design we also choose τ as 0.88. Length and width of the antenna follow τ. L_n length of the dipole n and W_n width of the dipole n. The dipole length is associated with the work frequency and W is related with dipole impedance [16] The biggest dipole with the length 172mm and width 4.87 mm is designed for the minimum working frequency which is 0.75 GHz, and the shortest dipole with the length 23mm and width 0.63mm is designed for the maximum working frequency of 3 GHz.

Measured S_{11} is compared to simulation result. There is a good agreement between them. Fig. 6. shows comparison of measured and simulated S_{11} for the antenna. Also VSWR results from the simulation and the measurement are very similar.

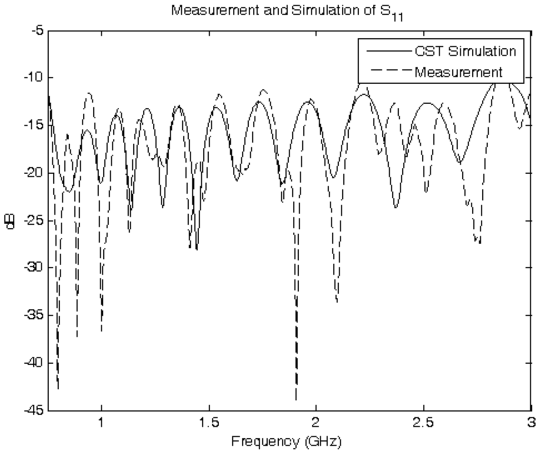


Fig. 6. Measurement and simulation results of the printed log periodic antenna array S-parameters

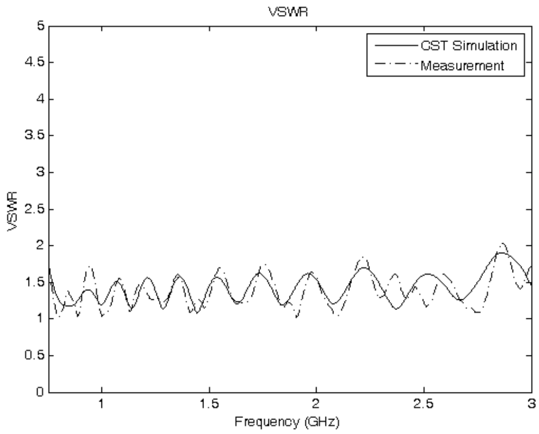


Fig. 7. Measurement and simulation results of the printed log periodic antenna VSWR

4. Results

The performance of the RF anechoic box and antenna is done by comparing the free space shielding effectiveness measurements of the absorber used in the box to measurements taken in anechoic box as well as using the designed antenna and a reference[22] antenna that is used specifically for shielding effectiveness measurements in the frequency range of 750-3000 MHz from Gigahertz Solutions. In order to prevent multipath, the MUT is placed as it covers the whole intersection of the box.

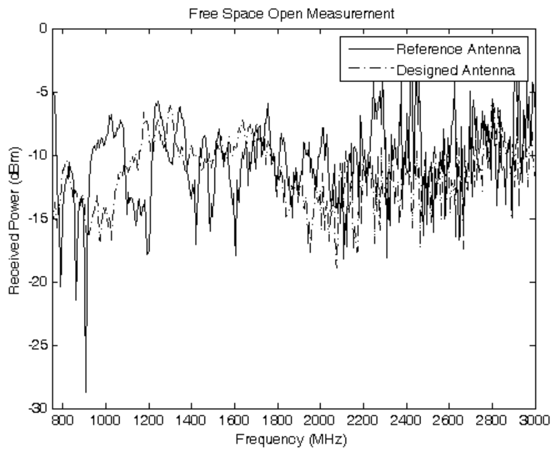


Fig. 8. Shielding effectiveness measurement of the absorber in open area

In Fig. 8., the shielding effectiveness measurement results from the open area measurement can be seen. The effects of multipath and multiple reflections is observed in the figure as abrupt changes in the received power. When the performance of the two antennas are considered, the trend of the received power appears the same. The received power when the measurement is held in the anechoic box is in Fig. 9. The abrupt changes are cleared and the received power follows a smoother trend which indicates the unwanted reflections and multipath effects are reduced. When the open area measurements are considered, the shielding effectiveness of the absorber is around 11dB in average. However, the results from the anechoic box indicate a shielding effectiveness of 9dB in average. Despite this small difference in average, the change of received power through the frequency can be interpreted as uniform in the open area measurement. The frequency behavior of the absorber can be observed clearly when the measurements are taken in the RF anechoic box.

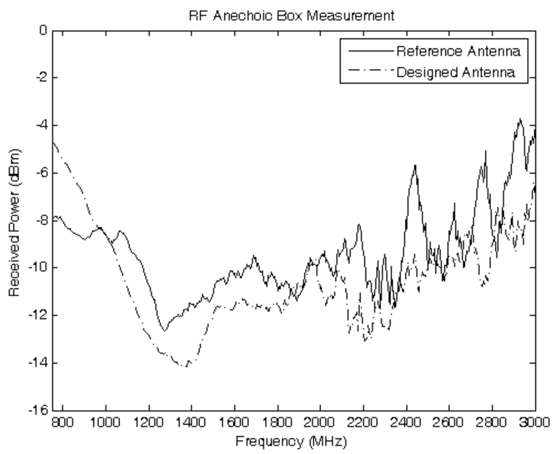


Fig. 9. Shielding effectiveness measurement of the absorber in the RF anechoic box

5. Conclusions

In this study, the design, implementation and performance analysis of an RF anechoic chamber with printed log-periodic antennas as transmitter and receiver antennas in the frequency range of 750-3000 MHz is presented. The RF anechoic box works as expected in the frequency range of interest as it prevents the unwanted reflection both inside and outside the box.

The designed compact printed log-periodic antennas are fabricated and tested for given frequency band. It is proved that simulation and measurement results are in agreement. That antenna is compared to the reference antenna for suitability for electromagnetic shielding measurement systems especially for small-sized RF anechoic boxes.

The developed electromagnetic shielding measurement system brings to a low-cost, compact and efficient measurement opportunity without the necessity of large scaled and expensive chambers.

In this system, there are some drawbacks on the high frequency range because of the absorber issues. It is planned to overcome that problem by addition of high frequency absorber to the chamber.

All measurements are realized as the antennas are aligned. Beams of antennas has not been considered yet. The current study is being continued on extracting radiation pattern of the designed antennas.

6. References

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