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A basic concept to anechoic chamber and determination of highly selective absorber material with respect to insertion loss and refection coefficient

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Abstract
In this study, we Introduce basic concept of anechoic chamber and their designing parameters. Historical background of anechoic chamber has inscribed through year since 1930 to nowadays. Interaction mechanism of electromagnetic wave to absorber material in term of their insertion and return losses has also introduced. Different types of absorber material used in chamber designing are compared with respect to insertion and return losses.

Keywords: Anechoic chamber, Insertion loss, Reflection coefficient

Introduction

Indoor RF measurement was the first subject that generates the concept of anechoic chamber. Indoor RF measurement without anechoic chamber is also possible but to enhance accuracy of measurement chamber facility required. Electromagnetic wave generated by radio frequency devices, antennas and radar has very low signal level in order of -100dBm or 3 μv [1]. This kind of signal can be easily masked off by extraneous signal in this environment. Hence, measurement must be performed in shielded region that provide high isolation from extraneous signal. At the time of indoor measurement, test device generate electromagnetic wave. Generated wave propagating in shielded region and will be reflected by the all sidewall, and ceiling and formed complex wave front near the test device. Complex wave front makes measurement tough; therefore, a free space environment without reflection is required to make measurement easy. To make reflection minimum suitable absorbing material must be installed over the entire inner surfaces of the shielded enclosure. Such a shielded enclosure is called anechoic chamber [1, 2].

Historical Background [3]

First theoretical and practical work was going on absorber material in the mid 1930's in Netherland Naamlooze Vennootschap Machinerieen. The first known absorber is much more similar to nowadays-used absorber that is coated with carbon black and TiO. Carbon black coating dissipates more energy and TiO provides good dielectric constant as desire for reduce thickness. During Second World War (1936-1945) Germany and USA both country try to enhance radar system. Germans were primarily interested in absorbers for radar camouflage, where United States was primarily directed toward absorbers that would improve radar performance. Germans developed two operational observing material included Wesch material and Jauman absorber, which use saw in camouflaging of submarine snorkels and periscopes. Wesch material was in form of semiflexible rubber sheet of about 0.3 inch thickness that was loaded with carbonyl iron powder. Jauman absorber was a rigid broadband material that was comprises of alternative layers of rigid plastic and resistive sheets to create a gradual transition of loss toward the front end to back surface [2,3]. The USA develops a material named Halpern-anti-radar-paint (HARP). American develops material used in both airborne and ship borne. In addition to the HARP materials, the so-called Salisbury screen absorber was also developed at the Radiation Laboratory during this period. In 1945's mid researcher focus over how to improve bandwidth of absorber and in this regard first patent were awarded to Tiley (Philco Corporation in the United States) Salati (Haseltine Corporation in Canada). In early 1950's absorber material development become commercial and lot of company take to participate in this regard. The material chosen for absorber production was loosely spun animal hair. Emerson of the U.S. Naval Research Laboratory demonstrated that spraying or dipping of carbon black onto hair makes a broadband absorber. Characteristic of absorber such as controlling of reflection coefficient and insertion loss caught the interest of Antenna testing organization in regard of indoor measurement. Indoor measurement of antenna parameter using absorber generates the concept of anechoic chamber at that time. Designing of anechoic chamber start around 1950's and carbon coated animal hair used as absorber material initially. In mid 1950s, urethane foam was found to be good carrier for the conductive solution. At the time of 1970s foam was primarily material available for anechoic chamber application [3].

Selection of Absorber Material

Absorbing material used in chamber designing is highly selective with respect to their insertion loss and reflection coefficient. Insertion loss of absorber -40dB and above is recommended.40dB insertion loss indicates that 1% of energy is reflected [1]. To maintain insertion loss above 40dB, absorber must have low normal incidence reflection, low forward-scatter and backscatter at wide-angle incidence. Free space and absorbing material interface causes impedance discontinuity and to keep recommended insertion loss impedance matching is required. Therefore, to transmit maximum signal into absorber, absorber impedance is approx. to free space impedance is required. When material with high value of impedance (approx to 377ohm) is used more energy can be transmitted into absorbing material but a much thicker material will be required to fully dissipate the electromagnetic energy [2]. Electromagnetic material used in anechoic chamber has different types, depending on the purpose and frequency [12]. Dielectric absorber and ferrite absorber are the commonly used electromagnetic material in chamber designing. Dielectric absorber such as urethane foam used in microwave frequency range and ferrite absorber used for low frequency range (below 1GHz). Low cost and broad operating bandwidth are also pressing issues in material selection. A typical ferrite material might have complex permittivity equal to $\mu_r = \varepsilon_r = 60(2 - j1)$ and resulting characteristic impedance equal to 377 ohms [4]. Insertion loss can be representing by equation (1) for lossy material;

$$\text{Insertion Loss} = e^{-\alpha t} \quad (1)$$

Where t=thickness of material in meter and

$$\alpha = Re\sqrt{j\omega\mu\sigma - \omega^2\mu\varepsilon} \quad (2)$$

Considered the conductivity of the ferrite material to be zero we can explore the value of alpha in term of wavelength;

$$\alpha = \frac{120\pi}{\lambda} \quad (3)$$

Tile thickness can vary from 3.9mm to 19mm, with the most common thicknesses being 6.5mm and 6.7mm. These thicknesses are ideally suited for chambers designed for IEC 1000-4-3 radiated immunity testing [13].For 6.5 mm thick ferrite tile insertion loss at 500 MHz is -35 dB.

$$\text{Insertion Loss} = e^{-\alpha t} = e^{-\frac{120\pi}{\lambda}t} = e^{-\frac{120\pi}{.60}(.0065)} = -35 \text{ dB}$$

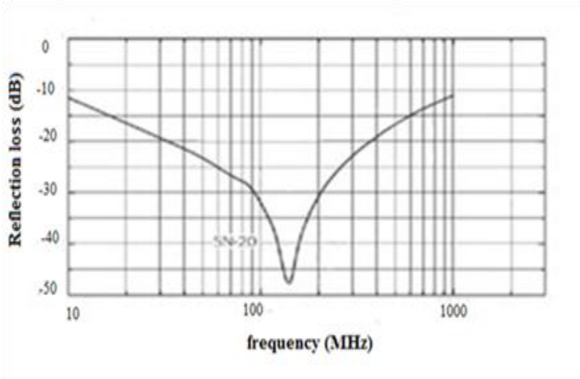

Figure 1: Performance characteristic (Normal incidence reflection loss of ferrite tile) [13]

After 1000 MHz reflection loss is not significant for standard tile dimension show in above figure. Therefore, in GHz range ferrite tiles are not used in chamber designing. Foam absorber is broadband in nature and based on the principle of tapered impedance. Steadily increase the impedance of foam absorber from that of "free space" at the incident surface of the absorber to high impedance. Energy is progressively absorbed and attenuated through ohmic loss accordingly impedance value as it propagated through the absorber.

The tapered shape of the pyramidal material play equivalent performs to the tapered resistances of the Jaumann Sandwich. Pyramidal shape absorber such design to cancel out all reflected wave. Many small reflections are created, as the electromagnetic wave passes into the pyramid and these reflections tend to cancel out. Pyramidal design relevant to absorber thickness. Dielectric behaves like conductor at high frequency and conductor behaves like dielectric [5]. Therefore, at high frequency eddy current circulate inside dielectric. If the value of current is large and cross-sectional area of absorber is small, their chance to burn the absorber. Hence, the thickness of absorber does matter in shape designing. From figure.2, it is clear that at the tip of the pyramid has; maximum value of resistance and back surface has less resistance value comparatively. It means multilayer of carbon-impregnated material with increasing loss tangent from the front layer towards the bottom layer must be stacked up. In equivalent Jaumann sandwich, model Value of resistance decrease from top to bottom and cross-sectional area increase from top to bottom. More cross section area means more energy dissipation capacity.

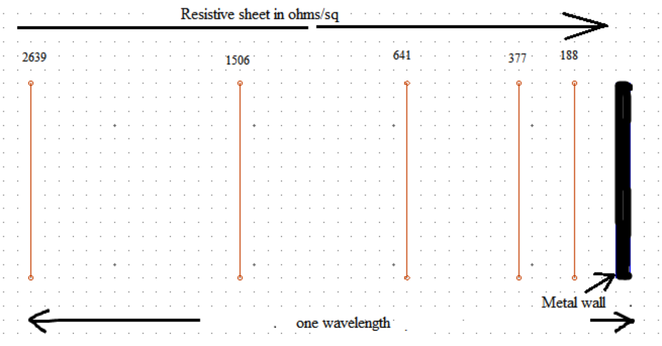

Figure 2: Distance from metal wall are tapered in term of resistance [8]

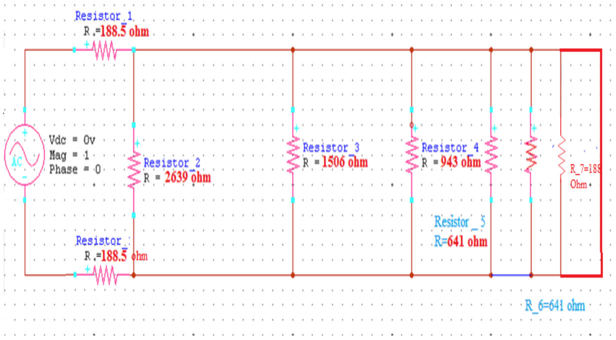

Figure 3: Jaumann sandwich based model for foam absorber [8]

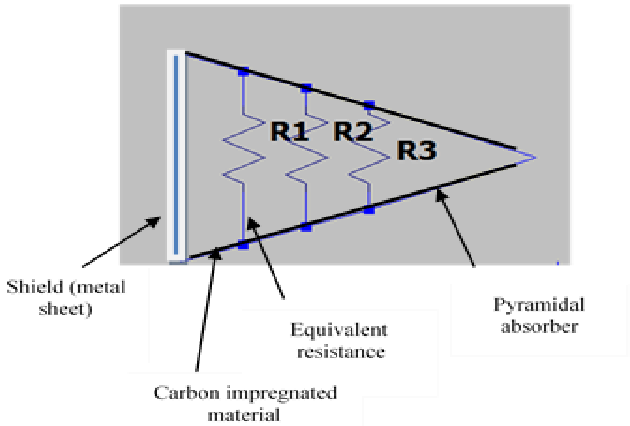

Figure 4: Jaumann sandwich model of pyramidal absorber [8]

Reflection coefficient is essential to determine the percentage of reflected energy from target. In case of absorber material selection the reflection coefficient also plays the vital role. Reflection coefficient is the ratio of the energy of reflecting and transmitting wave and can be represented as

$$\Gamma = \frac{E_{reflected}}{E_{\ transmitted}} \quad (4)$$

Size of Anechoic Chamber [1, 2]

Size of chamber mainly defined with antenna dimension including antenna maximum transverse dimension D, absorbing material dimension and separation distance between the antennas. Separation distance defined by Rayleigh range criteria and distance between the antennas must be greater than $\frac{2D^2}{\lambda}$, where λ is wavelength [9,10,11]. If we consider the test volume size is k and λ_{max} is the maximum wavelength than length, width and height of chamber is represented as

$$L > \frac{2d^2}{\lambda} + \lambda_{max} \quad (5)$$

$$W = \lambda_{max} + k \quad (6)$$

$$H = \lambda_{max} \quad (7)$$

Where L, W and H are the length width and height of chamber respectively. All defined equation including (5), (6) also check with absorber dimension and distance between the transmitter and receiver to satisfied the Rayleigh range criteria. Height and Width of absorber material must greater than $\frac{\lambda}{4}$ and $\frac{\lambda_{max}}{4}$ respectively.

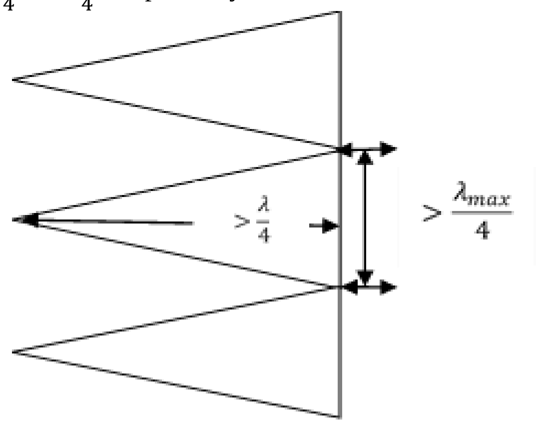

Figure 5: Pyramidal absorber dimension in term of wavelength

For large value of D, the size of anechoic chamber is very large and it is not possible to calculate field radiation at far field[4, 7]. In such a situation, near field technique is use to test the large antenna. In this technique, near field phase and amplitude measured over discrete matrix of point. Measured near field values transformed into far field data using Fourier transform technique. To achieve the specified absorber reflectivity the distance between radiating source and absorbing material must be greater than $\frac{\lambda_{max}}{2\pi}$. For 6-meter range with test volume size 2 meter and lowest operating frequency 50 MHz, then the anechoic chamber dimension may be in the range of 13 m long×8 m width×6 m height, if the 1.5 m length foam absorber used in lining and celling of the chamber wall [2]. To complete the designing of anechoic chamber, access door, ventilation lighting, electrical power supply, filters, connection cables, pneumatic air supply, turntable, motorized antenna designing is also essential.

Conclusion

Anechoic chamber provides an isolated environment for antenna testing. Absorber material selection for chamber is heavily depends upon insertion loss and reflection coefficient. A good absorber has high value of insertion loss and low value of reflection coefficient. Chamber dimension is the function of field frequency.

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