Design and Construction of a Small Reverberation Chamber

Preliminary Communication

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Abstract *– This paper describes the design of a small reverberation chamber. The lower usable frequency of the reverberation chamber designed in this paper is 2.3 GHz. The upper usable frequency depends on the conductivity of the walls and it is at least 18 GHz. The introduction gives basic information and usage of the reverberation chamber, while the theory is explained in the next section. Unlike other facilities used in the testing of electromagnetic compatibility, the reverberation chamber works with many higher order modes. While other chambers or cells try to avoid the appearance of higher order modes, which tend to destroy a uniform electromagnetic field, the reverberation chamber takes full advantage thereof, creating a statistically homogenous electromagnetic field. After a theoretical overview, there follows the design for building the reverberation chamber, as well as the method of its control, especially the movement of mode stirrers necessary for the reverberation chamber to operate. The lower usable frequency of the chamber depends on the size. We have designed the chamber to be used at 2.3 GHz and above, which resulted in a relatively small size of the chamber (only 0.0174 m3). The designed reverberation chamber was tested and the results validated the design.*

Keywords *– electromagnetic compatibility, electromagnetic waves, mode stirrer, mode tuner, reverberation chamber*

1. INTRODUCTION

A reverberation chamber (RC) is a tool used primarily to test electromagnetic compatibility of a certain device. It can be said for some device that it is electromagnetically compatible if it is not susceptible to electromagnetic radiation, or if it does not emit unwanted electromagnetic radiation and thus cause interference to any subsystem within it.

A reverberation chamber is used for testing susceptibility and emission. Emission can be measured only as the total radiation from the device under test and not the electric field at a certain distance which is often required in some norms.

A reverberation chamber is used for testing when the radiation pattern is unknown a priori (i.e., not a dipole), when the equipment under test (EUT) is relatively large compared to the wavelength or when there is no plane wave. A reverberation chamber can also be used for diversity transmission of mobile phones due to the similarity between multipath of an electromagnetic wave and multipath in the RC.

A reverberation chamber has metallic walls with small losses. It should not radiate outside and it has no absorbers. At resonant frequencies, reverberation chambers are resonators with a high Q factor. Mode stirrers are placed inside in order to change border conditions in the chamber, ensuring that the device under test is equally exposed to radiation or that its emission can be detected. A statistically uniform electromagnetic field is created inside the chamber. The testing inside the chamber must be performed at a frequency which is above the lower resonant frequency, that is, in the frequency range where the higher order modes can exist.

A fully functional reverberation chamber (Fig. 1) consists of metallic shielded room with finite conductivity and mode stirrers/tuners. For the testing, antennas and the measuring device must also be placed inside the chamber. To fully comprehend basic principles of operation, the chamber can be considered as a resonant cavity with perfectly conducting walls.

Unlike other methods for measuring in the area of electromagnetic compatibility [1-3] (OATS – Open Area

Test Sites, AC – anechoic chambers, TEM Cell – Transverse Electromagnetic Mode cell), which assume particular behavior of electromagnetic radiation emitted by the EUT or antennas, the reverberation chamber creates an environment similar to that of a multipath environment of modern cities – where there is no pattern of electromagnetic radiation. The reverberation chamber uses mode stirrers to create a statistically uniform field in parts of the chamber which are then used for measurement.

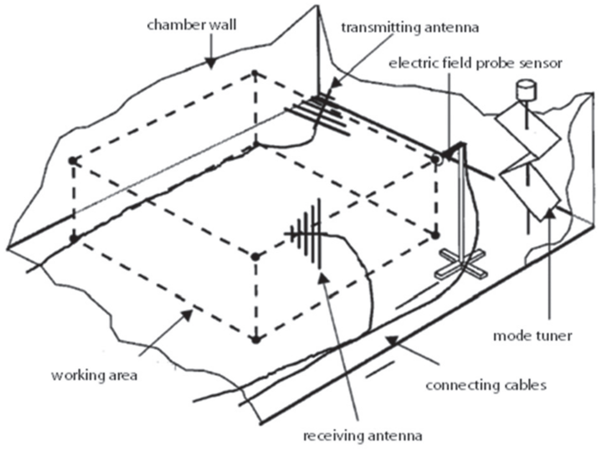

Fig. 1. Reverberation chamber.

The reverberation chamber has been a matter of research for some time now [4-6]. Usually, large reverberation chambers are built, but a general procedure can be applied to a smaller chamber as well [7-8].

The volume rather than the shape of the reverberation chamber is important. About 50% of volume is useful for testing which is more than with the Open Area Test Site.

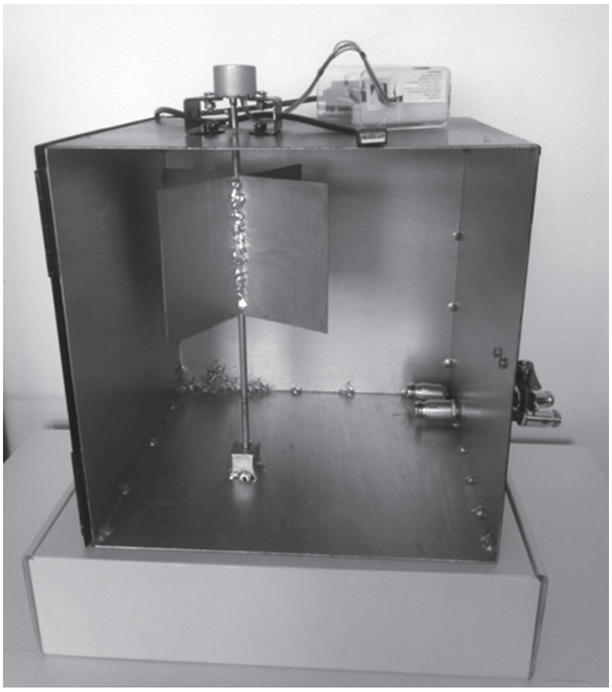

Fig. 2. Laboratory model of the reverberation chamber.

Reverberation chambers usually have a volume from 75 m^3 to 100 m^3 but it can be much smaller. They are used for testing at frequencies from 200 MHz up to 18 GHz. For frequencies below 200 MHz, the size of the chamber would be very large. For frequencies above 1 GHz, smaller chambers can be used (0.25 m^3 or smaller).

The reverberation chamber (Fig. 2) presented in this paper was built at the University of Zagreb, the Faculty of Electrical Engineering and Computing. Dipole antennas used later for the testing purposes are not shown here for clarity.

2. THEORY

In order to analyze electromagnetic fields, a simplified solution reverberation chamber can be considered as an ideal cavity resonator. The cavity resonator can be created by short-circuiting both ends of the waveguide on a distance large enough to produce standing waves. By using boundary conditions and wave equations, an electromagnetic field inside the chamber can be described as follows.

From theoretical analysis, the expression for frequencies of individual modes can be given as:

$$f_{m_x m_y m_z} = \frac{c}{2\pi}\sqrt{\left(\frac{m_x\pi}{a_x}\right)^2 + \left(\frac{m_x\pi}{a_x}\right)^2 + \left(\frac{m_z\pi}{a_z}\right)^2}, \qquad (1)$$

where a_x, a_y and a_z, are physical dimensions, c is the speed of light and m_x, m_y and m_z are integer numbers representing one half wavelength in each of the three dimensions, respectively [9]. The above expression is used when determining the lowest usable frequency of the reverberation chamber. By summing up all of the modes above, some cutoff frequency, LUF (the lowest usable frequency) can be calculated as [9]:

$$N \approx \frac{8\pi}{3}\cdot a_x a_y a_z \cdot \frac{f^3}{c^3} - \left(a_x + a_y + a_z\right)\cdot\frac{f}{c} + \frac{1}{2}, \qquad (2)$$

where dimensions a_x, a_y and a_z, are physical dimensions, f is the lowest usable frequency, and N is the number of required modes above the cut-off frequency.

60 to 100 modes above the cutoff frequency are usually required for the reverberation chamber to be able to perform.

When a large number of modes exist (>60) and measurements are averaged over a number of stirrer positions, the field in a reverberation chamber is, on average, uniform throughout half of the volume. The actual LUF will depend on many factors and may differ from theoretical calculations. The chamber volume has the largest impact on the LUF (lowest usable frequency). The Q factor can be calculated from [10]:

$$Q \approx \frac{3}{2}\cdot\frac{V}{A\delta}, \qquad (3)$$

where V is the chamber volume, A is the surface of inner walls and δ is the skin depth of the walls defined by:

$$\delta = \sqrt{\frac{1}{\pi f \sigma \mu}}, \qquad (4)$$

where σ is the conductivity and μ is the permeability of the inner walls.

For the reverberation camber described in this paper, chamber volume V is equal to 0.0174 m^3, the surface area of the walls is equal to 0.4042 m^2. The inner walls are painted with aluminum paint, thus increasing conductivity. The calculated Q factor is approximately 120,000 for a frequency of 2.4 GHz.

In order to approximately determine the LUF value, the following equation can be used [11]:

$$f_{\mathrm{LUF}} = 3 f_c, \qquad (5)$$

where f_c is the frequency of the resonant cavity having the same physical dimensions as the reverberation chamber. It is equivalent to the frequency of the first mode which begins to propagate inside the chamber. The first modes to propagate are usually TM_{110}, TE_{011} or TE_{101} [9].

The lowest usable frequency for the reverberation chamber presented in this paper calculated for $N = 60$ modes using (2) is around 2.28 GHz, or around 2.31 GHz for TE_{011} if (1) and (5) are used.

The reverberation chamber is similar to a microwave oven. It has a shielded room which "spreads" the field evenly by using mode tuners. By rotating, mode tuners/stirrers (Fig. 3) change the boundary conditions inside the chamber and make the field uniform in a working volume of the chamber.

Mode tuner/stirrer design is mostly empirical [5]. The vane height in our case is slightly longer than the reverberation chamber height. This is done so that the step engine placed outside of the chamber could turn the mode tuner/stirrer. The size of the wing was chosen to be 8x10 cm (a larger dimension would decrease the working area), while the angle between them was 90°.

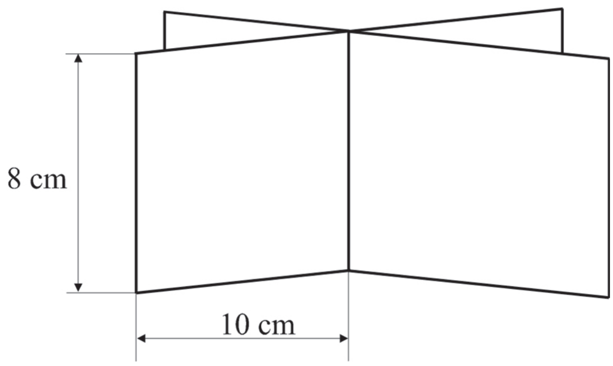

Fig. 3. Mode Tuners/Stirrers.

By rotating, tuners shift maximums and minimums inside the chamber, thus creating a uniform field inside the working area of the chamber. The reverberation chamber can operate in two ways: mode-stirred and mode-tuned mode. Mode-stirred operation means that the mode stirrer constantly rotates at the speed of 4 - 30 RPM (revolutions per minute). Results are averaged over some time period. In mode-tuned operation, a new measurement is done for each step of the mode tuner. For higher frequencies, fewer steps need to be taken.

A smaller tuner impacts the field only slightly, while a larger one creates many higher order modes and thus creates more field maximums inside the chamber. Once a large enough number of modes is achieved, a statistically uniform field is formed in the working volume of the chamber.

3. DESIGN

The Electromagnetic Reverberation Chamber discussed in this paper was built at the Department of Radiocommunications, the Faculty of Electrical Engineering and Computing, the University of Zagreb, Since the reverberation chamber is usually large and expensive, it was decided that a smaller reverberation chamber should be built. The lowest usable frequency chosen was 2.3 GHz, a little below 2.4 GHz, which is a frequency with many applications (Wi-Fi, a microwave oven, etc.).

Chamber exterior was built from metal alloy, a mixture of iron and aluminum. Chamber walls were measured and cut to appropriate dimensions and welded together using the MAG (metal active gas) welding technique. MAG welding is a subtype of GMAW (gas metal arc welding) in which an electric arc forms between a consumable wire electrode and the work piece metals, which heats the work piece metals, causing them to melt and join.

The shape of the chamber is not important since many different shapes perform similarly. That is why the cubic form, which is relatively easy to construct, was chosen.

Chamber dimensions (Fig. 4) are 28x27x23 centimeters, which, by the theoretical equations mentioned in Section 2, should achieve the lowest usable frequency at around 2.3 GHz. Since space is fairly limited (after antennas and tuners are installed), only smaller objects can be measured.

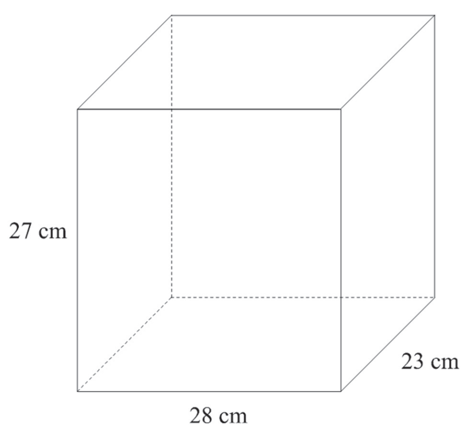

Fig. 4. Reverberation chamber dimensions.

For 2.4 GHz, λ=12,5 cm, thus the transmitting and receiving antenna should be placed at least λ=6,25 cm away from each other in order to avoid coupling between them. Since the width of the reverberation chamber described in our paper is 28 cm, there is enough space available for two dipole antennas and small equipment to be tested.

After welding was completed, interior walls of the chamber were painted using aluminum enriched paint to increase wave reflection.

Apart from the front wall, which is used as a door and can be fully opened to ease access to the interior parts, there were several other holes drilled in for connectors and for the step motor. Door handling was simplified by using only a latch which holds together the door to the sides of the chamber. For better sealing, copper fingers should be used to prevent field leakage at higher frequencies.

Mode tuners/stirrers greatly impact field distribution inside the chamber. In theory, a rotationally asymmetric tuner should prove to be better in creating a more uniform field inside the chamber. Tuners are placed on a mount inside the chamber and connected to the step motor, which is located outside of the chamber.

For input and output cables, two RG213/U 50Ω coaxial cables with *N* type connectors, up to 18 GHz, were used.

A step motor was used to control mode tuners. The step motor (or stepper motor) is an electromechanical device which converts electrical pulses into discrete mechanical movement. The motor used for this chamber can either rotate continually by smoothing out each discrete step movement, or by moving in a number of discrete steps. The step motor is connected to the tuner with two screws holding it in place. The motor is placed outside of the chamber to reduce interference with the measurement done inside the chamber. The step motor is controlled by the *Arduino* microcontroller. *Arduino Duemilanove*, used along with the *Adafruit* Motor Shield, allows the user to programmatically define step motor movement. The controller can be connected to the computer via a USB cable which powers both the controller and the step motor.

4. TESTING

The reverberation chamber was tested according to the MIL STD-461F. The setup included a USB powered RF signal generator Windfreak Technologies SynthNV 34.4MHz – 4.4 GHz, a PC laptop, a reverberation cell and a Narda SRM 3000 spectrum analyzer (Fig. 5).

Mode stirrers were turning continuously at 30 rpm. The transmitting antenna and the receiving antenna were placed inside the reverberation chamber orthogonally to each other. The antennas used were dipoles (due to the small size) with a gain of 2.14 dBi. The input level of the generator was set at -9.5 dBm. The received power was measured first when mode stirrers remained still and then when they were in operation (turning). The results are shown in Table 1 and Fig. 6. The highest gain measured with the spectrum analyzer was at frequencies of 2.3 GHz, 2.5 GHz and 2.9 GHz.

Fig. 5. Measurement setup.

Mode stirrers were turning continuously at 30 rpm. The transmitting antenna and the receiving antenna were placed inside the reverberation chamber perpendicularly to each other. The antennas used were dipoles (due to the small size) with a gain of 2.14 dBi. The input level of the generator was set at -9.5 dBm. The received power was measured first when mode stirrers remained still and then when they were in operation (turning). The results are shown in Table 1 and Fig. 6. The highest gain measured with the spectrum analyzer was at frequencies of 2.3 GHz, 2.5 GHz and 2.9 GHz.

Table 1. Measurement results.

P_{tx} = -9.5 dBm			
f (GHz)	P_{rx} (dBm) no operation	P_{rx} (dBm) operating	Operation Gain (dB)
2.0	-12.51	-8.46	4.05
2.1	-17.87	-14.67	3.2
2.2	-21.58	-16.43	5.15
2.3	-19.87	-10.13	9.74
2.4	-19.51	-15.76	3.75
2.5	-26.8	-19.20	7.6
2.6	-28.6	-26.1	2.5
2.7	-31.41	-29.73	1.68
2.8	-19.45	-14.63	4.83
2.9	-17.82	-8.95	8.87
3.0	-7.91	-15.74	7.83

It can be seen that the reverberation chamber with stirrers turning increases the level of the received power on all tested frequencies from approximately 2 dB to approximately 10 dB, the highest at 2.3 GHz. The reverberation chamber gain is higher than 3 dB, except for the frequencies of 2.6 GHz and 2.7 GHz, where it was below 3 dB. This will be investigated further in the future.

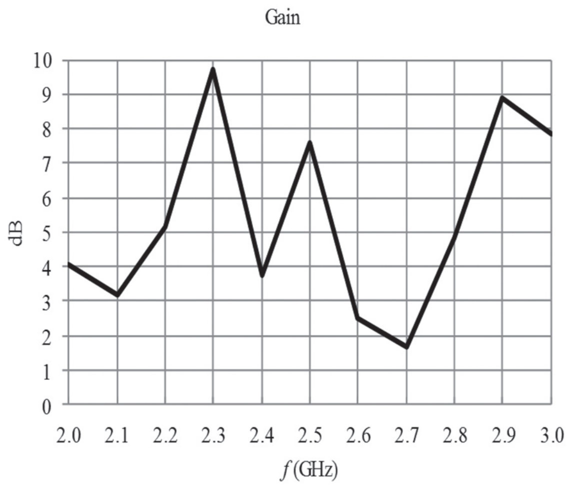

Fig. 6. Reverberation chamber gain.

5. CONCLUSION

The reverberation chamber was built with a minimum frequency of 2.3 GHz. It can be used for EMI measurements of small objects and as a tool for student experiments.

Since the chamber was made in a simplified way, there is a lot of room for improvements. Tuners and walls could be replaced by or supplemented with better materials, the chamber could be expanded on one side (this would allow using lower frequencies), a stronger and better step motor could be used, holes and doors could be improved, or copper fingers added for preventing field leakage [12].

The measured results showed that the tested reverberation chamber can be used from the frequency of 2.3 GHz and above. Further research will include measuring the uniformity of the electric field inside the chamber with a probe. Building a larger reverberation chamber might also be a matter of research since it would enable the lower LUF (lowest usable frequency).

6. REFERENCES

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