Calculation of absorption cross section in a reverberation chamber

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Abstract. In this paper, the mechanism of the power lost in the reverberation chamber is analyzed and a model to calculate the absorption cross section of loaded object is introduced. The cavity quality factor Q can be obtained from calculating the absorption cross sections of loaded objects. The cavity Q is proportional to the frequency selected, the relative permittivity and inversely proportional to the average absorption cross section of the lossy objects.

1. Introduction
Reverberation chambers are being used as an alternative test facility for a wide range of electromagnetic compatibility measurements, such as radiated immunity, radiated emissions, shielding effectiveness of composite materials, antenna efficiency and probe calibration. In practice, a typical reverberation chamber has lossy walls and is loaded with other objects, many of which absorb electromagnetic energy. This behavior may influence the chamber quality factor (Q) and the performance of the chamber. The key issue is whether these losses degrade the reverberation performance under an acceptable value, which needs further more research. Our concern, now, is what the relation between the quality factor and the loaded reverberation chambers.

A convenient way to model the losses of the loaded objects is by the absorption cross section which depends on the size, shape, and electrical parameters of the loaded objects. Especially when the losses are related to incident plane waves, the absorption cross section is an intuitively suitable parameter because it is an equivalent area over which an amount of the incident power falls [1]. The purpose of this paper is to describe how to calculate the absorption cross sections. The second part of this paper analyzes the path of the power lost in the reverberation chamber, and the third section introduces a model and investigates the absorption cross section deeply. Finally, in section fourth conclusions will be drawn.

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2. The path of power lost

The power dissipated in reverberation chamber can be divided into two parts, one is dissipated in cavity walls, the other one is absorbed by loaded objects within the cavity. The $Q$ of a reverberation chamber with finitely conducting walls and loaded objects is given by the following [2]:

$$Q^{-1} = Q_{wall}^{-1} + Q_{load}^{-1} \quad (1)$$

The $Q$ is associated with the total power lost in cavity, and the $Q_{wall}$ is associated with the wall loss, and the $Q_{load}$ is associated with the loss due to the loaded objects. The $Q_{wall}$ can be expressed as:

$$Q_{wall} = \frac{3V}{2S} \delta \mu_r \quad (2)$$

Where $S$ is the surface area of the walls of the cavity, $V$ is the volume of the cavity, $\mu_r$ is the relative permeability of the walls, $\delta$ is the skin depth of the wall. And the $Q_{load}$ can be expressed as:

$$Q_{load} = 2\pi V / \lambda \langle \sigma_a \rangle \quad (3)$$

Where $\langle \sigma_a \rangle$ is the averaged absorption cross section.

From equations (2) and (3), it is not difficult to find the averaged absorption cross section $\langle \sigma_a \rangle$ is the key factor of equation (1), for which can be used to determine the $Q$ of the whole chamber with many of loaded spheres.

3. Absorption cross section

The absorption cross section of the loaded object is defined as the power dissipated in the object under planewave incidence [3]. The literature [4] gives the expression of absorption cross section, as follows:

$$\langle \sigma_a \rangle = \pi a^2 (\eta - \eta_i) \quad (4)$$

Where:

$$\eta = \frac{2}{(ka)^2} \sum_{n=1}^{\infty} (2n+1) \text{Re}[a_n + b_n] \quad (5)$$

$$\eta_i = \frac{2}{(ka)^2} \sum_{n=1}^{\infty} (2n+1) \left[ |a_n|^2 + |b_n|^2 \right] \quad (6)$$

The parameters $a_n$ and $b_n$ are given by:

$$a_n = \frac{\psi_{\nu_n}(y)\psi_{\nu_n}(x) - m\psi_{\nu_n}(y)\psi_{\nu_n}(x)}{\psi_{\nu_n}(y)\xi_{\nu_n}(x) - m\psi_{\nu_n}(y)\xi_{\nu_n}(x)} \quad (7)$$

$$b_n = \frac{m\psi_{\nu_n}(y)\psi_{\nu_n}(x) - \psi_{\nu_n}(y)\psi_{\nu_n}(x)}{m\psi_{\nu_n}(y)\xi_{\nu_n}(x) - \psi_{\nu_n}(y)\xi_{\nu_n}(x)} \quad (8)$$

Where $x=ka$, $y=mx$, $k=2\pi/\lambda$ and is the free-space wave number, and $m$ is the refractive index. $\psi_{\nu_n}$, $\xi_{\nu_n}$ are the Riccati-Bessel functions defined in [5] and [6].
The equation (4) is based on the assumption that the loaded objects are all homogeneous spheres, and equation (4) expressed the absorption cross section of one single object. With this assumption, \( a \) is the radius of loaded object, and the total absorption cross section of all objects can be calculated by:

\[
\langle \sigma_a \rangle = \sum_{i=1}^{N} \langle \sigma_{o_i} \rangle
\]

If the objects are identical, (9) can be simplified to

\[
\langle \sigma_a \rangle = N \langle \sigma_{o_1} \rangle
\]

Actually, the incident electromagnetic wave to the surface of objects is oblique, as shown in figure 1. \( \theta_i \) is the angle of incidence to the normal of the surface, and \( \theta_m \) is the angle of the refracted wave (inside the material) to the normal, and \( \theta_e \) is the angle of the refracted wave (outside the material) to the normal.

In practice, the absorption cross section of a homogeneous sphere is independent of both the incidence angle and polarization of the incident field [2]. This is identical to the reverberation chamber environment characteristics which are stated as statistically uniform, isotropic and randomly polarized. With the discussion above, obviously, the absorption cross sections of the loaded spheres have a closed relation with the relative permittivity of the loaded objects. A plot of the result can be seen in figure 2.

![Figure 1. Example of planewave into sphere object.](image1)

![Figure 2. Absorption cross section for different relative permittivity.](image2)

From figure 2, it is not difficult to obtain the conclusion that the absorption cross section fall down with the increasing relative permittivity of the loaded objects, which indicated that the loaded dielectric object should be chosen with larger relative permittivity.

The curve in figure 3 is the relation between absorption cross section and the radius of sphere, which seems like quadratic curve.
The absorption cross section can be used to determine the $Q$ of the chamber with lots of loaded objects, and figure 4 shows the $Q$ of loaded chambers with various numbers of frequencies. The more absorption cross sections, the more electromagnetic energy lost. As expected, the $Q$ of the loaded chamber decreases with the increasing absorption cross sections. IEC61000-4-21 provides an access to evaluate the reverberation chamber performance, while it is possible to investigate the degradation of the useable of a reverberation chamber use the quality of $Q$. But the problems are how much quality of $Q$ lost can be seen as the chamber’s effectiveness degrades and what is the expression for the threshold metric of $Q$ that must be exceeded. Both of these are needed to investigate more in further time. Figure 5 gives the same trend that the decrease in the chamber with the absorption cross section as shown in figure 4.

According to figure 4 and figure 5, the $Q$ of the loaded chamber increases with the increasing frequency. In figure 4, we can see that as the frequency increases, the curves are much closer to each
other, which indicates that the quality of $Q$ trend to be horizontal up to high frequencies. It means that the cavity $Q$ should be within a certain range, and not be infinite. A completely lossless reverberation chamber results in poor performance. These calculations are all used the reverberation chamber model with the dimensions as $4.3 \times 8 \times 10.4$ m.

After the discussion, the quality of $Q$ can be relation with the relative permittivity of the loaded objects. Figure 6 presents the relation between the quality factor $Q$ and the relative permittivity of the loaded objects. As expected, the $Q$ of the loaded chamber increases with the increasing relative permittivity and frequency.

![Figure 6. Quality of Q for different relative permittivity.](image)

4. Conclusion
This paper presents a model to calculate the absorption cross sections of loaded objects within the reverberation chamber. This model simplified the loaded objects into a various number of identical lossy spheres. The cavity $Q$ can be obtained from calculating the absorption cross sections of loaded objects. The analyses show that the absorption cross sections have closed relation with the radius, relative permittivity of the lossy spheres. The cavity $Q$ is proportional to the frequency selected, the relative permittivity and inversely proportional to the average absorption cross section of the lossy objects. However, how to evaluate the chamber’s effectiveness degrades and what is the expression for the threshold metric of $Q$ that must be exceeded. These topics should be further investigated in the future research.

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