Effect of a Metallic Object on the Quality Factor of a Reverberation Chamber

Stefan van de Beek\textsuperscript{1}, Kate A. Remley\textsuperscript{2}, Christopher L. Holloway \textsuperscript{2}, John Ladbury \textsuperscript{2}, Frank Leferink\textsuperscript{1,3}

\textsuperscript{1}University of Twente, Enschede, Netherlands
Email: g.s.vandebeek@student.utwente.nl
\textsuperscript{2}National Institute of Standards and Technology, Boulder, CO, 80305
\textsuperscript{3}Thales Nederland B.V., Hengelo, Netherlands

Abstract—In this paper the effect of a metallic object on the quality factor of a reverberation chamber is investigated. If we assume equal material properties for both the metallic object and the walls of the reverberation chamber, the decrease in $Q$ due to a metallic object can be easily calculated. It is shown that the conductivity of the walls of the used NIST reverberation chamber is much lower than the conductivity of thin foil.

I. INTRODUCTION

New technologies such as machine-to-machine (M2M) communications are becoming commonplace, and these M2M devices need to be characterized and tested for radiated emissions and radiated susceptibility. Some of the M2M devices can be large-form-factor devices, e.g., a vending machine. While small devices can be tested with current methods in the anechoic chamber, the use of anechoic chambers may not be practical for large devices. Reverberation chambers could be useful for physically large devices, providing a reliable and repeatable test environment.

In recent years, reverberation chambers have been used more and more as a facility for characterizing and testing wireless devices; see \cite{1} and \cite{2} for a list of applications. A common reverberation chamber consists of a large room with conducting walls and a metallic rotating paddle that stirs the electromagnetic (EM) modes in the cavity. There are many other types of reverberation chambers that rely on different ways of stirring the field; e.g., position stirring or frequency stirring. The same theory applies in reverberation chambers regardless of the stirring method. In an ideal reverberation chamber the field is spatially uniform and isotropic [\textsuperscript{3}].\textsuperscript{4}

The performance of the reverberation chamber can be affected by the physical characteristics of the device-under-test (DUT). A DUT can load the chamber and this loading will alter characteristics of the chamber. In [\textsuperscript{5}], it was shown that loading a chamber reduces the spatial uniformity. In [\textsuperscript{5}], equations are derived for maximum loading expressed by a threshold quality factor $Q_{thr}$. For an effective reverberation chamber, the quality factor $Q$ should exceed this threshold value.

In this paper we are interested in the effect of a large metallic object on the $Q$ of the reverberation chamber. In the next section, it is shown how the $Q$ can be calculated theoretically. Next, the experimental method of measuring the $Q$ in the reverberation chamber is presented. Finally, the results are shown and conclusions are drawn.

II. THE QUALITY FACTOR

As stated in [\textsuperscript{6}], the $Q$ is defined by

$$Q = \frac{\omega U}{P_d},$$

where $\omega$ is the angular frequency, $U$ is the energy stored in the cavity and $P_d$ is the power dissipated. For steady-state conditions the dissipated power $P_d$ equals the transmitted power $P_t$ in a reverberation chamber [\textsuperscript{6}]. In [\textsuperscript{6}] it is explained that there are four types of loss that contribute to $P_d$. That is; (1) loss due to power dissipated in the walls, (2) loss due to power-absorbing objects in the chamber, (3) the leakage through apertures, and (4) loss due to the power dissipated in the loads of receiving antennas.

For an unloaded reverberation chamber the wall losses are usually dominant. If the wall losses are dominant the $Q$ can be approximated by [\textsuperscript{7}]:

$$Q = \frac{3V}{2\mu_r\delta A},$$

where $V$ is the volume of the chamber, $\mu_r$ is the relative permeability of the wall, $\delta = \sqrt{2/\omega \mu_w \sigma_w}$ is the skindepth, $\omega$ is the angular frequency, $\mu_w$ is the wall permeability, $\sigma_w$ is the wall conductivity, and $A$ is the wall surface area of the chamber.
From this equation we can conclude that if we put a metallic object in the reverberation chamber the $Q$ is lowered because of two mechanisms. First, the net volume of the chamber will decrease. Second, by putting this object in the chamber the wall surface area essentially increases, i.e., the wall loss will decrease. Second, by putting this object in the chamber the wall surface area essentially increases, i.e., the wall loss will decrease. Using a similar approach as described in \cite{7} we can derive the $Q$ of a reverberation chamber loaded with a metallic object.

$$Q_{\text{tot}} = \frac{3(V - V_o)}{2(\mu_r \delta A + \mu_r o \delta_o A_o)}.$$ \hfill (3)

Here $V_o$ is the volume of the metallic object, $\mu_r o$ is the relative permeability of the object, $\delta_o$ is the skindepth of the object, and $A_o$ is the surface of the object.

III. EXPERIMENTAL METHOD

Measurements were made in the NIST reverberation chamber with dimensions 4.6 m x 3.1 m x 2.8 m. This chamber has a single vertical mode-stirring paddle. The loading in the chamber was obtained by stacking metallic boxes with dimensions 0.61 m x 0.41 m x 0.32 m. The metallic boxes were made by wrapping cardboard boxes in thin foil, see Fig. 1. We looked at the $Q$ of the chamber in four different configurations: loaded with 4 boxes, 8 boxes, 12 boxes, and the unloaded chamber.

A NIST-fabricated monopole and a dual ridge horn antenna were placed in the chamber. The monopole was tuned to a frequency of 1.9 GHz and mounted on a groundplane with dimensions 20 cm x 20 cm. The dual-ridge horn antenna had an aperture dimension of 13.5 cm x 22.5 cm. With use of a VNA, the complex scattering parameters (S-parameters) between the horn and monopole were measured. For every loading configuration, the $S_{21}$ between the horn and the monopole was measured over 72 stirrer positions. For every stirrer position 16000 frequency points from 1.5 GHz to 2.5 GHz were measured. A picture of the setup with 12 boxes in the chamber can be seen in Fig. 2.

The $Q$ was determined from measurements by making use of the fact that the losses, and so the $Q$, in the chamber are related to the decay time \cite{6}.

$$Q = \omega \tau_{\text{RC}}.$$ \hfill (4)

In this equation $\tau_{\text{RC}}$ represents the decay time of the chamber in seconds.

The $\tau_{\text{RC}}$ was determined from the power delay profile (PDP) of the multipath channel in the reverberation chamber \cite{2}, \cite{8}. Since the impulse response $h(t)$ characterizes the multipath channel the PDP can be calculated from $h(t)$ of the chamber \cite{9}. The PDP in the chamber is given by \cite{2}

$$\text{PDP}(t) = \langle |h(t,n)|^2 \rangle,$$ \hfill (5)

where the ensemble average is taken over the stirrer positions $n$, and $h(t,n)$ is the impulse response of the chamber for the $n$th stirrer position. The impulse response $h(t,n)$ is given by

$$h(t,n) = \text{IFT}[S_{21,n}(f)].$$ \hfill (6)

If the early time behavior of the reverberation chamber is neglected, the PDP can be approximated by \cite{8}

$$\text{PDP}(t) = \langle |h(t,n)|^2 \rangle = P_o e^{-t/\tau_{\text{RC}}}.$$ \hfill (7)

In \cite{8} it is shown that if the early time behavior is neglected, the RMS delay spread is equal to $\tau_{\text{RC}}$. The decay time $\tau_{\text{RC}}$, or RMS delay spread, can now be determined by recognizing that the slope of ln[PDP(t)] will be equal to 1/$\tau_{\text{RC}}$.

IV. RESULTS

From \cite{3} we can calculate the decrease in $Q$ due to the metallic boxes in the reverberation chamber. If we assume that the conductivity and the permeability of the outer surface of the boxes is equal to $\sigma_w$ and $\mu_w$, we can derive from \cite{3} that with twelve boxes in the chamber the $Q$ will decrease by 10%. The decrease in volume is not significant, since 12 boxes occupy only 2% of the total volume of the chamber.

The $Q$ was determined determined every 100 MHz from 1550 MHz to 2450 MHz. The $\tau_{\text{RC}}$ was determined over a bandwidth of 100 MHz. In Fig. 5 the $Q$ is plotted as a function of frequency for the various loading configurations. As can be seen the $Q$ decreases with more boxes. At 1.95 GHz the $Q$ of the chamber loaded with 12 boxes is 20% lower than the $Q$ of the unloaded chamber. The measured decrease of $Q$ is higher than expected from \cite{3}. This could be caused by an unequal conductivity of the thin foil and the walls, i.e., a lower conductivity of the thin foil compared to the walls.

As previously explained, the impact of the decrease in volume on $Q$ is very small. This means that if we would hang thin foil sheets in the chamber with the same surface area corresponding to the number of boxes the loading would be approximately the same. This hypothesis was tested by hanging aluminum sheets in the chamber corresponding to a surface area of 4 boxes, 8 boxes, and 12 boxes (Fig. 4).

The $Q$ for these loading configurations was measured. In Fig. 5 it is compared to the unloaded chamber and the chamber loaded by four boxes. As can be seen, the sheets hardly load the chamber and the effect on the $Q$ can be neglected. It can
Fig. 3. The quality factor $Q$ on a linear scale as a function of frequency. The different curves represent different loading configurations.

Fig. 4. Aluminium sheets hang in the reverberation chamber.

Fig. 5. The $Q$ as a function of frequency. The different curves are for the different loading configurations.

Fig. 6. The different loading configurations: a) no foil, b) box wrapped in foil, and c) seams of the foil taped with conducting tape.

be seen that if we hang thin foil sheets in the chamber with a surface area comparable the surface area of twelve stacked metallic boxes ($6.5 \text{ m}^2$) the decrease in $Q$ is less than 2 %. From (3), we would expect the $Q$ to decrease by 8 %, assuming the same materials properties of the thin foil and the walls and a constant volume. So we can conclude that the conductivity of the thin foil is much higher than the conductivity of the walls.

These results suggest that the cardboard boxes loaded the chamber. Apparently energy is coupled into the boxes and the cardboard boxes are lossy. This was shown more clearly by additional measurements. We measured the $Q$ when the chamber was loaded by cardboard boxes without foil (Fig. 6(a)), cardboard boxes wrapped in foil (Fig. 6(b)), and cardboard boxes wrapped in foil with the seams closed by conducting tape (Fig. 6(c)).

Results of these loading configurations together with the unloaded chamber are shown in Fig. 7. It can been that the bare cardboard boxes load the chamber, so it is concluded that the cardboard is lossy. When the boxes are wrapped in foil, the lossy material is partly shielded from the reverberation chamber. For this reason the $Q$ is higher when the boxes are wrapped in foil. When we increase the shielding between the cardboard boxes and the chamber by closing the seams of the foil with copper tape the $Q$ increases even higher.
V. CONCLUSION

In this paper we investigated the effect of a metallic object on the $Q$ of a reverberation chamber. This was done by wrapping cardboard boxes in thin foil.

The $Q$ can theoretically be calculated if the conductivity and the permeability of the metallic object and the walls are known. If we assume that the properties of the metallic object are equal to the material properties of the walls you can calculate the decrease in $Q$ due to the loading.

We have shown that in this reverberation chamber the conductivity of thin foil is much higher than the conductivity of the walls. The impact of putting 6.5 m$^2$ thin foil in the reverberation chamber on the $Q$ was less than 2%.

Results have shown that the decrease in $Q$ is caused by the cardboard being lossy. Energy is coupled into the boxes and is absorbed by the cardboard.

REFERENCES


