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Chamber-Decay Time in a mm-Wave Reverberation Chamber

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***Abstract*—In this work, we present results of a novel mm-wave reverberation chamber, where we discuss the role of the chamber quality factor and chamber decay time, or time constant, for mm-wave applications. For the first time, we analyze the uncertainty due to antenna positioning for these metrics in such a chamber, where we show that the quality factor computed in the frequency domain has a higher uncertainty due to antenna positioning than its time domain counterpart. We describe that the the chamber decay time and quality factor are lower for mm-wave chambers as compared to lower-frequency (sub-6 GHz) chambers, but that they can still function as ideal candidates for metrics revolving around losses.**

I. Introduction

Reverberation chambers (RCs) are shielded enclosures that behave as a resonant cavity. By inserting metallic structures, referred to as *mode-stirrers* (see Fig. 1), the distribution of modes in the chamber changes. When averaged over many different mode-stirring samples, the field distribution becomes, on average, uniform. This allows a reverberation chamber to measure any losses that occur in the chamber very accurately. With this information, metrics can be measured fast and accurate that would usually require an integration over a sphere in an anechoic chamber such as antenna efficiency, total radiated power, total isotropic sensitivty, etc. [1]–[4].

All losses in the chamber can be measured using the chamber's quality factor (Q), which can be extracted from a transmission-coefficient measurement between two antennas that are connected to a vector network analyzer (VNA). When the Q is computed in the time-domain, referred to as the chamber-decay time or time constant, it does not contain the losses due to the antenna efficiencies [1]. Therefore, the chamber-decay time allows one to investigate only the losses in the chamber, from which metrics such as absorption cross section (ACS) and antenna efficiency can be extracted [1]–[3]. The ACS of a material sample can be derived from the difference in chamber-decay time between two measurements where the sample is present in the chamber in the first measurement, and not in the second. Additionally, since the time constant does not contain the antenna losses, while the Q computed in the frequency domain does, the antenna efficiency can be extracted by dividing the two [1].

For the 5G FR2 mm-wave frequency range (24.25 - 43.5 GHz) [5], material losses in the chamber may become significantly higher compared to the FR1 sub-6 GHz range. This effect, among others, can be evaluated using the chamber decay time. For the first time, we investigate results of the chamber decay time and the Q computed in both the time- and frequency domain in a novel mm-wave RC, including an uncertainty analysis, and we describe challenges that could arise in using it to assess metrics revolving around losses. These results are analyzed in Section II and the work is concluded in Section III.

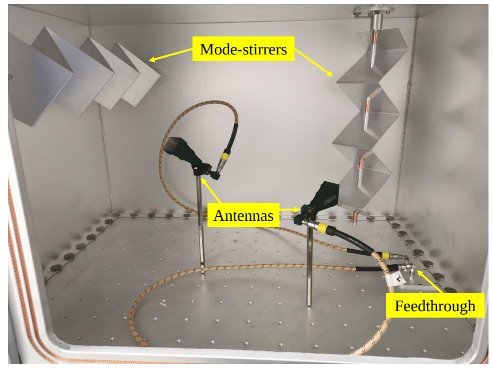

Fig. 1. Setup in the mm-wave RC for 22-40 GHz.

II. Time Constant

The chamber-decay time or time constant, τ_{RC}, is defined by the slope of the exponentially decaying part of the power delay profile (PDP), which is defined by the inverse Fourier transform of an S_{21} measurement [4]. In this work, we estimated the time constant in a $V = 0.2311$ m^3 reverberation chamber with two stirrers, as shown in Fig. 1, where we used two horn antennas operating in the 22 - 40 GHz band connected to a VNA (IF BW of 1 kHz and 100 kHz frequency spacing) to measure S_{21}. Both stirrers were varied over 10 positions, yielding $N = 100$ mode-stirring samples. We repeated the measurement for $P = 9$ different antenna positions. Independence between positions was verified using Pearson's cross correlation with a threshold of 0.3. We frequency averaged all results in post-processing using a 100 MHz averaging bandwidth. The Q computed in the time domain can be calculated using $Q_{TD} = \omega \tau_{RC}$, where $\omega = 2\pi f$, and where f is the frequency. The Q in the frequency domain is computed using

$$Q_{FD} = \frac{16\pi^2 V \langle |S_{21}|^2 \rangle}{\lambda^3}, \quad (1)$$

where λ is the wavelength. The results of the chamber decay time are shown in Fig. 2, and the results of Q_{TD} and Q_{FD} are

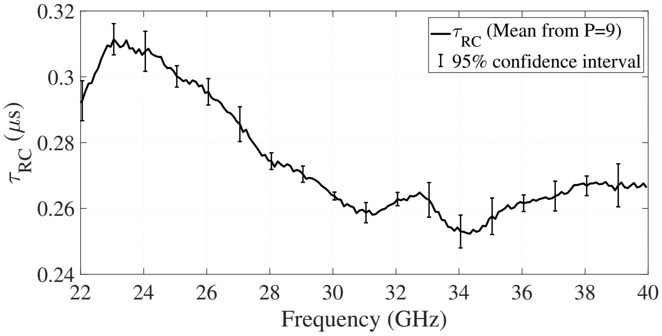

Fig. 2. Best estimate of the time constant and the uncertainty (2σ, 95 % confidence) due to antenna positioning.

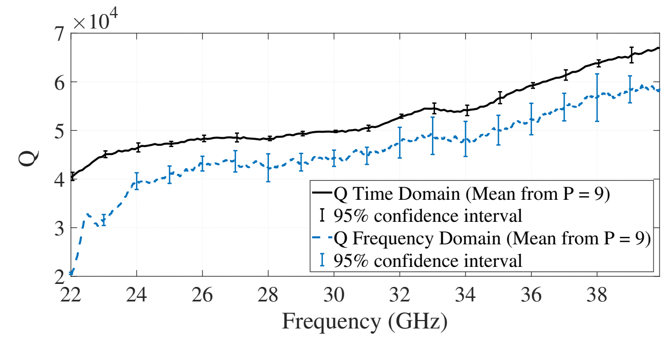

Fig. 3. Best estimate of the Q_{FD} and Q_{TD}, with the uncertainty due to antenna positioning marked with error bars (2σ, 95 % confidence). Q_{FD} is lower since it contains antenna losses, while Q_{TD} does not.

shown in Fig. 3. We show the average of all positions (900 samples) as a best estimate, and we show the 2σ deviation (95 % confidence interval) due to the deviation between positions with error bars.

Compared to measurements in reverberation chambers that operate in a lower frequency range, the chamber decay time, Q_{TD} and Q_{FD} of unloaded mm-wave RCs are significantly lower, as was also the case in [1]–[3], [6] (Q_{FD} is lower than Q_{TD} since it includes antenna losses). This means that a signal transmitted in a mm-wave chamber such as the one used in this work still reaches the noise floor over three times faster than the chambers used in [4]. This may be due to leakage or increased material losses, however, note that the latter is partially compensated for by reducing the size of the chamber. When the chamber decay time decreases, for example due to losses or leakage, it becomes increasingly challenging to differentiate chamber loss from other types of loss when they are very small (for example materials that have a small loss tangent, permittivity or surface). However, other works have shown promising results in mm-wave chambers with chamber losses in the same order or lower [1]–[3].

In this chamber, τ_{RC} decreases between 23 to 31 GHz, and stabilizes after, while both Q_{TD} and Q_{FD} increase. This may be attributed to the fact that the equations for Q_{TD} and Q_{FD} contain a correction for frequency, while τ_{RC} does not. Nonetheless, all metrics show that the ideal operational frequency range of this novel mm-wave chamber can be extended further than 40 GHz.

Fig. 3 shows that the standard uncertainty due to antenna positioning of Q_{TD} and τ_{RC} (approximately 0.04 dB, σ) tends to be significantly smaller than that of Q_{FD} (approximately 0.1 dB, σ). The standard uncertainty (σ) due to a lack of spatial uniformity in this chamber is approximately 0.04 dB. The higher uncertainty in Q_{FD} may be attributed to the dependence on antenna losses, which may vary due to its proximity to the walls and stirrers. Earlier work has also shown that Q_{TD} and τ_{RC} are much less affected by positional changes when lossy material is added to the chamber (proximity effect) [7]. The low uncertainty of these metrics computed in the time domain makes them an ideal candidate to measure, with a high accuracy, any type of loss that occurs in the RC, such as the ACS of material samples.

III. Conclusion

In this work, we presented results of a novel mm-wave reverberation chamber, where we focused on assessing its performance by using the chamber decay time, or time constant, and the Q computed in both the time and the frequency domain. For the first time, we have shown that these time-domain metrics in a mm-wave chamber have a significantly lower uncertainty due to antenna positioning, 0.04 dB, as compared to their frequency-domain counterparts, 0.1 dB. While the chamber decay time and Q are approximately three times lower for the chamber in this work and other mm-wave reverberation chambers when compared to lower-frequency chambers, they can still function as ideal candidates for assessing chamber performance and metrics revolving around losses, such as antenna efficiency or absorption cross section.

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