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De-Embedding Unwanted Radiation from Phased-Array Systems in a Reverberation Chamber

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***Abstract*—In this work, we analyze for the first time antenna-efficiency measurements of a mm-wave phased-array antenna for smartphone applications by use of the reverberation-chamber-based three-antenna method. We measure the efficiency of the total system (array including an RF beamformer), and we introduce a new method to de-embed radiated emissions by other parts of the system from the efficiency result. We compare the measured result to a simulation model and conclude that the reverberation-chamber approach can yield accurate results when unwanted radiation is properly accounted for.**

***Index Terms*—millimeter wave, phased-array system, radiated emissions, reverberation chamber, wireless testing**

I. Introduction

An important metric to quantify loss management in phased-array systems is the antenna efficiency [1]. A very effective concept to measure antenna efficiency which has gained popularity over the last two decades is the reverberation chamber (RC), which can yield more accurate results when it comes to power-based metrics such as total radiated power or antenna efficiency when compared to its anechoic counterpart [2], [3].

Some previous works have measured the efficiencies of phased-array systems in a reverberation chamber [4]–[6]. Most were performed in the sub-6 GHz band, and only one performed measurements in the FR2 band by use of a total-radiated power measurement [6]. Nonetheless, to the authors' best knowledge, no works have been published on directly measuring the efficiency of a phased-array-antenna system in the FR2 band using general RC-based antenna-efficiency methods such as the three-antenna method [2]. Also, previously published works do not distinguish radiation created by the antenna and radiation originating from other parts of the system.

In this work, we show for the first time measurements of a phased-array system in a recently developed mm-wave reverberation chamber, using the well-known three-antenna method [2]. We introduce a new method for de-embedding the unwanted radiation caused by other components of the system, such as the RF beamformer, and compare this method with the conventional approach. In Section II, we describe the experimental setup and our new method for de-embedding unwanted radiated emissions, including results, and the work is concluded in Section III.

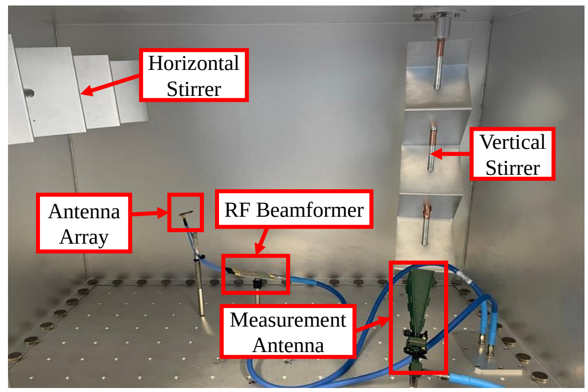

Fig. 1. Setup of the phased-array system in the mm-wave RC.

II. Experimental Results and De-embedding the RF Beamformer

For all measurements in this work, we used a 0.213 m^3 mm-wave reverberation chamber with 100 independent mode-stirring samples (see Fig. 1 for the setup). We measured in the 26.5-30.5 GHz band, using an end-fire antenna array with eight ports, optimized for operation at 28 GHz as the antenna under test (AUT). RF beamforming was performed using a 1:8 Wilkinson splitter (WS) to realize a broadside beam, as shown in Fig. 2. We used two standard-gain horn (SGH) antennas (26.5-40 GHz) as reference antennas. The measurements were performed using a vector network analyzer (VNA) with an IF BW of 1 kHz, 200 kHz frequency spacing, 10 μs dwell time, and 0 dBm stimulus power. For validation, we compare the results with simulations of the antenna, extracted from time-domain simulations using CST Microwave Studio.

We estimate the antenna efficiency of the total phased-array-antenna system using the non-reference RC-based three-antenna method, extensively explained in [2]. We then estimate the efficiency of only the antenna array by de-embedding the RF beamformer including cables using a similar approach as presented in [5]. However, this approach and other generic de-embedding methods assume that all losses of the RF beamformer are thermal and that no power is radiated by it. Unwanted radiation could add to the total radiated power of the system and could result in an overestimation of the efficiency of the antenna when de-embedding the RF beamformer.

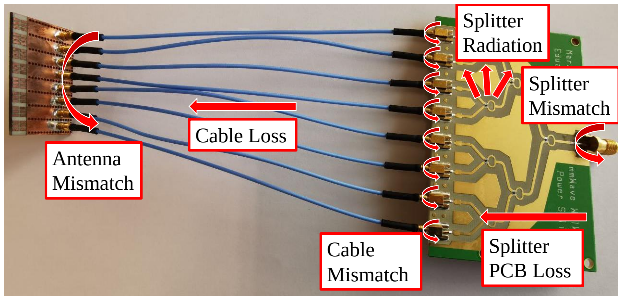

Fig. 2. The phased-array system that is placed inside the reverberation chamber, consisting of a phased-array antenna, cables, and a Wilkinson splitter with various losses quantified.

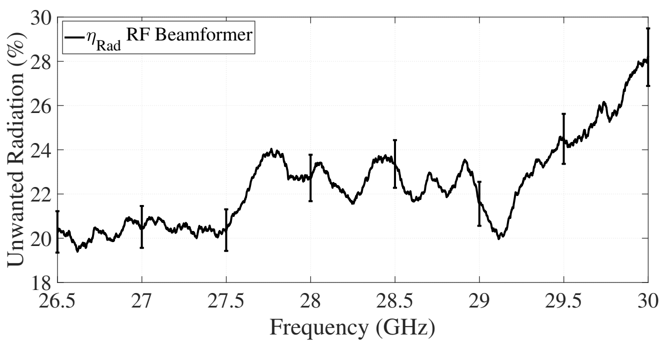

Fig. 3. Radiation efficiency of the RF beamformer to characterize its unwanted radiation. The error bars correspond to the 95 % confidence interval.

Especially in a reverberation chamber, conventional methods do not allow for distinguishing different sources of radiation. Therefore, we extend the conventional de-embedding approach to include the radiation losses of the rest of the system as follows

$$\eta_{\text{Antenna}}^{\text{tot}} = \frac{\eta_{\text{TS}}^{\text{tot}} - \eta_{\text{WS}}^{\text{tot}}}{L_{\text{PCB,WS}} L_{\text{Mism,Cable}} L_{\text{Cables}} L_{\text{Mism,WS}} (1 - \eta_{\text{WS}}^{\text{rad}})}, \quad (1)$$

where L corresponds to the losses due to various contributions, as shown in Fig. 2, and where $\eta_{\text{WS}}^{\text{tot}}$ is the total antenna efficiency (including mismatch) of the RF beamformer, corresponding to its unwanted radiation. $\eta_{\text{TS}}^{\text{tot}}$ is the total efficiency of the total system. We measured the radiated emissions of the splitter by measuring its radiation efficiency using the three-antenna method, where all ports were terminated in 50-Ohm loads. The unwanted radiated emissions of the RF beamformer are shown as the radiation efficiency in Fig. 3. The errorbars correspond to the 95 % confidence interval, extracted from the standard deviation from nine measurements, multiplied by a 2.26 coverage factor. This measurement was verified by evaluating the efficiency of the two SGH antennas compared to a reference, but not shown here for the sake of brevity.

The measured and simulated antenna-efficiency results are shown in Fig. 4. We show the efficiency of the full setup, and that of the antenna alone, where the splitter and cables were de-embedded using the conventional approach, and the approach using (1). As expected, the efficiency estimate is higher for the antenna alone (when the splitter is de-embedded) as compared to the full system. It can be seen that the efficiency is significantly overestimated using the conventional approach (the efficiencies are above 200 %). However, when considering unwanted radiation, it is very close to the simulated values (within 0.5 dB), showing the accuracy of this method, and the necessity of taking unwanted radiation into account.

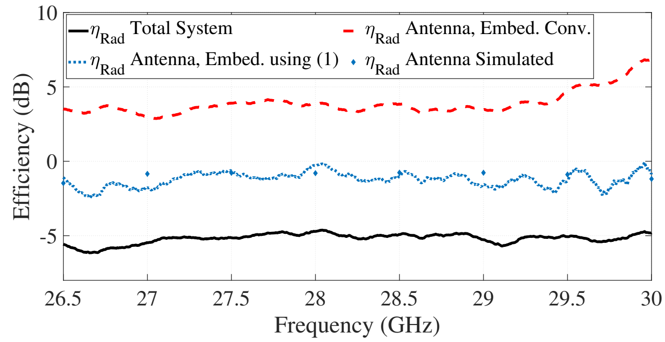

Fig. 4. Estimated radiation efficiencies in dB of the total system (TS) (black curve) casing, and of the antenna with de-embedded splitter and cables using the conventional way (red-dashed curve) and using (1) (blue-dotted curve), compared to simulations (blue-diamond marked). Note that the conventional way of de-embedding yields a wrong estimate above 100 %.

III. Conclusion

In this work, we have shown for the first time reverberation-chamber antenna-efficiency measurements of a passive phased-array system at mm-wave frequencies. We introduced a new way of de-embedding radiated emissions from other components of the system to obtain the antenna efficiency, since conventional methods would overestimate the efficiency by approximately 4-5 dB (over 100 % absolute overestimation) for this specific system. The measured results using this method are within 0.5 dB of the simulated results. Therefore, we conclude that the three-antenna method can be a suitable solution to measure phased-array antennas, and that the new way of de-embedding yields significantly more accurate results as compared to conventional de-embedding methods.

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