On Free-Space Antenna Reflection Phase Measurements in a Reverberation Chamber

L.A. Bronckers, A. Roc'h and A.B Smolders
Department of Electrical Engineering
Eindhoven University of Technology
Eindhoven, The Netherlands

***Abstract*—A reverberation chamber is a very useful tool to obtain the radiation efficiency of an antenna. While it has been shown that the magnitude of the reflection coefficient can be obtained from these measurements as well, this has not yet been shown for the phase of the reflection coefficient. This would allow for a full characterization of the antenna's behavior as seen from its input port. In this paper it is shown that the phase of the free-space reflection coefficient can be obtained from measurements in a reverberation chamber by taking the angle of the ensemble average of the individual reflection coefficients. This has been empirically verified by comparing several sets of measurement data from the reverberation chamber to their anechoic chamber equivalents for several antennas.**

I. Introduction

An important characteristic of measured S-parameters in a reverberation chamber (RC) is that the absolute value of the ensemble average should match the absolute value of a single measurement in an anechoic chamber (AC), if a sufficient amount of independent samples is taken in the RC [1], [2]. This allows one to obtain all required data for antenna efficiency measurements in the RC, without requiring one to perform a separate test in an anechoic environment. This principle has been verified up to 6 GHz [1]. For the design of a matching circuit for the antenna under test, it would be very useful to also obtain the phase of the reflection coefficient. However, to the best of the authors' knowledge, no comparison has yet been made with respect to the phase of the reflection coefficient. In this paper an expression to obtain the free-space reflection coefficient phase from reverberation chamber measurements is given and verified. In Section II the theory is discussed and the experiment is described, followed by the results and discussion in Section III and a conclusion in Section IV.

II. Theory and Experiment

In most applications, the antenna will radiate into free-space, which has an impedance derived from Maxwell's equations given by $\eta_0 = \frac{E}{H} \approx 377\Omega$. Therefore it is desirable to perform measurements under this condition. Meanwhile, for an ideal reverberation chamber, it has been shown that [2]:

$$\eta_0^2 = \frac{\langle|\vec{E}(\vec{r}_1)|^2\rangle}{\langle|\vec{H}(\vec{r}_2)|^2\rangle}, \tag{1}$$

where $\langle\cdot\rangle$ denotes the ensemble average, $\vec{E}$ and $\vec{H}$ are electric and magnetic field and $\vec{r}_1$ and $\vec{r}_2$ are arbitrary locations within the working volume. Equation 1 was also verified in the 200-500 MHz region using field probes [3]. As $\vec{r}_1$ and $\vec{r}_2$ are arbitrary locations, they can also to be the same. Thus, if the ensemble average is taken, the ratio of the electric and magnetic fields is equal to the free-space impedance in an ideal RC. Therefore, the antenna should, on average, 'see' the free-space impedance. Since the antenna can be assumed to be linear and reciprocal, this means that its reflection coefficient should converge towards the free-space reflection coefficient. Defining $S_{11,RC}$ as a single complex reflection coefficient obtained in the reverberation chamber, and $S_{11,AC}$ as a complex reflection coefficient obtained in an anechoic chamber, it has already been demonstrated that [1], [2]:

$$|\langle S_{11,RC}\rangle| = |S_{11,AC}|, \tag{2}$$

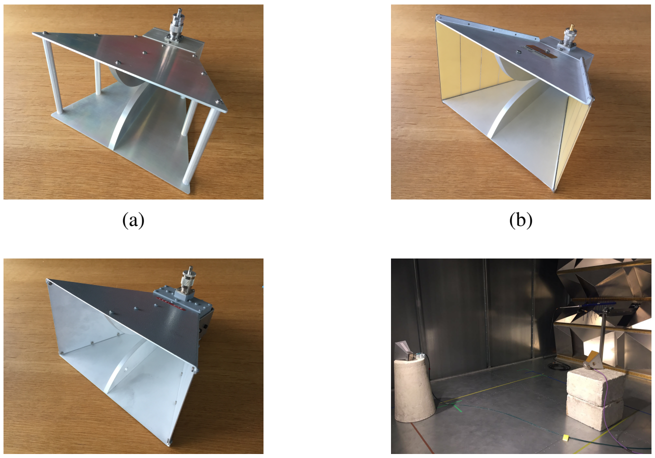
which confirms that at least the absolute value of the reflection coefficient in the RC converges towards the absolute value of the free-space reflection coefficient, allowing one to compensate for impedance mismatch in antenna efficiency measurements. From (1) and the reasoning above, the following should also hold:

$$\phi(\langle S_{11,RC}\rangle) = \phi(S_{11,AC}), \tag{3}$$

where $\phi(\cdot)$ signifies taking the phase. In words, that the phase of the ensemble average of the measured reflection coefficients in the RC converges towards the free-space reflection phase of the antenna. The equality introduced in (3) will be verified experimentally by comparing measurement results from the RC to those from the AC.

The antennas used for the experimental verification are three double-ridged horns, namely a Com-power AH-118, referred to as horn A [4]), an EMCO 3115, referred to as horn B [5]) and a Schwarzbeck BBHA-9120-D, referred to as horn C [6]). They are shown in Fig. 1a, 1b and 1c, respectively. All antennas have return loss higher than 7 dB across the 1-6 GHz band that is used, except for Horn A which peaks to 5.8 dB at 1.9 GHz.

The VNA is calibrated up to the antenna connectors for both measurements in RC and AC. The antennas are positioned in the reverberation chamber at Eindhoven University of Technology. This is a 4.05 x 5.7 x 3.15 m^3 room that uses a folding wall as stirring mechanism [7], as shown in Fig. 1d, with $N = 100$ different positions in a linear fashion. The measurements are performed in tuning mode. In addition,



(a) (b) (c) (d)

Fig. 1. Horn A (a), Horn B (b) and Horn C (c), including their SMA adaptors, and the setup in the RC (d).

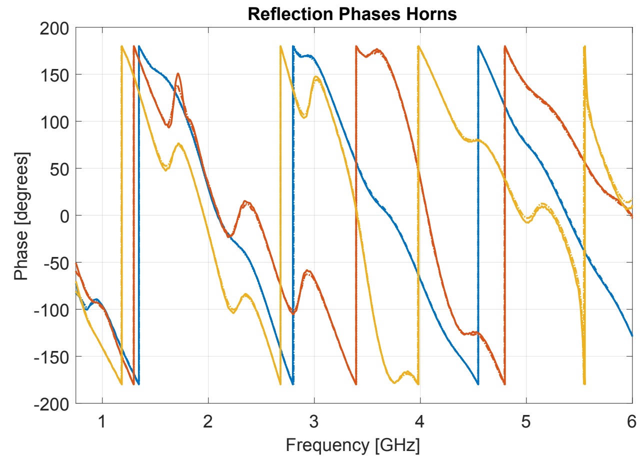


Fig. 2. Measured phases of input reflection of Horn A (blue), B (red) and C (yellow). Results from the anechoic chamber are shown in solid lines, while the measurements from the reverberation chamber are shown in dotted and dashed lines.

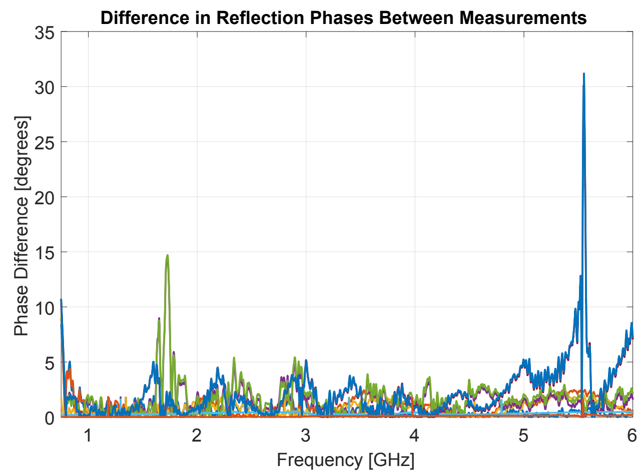


Fig. 3. Differences between all measured phases.

frequency-stirring over a 100 MHz bandwidth is performed. In the AC the horns are placed one at a time, facing at least 3 m of free space before encountering an absorber. Each of the antennas is measured twice in the RC and once in the AC.

III. Results and Discussion

The results of the measurements are shown in Fig. 2 for all three horns. Each of the horns exhibits a distinct behavior, which is to be expected as they are only conceptually similar, being quite different in their execution. In the figures it can be seen that the curves for all measurements overlap; it is quite difficult to distinguish the dashed and dotted lines of the RC measurements from the solid lines of the AC measurements. Therefore, the phase differences between the measurements are shown in Fig. 3. In this figure it can be observed that, except for inaccuracy peaks for some of the measurements around 1.7 GHz and 5.6 GHz, the differences remain below 5%. As the phase accuracy of the open and short standards in the calibration kit used are guaranteed within $\pm 2.0\,\mathrm{deg}$ [8] and some cables were moved between calibration and measurement, it seems likely that the differences are due to measurement inaccuracies.

IV. Conclusion

In this paper it is shown that the phase of the free-space reflection coefficient can be obtained from measurements in a reverberation chamber. This can be done by taking the angle of the ensemble average of the indidivual reflection coefficients, which has been empirically verified by comparing several sets of measurement data from the reverberation chamber to their anechoic chamber equivalents for several antennas. The difference between the measurements is found to be sufficiently small to conclude that the phase of the free-space reflection coefficient can indeed be derived from reverberation chamber measurements. This means that the antenna's behavior at its input port can be fully characterized in a reverberation chamber, allowing for instance the design of a matching network.

References

[1] C. L. Holloway, H. A. Shah, R. J. Pirkl, W. F. Young, D. A. Hill, and J. Ladbury, "Reverberation Chamber Techniques for Determining the Radiation and Total Efficiency of Antennas," *IEEE Trans. Antennas Propag.*, vol. 60, no. 4, pp. 1758–1770, apr 2012.

[2] D. A. Hill, *Electromagnetic Fields in Cavities*. Hoboken, NJ, USA: John Wiley & Sons, Inc., sep 2009, vol. 43, no. 08.

[3] G. H. Koepke and M. L. Crawford, "Design, evaluation, and use of a reverberation chamber for performing electromagnetic susceptibility/vulnerability measurements," 1986.

[4] Com-Power Corporation, "Double Ridge Horn AH-118 Datasheet."

[5] ETS-Lindgren, "Double-Ridged Waveguide Horn Antennas Datasheet."

[6] Schwarzbeck Mess-Elektronik, "BBHA-9120-D Datasheet."

[7] R. Serra, A. C. Marvin, F. Moglie, V. M. Primiani, A. Cozza, L. R. Arnaut, Y. Huang, M. O. Hatfield, M. Klingler, and F. Leferink, "Reverberation chambers a la carte: An overview of the different mode-stirring techniques," *IEEE Electromagn. Compat. Mag.*, vol. 6, no. 1, pp. 63–78, 2017.

[8] Maury Microwave Corporation, "TC-CK-35 3.5mm Instrument-Grade VNA Calibration Kit," p. 91764, 2010.