Passive reconstruction of the impulse response between two antennas in a reverberation chamber

Reconstruction passive de la reponse impulsionnelle entre deux antennes en chambre réverbérante

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Abstract:
The impulse response between two receiving antennas can be retrieved via cross-correlation techniques leveraging field uniformity within a reverberation chamber (RC). Exploiting the diffuse wave field generated by rotation of a mechanical mode stirrer inside an RC excited by a single transmitting antenna, we demonstrate the convergence of the cross-correlation toward the impulse response between the two receiving antennas. The obtained experimental results show that it is possible to characterize passively the coupling between two antennas in an RC.

Resumé:
La réponse impulsionnelle entre deux antennes en réception peut être récupérée via des techniques d'inter-correlation dans une chambre réverbérante (CR). En exploitant le champ diffus généré par la rotation d'un brasseur de modes mécanique à l'intérieur d'une CR excitée par une seule antenne émettrice, nous démontrons la convergence de la fonction d'inter-corrélation vers la réponse impulsionnelle entre les deux antennes réceptrices. Les résultats expérimentaux obtenus montrent qu'il est possible de caractériser passivement le couplage entre deux antennes dans une CR.

1 Introduction

The field of wireless communications is constantly evolving. This considerable growth has spawned huge needs in terms of developing new characterization techniques to measure the performance of antennas. For many applications, the coupling between receiving antennas should be estimated. When, the antenna are embdeded in a complex system, it can be difficult, if not impossible to measure the direct responses between the antenna ports. Here we propose to validate the principle of a passive method based on the field cross-correlation in a Reverberation Chamber (RC). We exploit the properties of the RC to generate a diffuse field using a single source and a mechanical mode stirrer. Averaging over different realizations, the reconstructed signal is expected to converge towards the impulse response between two receiving antennas. This technique allows to passively characterize the two receivers and can be extended later to characterize an antenna network as in the MIMO case.

2 Cross-correlation function and impulse response

The relation between the transfer function and the correlation function is reflected by the fact that under the assumption of a diffuse field, the correlation of the signals recorded by two passive sensors contains essentially the same information on the medium as the signal that one would have acquired, if one of these sensors was active (transmitter) and the other was passive (receiver). In the case of a diffuse field, the correlation function converges to a function proportional to the sum of the causal and anticausal transfer functions between two sensors. This method was developed in different areas of theoretical and experimental physics and it has been applied to all types of waves (seismic [1], acoustic [2], elastic [3] and electromagnetic [4]).
The cross-correlation function C_{ab} between two points a and b can be obtained in the frequency domain from the measured impedance parameters Z using (1). The correlation function obtained has a part with positive times (or causal part) and a part with negative times (anti-causal part).

$$C_{ab}(f) = \sum_k Z_{ak} Z^*_{bk} \tag{1}$$

with

k=source index

In the following, a single source is used and the different excitation configurations are generated by rotating the mode stirrer, so the sum applies on the different stirrer positions.

3 Experimental Setup

The experiment was made in an RC (2.751m x 2.951m x 2.354m, LUF around 400 MHz) as depicted in Fig. 1. The antennas under test (AUT) are two horn antennas (a and b) facing each other used in receiving mode and separated with a distance of 44 cm. The source antenna (c) is directed to a mechanical mode stirrer in order to generate a diffuse field. The measurements are carried out at 100001 frequency points uniformly spaced on the frequency band of [1-4] GHz for 60 regularly space stirrer positions over a whole rotation.
In order to study the convergence of the correlation function towards the estimated impulse response between the two receiving antennas, we examine the influence of the spacing between AUT. The antenna a is fixed, we move the antenna b so that the distance between both antenna apertures varies from 44 cm to 64 cm with a step of 10 cm.

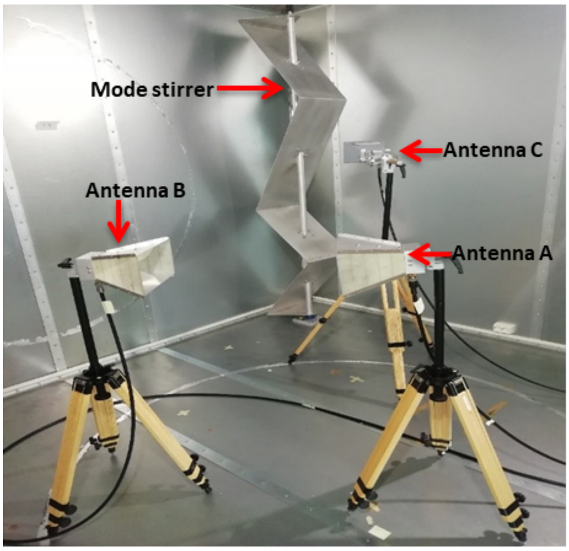

Figure 1 – Experimental setup in ESYCOM laboratory RC.

4 Results

Once the measurement data have been recovered, they are processed in the frequency domain because the calculation of the frequency correlation function is faster. First, we eliminate the amplitude information from the Z_{ij} parameters by working only with the information contained in the phase Φ_{ij} of the signals. This allows for equivalent contributions from all frequencies in the working band. The effectiveness of phase information has already been demonstrated in [5].
Let Z' in (2) be the new parameters taking into account only the phase information, the indices a and b for the receiving antennas, and c for the source antenna. The C_{ab} cross-correlation is then calculated as in (3). The cross-correlation function is then converted in the time domain using an inverse Fourier transformation and it is averaged over the different stirring positions and excitation antenna orientations.

$$Z'_{ij}(f) = \exp\left(j.\Phi_{ij}\right) \tag{2}$$

and :

$$C_{ab}(f) = Z'_{ac}{Z'_{bc}}^{*} \tag{3}$$

Fig. 2 shows the real part of results obtained by calculating the correlation function (blue curve) and by direct measurement of the impulse responses between the antennas a and b (red curve for causal part and green curve for anticausal part). As expected, the results obtained are roughly superimposed and the cross-correlation function converges towards the mean impulse response between the antennas so that we can recover the ballistic wave and the first echoes in the RC.

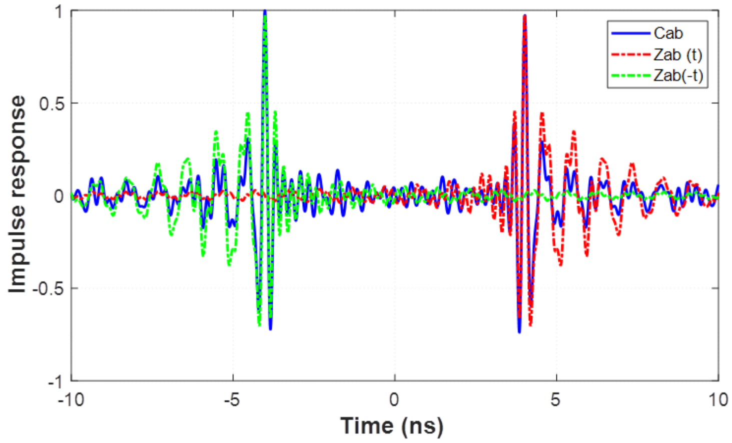

Figure 2 – Calculated cross-correlation function (blue) and measured impulse responses (red and green) in the time domain.

In order to see the measurement dynamics and after having applied an adequate time window between 3.49 ns and 10 ns to eliminate the first echoes while keeping the useful signal corresponding to the transfer function between antennas a and b, the results obtained for the correlation function and the direct measurement are normalized and plotted in dB (Fig. 3).The order of magnitude of the Zab frequency variation is recovered by the cross-correlation function.

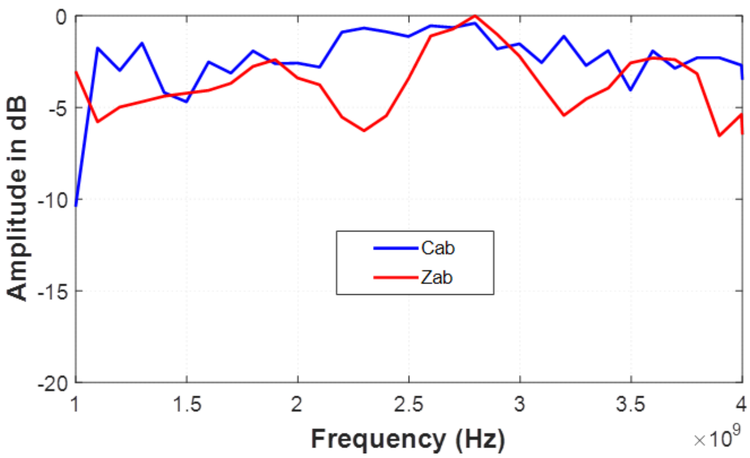

Figure 3 – Calculated cross-correlation function (blue) and measured response (red) in the frequency domain.

The result obtained for three different spacings between the AUT is shown in Fig. 4. Two peaks clearly appear and correspond to causal (the part with positive times) and anticausal (part with negative times) impulse responses. The position of the two symmetric peaks is translated towards larger times (in absolute value) when increasing the distance between both antennas. We can verify that, as expected, the peak position displacement between two consecutive measurements corresponds to a distance variation of 10 cm.
The symmetry obtained is a good indicator of the cross-correlation convergence. Note that when the distance between the AUT increases, the measurement becomes more sensitive to external interferences due to the decrease of the direct path amplitude. As the presented results in Fig. 4 are normalized to keep the maximal amplitude equal to one, this effect is noticeable on the symmetry of the time response. The further the receiving antennas are, the more slowly the cross-correlation converges to the theoretical response.

5 Conclusion

In this communication, we have demonstrated the ability to reconstruct the impulse response between two receiving antennas by computing the cross-correlation of the diffuse field in RC using a single source. We have

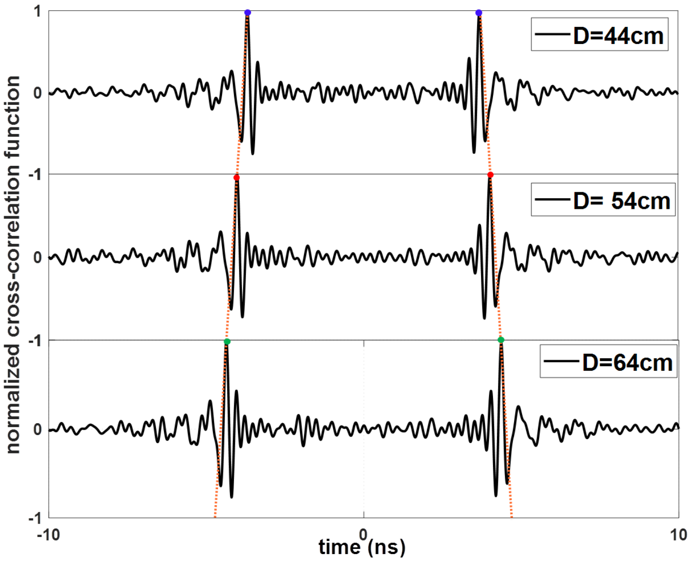

Figure 4 – Cross-correlation function for three different spacings between the two AUT.

presented the measurement results obtained allowing to validate the principle of reconstruction of the impulse response by studying the influence of the spacing between the receiving antennas on the convergence of the field cross-correlation towards the impulse response between the antennas. This approach provides a new framework for applications such as characterizing antennas that can only be used in their receiving mode. As in the case of MIMO network for 5G, in order to characterize the network set, it suffices to exploit the field received on the set of receivers and by post processing to be able to characterize all the network instead of making measurements for each pair of antennas one after the other.

6 References

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