Reflection Coefficient Measurements in the L-Band with Low Directivity Antennas in a Multipath Site

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I. Introduction

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***Abstract*—Reflection coefficient measurements can be performed by using two antennas and a material under test sample of a known radar cross section. At frequencies in the L-band high-directivity antennas such as horn antennas would have large physical size. In this work, we propose a method based on planar, low-directivity antennas. Although they are smaller than horn antennas corrections concerning the effect of the mutual proximity on the mutual coupling and on the global radiation pattern should be taken into account. We also propose a new version of our distance averaging method adapted to radar-type configurations in order to measure the reflection coefficient in a multipath site. Our approach was validated by measurements on a rectangular aluminum plate.**

Keywords—microwave reflection coefficient, L-band, low-directivity antennas, distance averaging method

I. INTRODUCTION

Microwave materials are mostly characterized in terms of permittivity and loss tangent. The properties can be extracted by using two antennas and a material sample [1], and by measuring either the reflection coefficient or the transmission coefficient through the sample. Alternatively, the material under test (MUT) can be included in a microwave circuit such as a resonator [2] or a waveguide mount [3].

Existing measuring techniques based on antennas and a MUT sample placed in a non-anechoic site [1] usually cover frequency ranges in the order of 10 GHz or above, and lenses are used in order to address the field-zone problem and the edge diffraction effect [4].

In a previous work [5], we proposed a deembedding technique for material characterization in a multipath environment, at frequencies ranging from S-band to K_u-band (2 to 18 GHz) based on measuring the mutual coupling between antennas, the reflection coefficient on the sample of material under test, and the reflection coefficient on a conducting plate with the same size as the sample.

At lower frequencies, a large material sample in terms of wavelength is needed. Moreover, the sample should be placed in the far-field zone of the antennas; otherwise the measured reflection coefficient would depend on the distance.

We have previously presented [6], a method for antenna gain evaluation in a multipath environment, based on averaging data measured at different distances between the probe antenna and the antenna under test. Weighting on measured data was solely used to compensate the effects of the propagation, as it would be in the far-field region. Our distance averaging method was also used in order to remove multipath effects for material characterization in a non-anechoic site [5].

In this work, we propose to apply our distance averaging technique for reflection coefficient measurements. As opposed to the previous approach [5], one should not move anymore the entire setup, but to only move the sample away from the antennas. That strategy provides one with data for the distance averaging in order to reduce the multipath effect. Moreover, we measured the reflection coefficient at lower frequencies than in our previous work [5] i.e., in a frequency range including the L-band. Since horn antennas for that frequency range would be physically large (a length typically in the order of 1 m and an aperture width of approximately 0.5 m) we used a pair of Vivaldi dipoles instead. Although much smaller (a size around 20 cm by 20 cm), they exhibit a stronger mutual coupling compared to a pair of horn antennas; a differential approach was therefore needed in order to compensate that disadvantage. A gain figure of the two-antenna system should be evaluated, since the mutual proximity of the antennas impinges on the radiation pattern, compared to other antenna types with a higher directivity (e.g., horn antennas).

Compared to our previous work [5] in which a metal plate has been used for deembeding, no calibration measurement was performed, but a rectangular sample with an a priori known radar cross section (RCS) was employed.

We validated our approach by measuring the reflection coefficient of a rectangular aluminium plate; the result was very close to the theory, despite of the small electrical size of the sample.

II. COEFFICIENT MEASUREMENTS ON AN ELECTRICALLY SMALL SAMPLE

Let us consider a radar type setup (Fig. 1) consisting of a sample of material to be characterized and a set of two identical antennas, one in receiving mode and the other in transmitting mode. The reflection coefficient of the sample, denoted by Γ, is to be found.

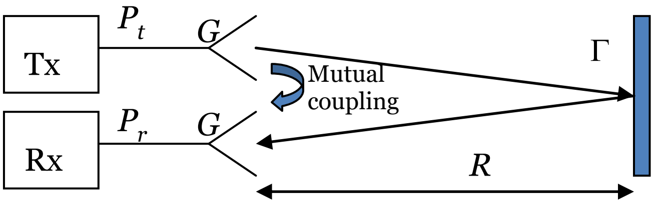

Fig.1 Radar-type setup for material characterization.

The reflection coefficient can then be found from the radar equation [9]

$$\Gamma = \sqrt{\frac{(4\pi)^3 R^4}{A\,G^2\lambda^2}\frac{P_r}{P_t}} \tag{1}$$

where P_t is the transmitted power, P_r is the received power, G is the gain of each antenna, and R is the distance between the target and the antenna system. It should be noted that relation (1) was derived under the hypothesis of the Friis transmission formula [7] i.e., the antennas and the target are infinitely small compared to the distance, both antennas are perfectly impedance matched, and the target range is in the far-field zone [7].

When using a sample of a regular shape (e.g., rectangular) its radar cross section (RCS), denoted by A can be computed analytically, provided the target is in the far-field zone.

The effect of mutual coupling between the antennas should be removed by firstly measuring a transfer factor without sample. Let S_{21}^{total} be the transfer function measured with the sample and $S_{21}^{coupling}$ the same figure measured without sample.

In (2), the effect of the impedance mismatch on both antennas was taken into account [8]. The reflection coefficient can then be found as

$$\Gamma = \sqrt{\frac{(4\pi)^3 R^4}{A\,G^2\lambda^2}\cdot\frac{R_0}{R_a(1-|S_{11}|^2)}}\cdot\frac{\left|S_{21}^{total}-S_{21}^{coupling}\right|}{|1-S_{22}|} \tag{2}$$

where R_0 stands for the normalizing impedance (usually set at 50 ohms) and R_{a2} is the radiation resistance of the receiving antenna.

The RCS for a rectangular sample of a given surface S by considering the conditions in the Friis formula is [9]

$$A = \frac{4\pi S^2}{\lambda^2}\left[\sin\theta\cdot\mathrm{sinc}\left(\frac{2\pi b\cos\theta}{\lambda}\right)\right]^2 \tag{3}$$

For a normal incidence,

$$A = \frac{4\pi S^2}{\lambda^2}\ . \tag{4}$$

Consequently,

$$\Gamma_{\text{far-field}} = \frac{4\pi R^2}{G\cdot S}\cdot\frac{\left|S_{21}^{total}-S_{21}^{coupling}\right|}{|1-S_{22}|}\sqrt{\frac{R_0}{R_a(1-|S_{11}|^2)}} \tag{5}$$

III. Results

We aim to measure the reflection coefficient of a rectangular, aluminum plate in the frequency range 1 to 3 GHz. Referring to the notations in Fig. 2, the plate was a=36.7 cm by b=22.5 cm in size, and the antenna system consists of two Vivaldi dipoles with an aperture $2h_1$=16.8 cm placed parallelly at a distance D=22 cm one from the other (Fig. 2).

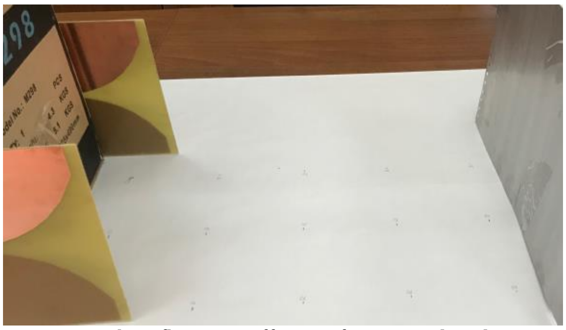

Fig. 2 Measuring the reflection coefficient of a rectangular, aluminum plate of 36.7 cm by 22.5 cm.

Figure 3 shows the variation of the mutual coupling as a function of the frequency.

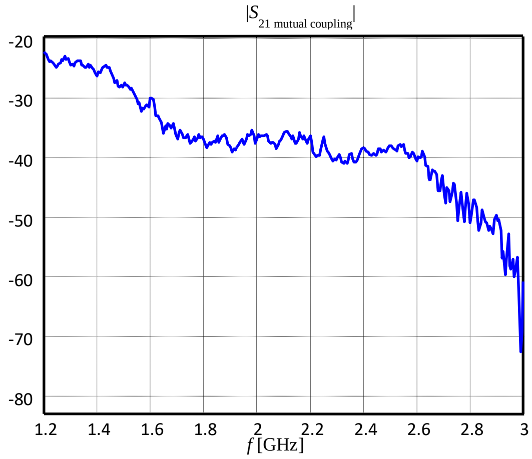

Fig. 3 Variation of the mutual coupling over the frequency of the interest.

In order to remove the multipath effect we adapted the distance averaging method [6], for radar-type measurements (Fig. 1). A modified form of the normalized transfer function was accordingly derived, by multiplying the actual transfer function by the second power of the distance,

$$\bar{S}_{21} = \sum_{k=1}^{N}\left(\frac{R_k}{R_{ref}}\right)^2\left|S_{21\ \text{total}}^{k} - S_{21\ \text{mutual coupling}}\right| \tag{6}$$

where R_k is a set of N distances between the antennas and the sample, R_{ref} is the distance to a reference chosen at 1 m, and $S_{21\ \text{total}}^{k}$ are the corresponding transfer functions before subtracting the transfer by mutual coupling.

The transfer functions for a set of eight distances ranging from 80 cm to 150 cm, and the average transfer function, are given in Fig. 4.

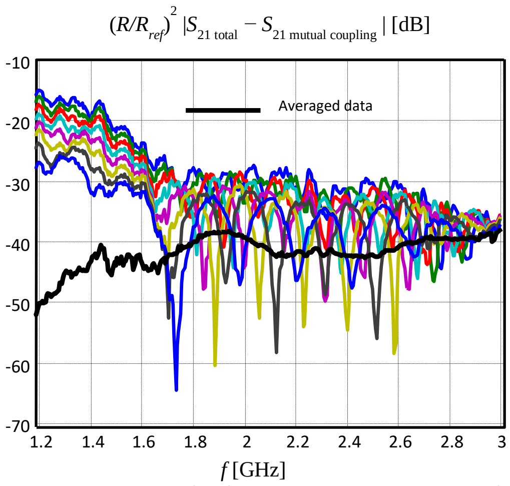

Fig. 4 Normalized transfer functions and averaged data for radar-type measurements.

The resulting reflection coefficient was calculated from (1) both with a gain measured separately on the transmitting and receiving antennas, and with a gain measured on the antenna system, respectively i.e., transmitting and receiving antennas side by side, as they were in the setup for reflection coefficient measurements (Fig. 5).

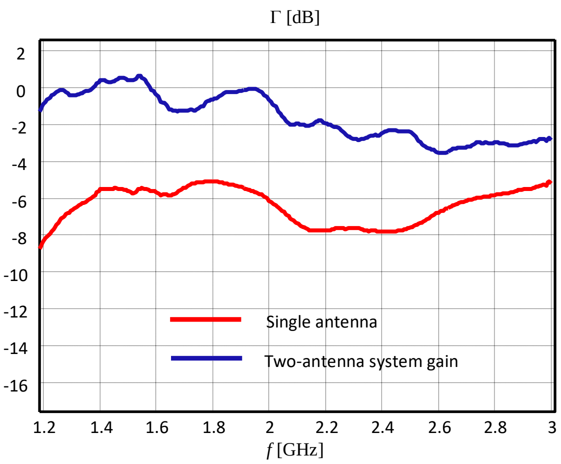

Fig. 5 Reflection coefficient.

It comes out that the mutual proximity of the transmitting and receiving antennas when measuring the gain does not only result in a mutual coupling, but it also significantly changes the global gain figure. That is, the two antennas should not be characterized separately prior to measuring the reflection coefficient, but as a system.

IV. CONCLUSIONS

Low-directivity antennas are generally used when measuring the reflection coefficient at frequencies in the lower part of the microwave range. For the set of Vivaldi-type dipoles that we used for validation the mutual coupling can reach 20 dB; however, our differential approach could successfully compensate it. The mutual proximity of the transmitting and receiving antennas results in discrepancies of the gain figures of up to 5.5 dB and we showed that antennas should be characterized as a system and not separately. Multipath propagation induces magnitude variations on the measured, normalized transfer functions of more than 30 dB when using a regular room in a building as measuring site. We adapted our distance averaging method to reflection coefficient measurements and thus, the multipath propagation effects dramatically diminished.

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REFERENCES

[1] L. Rocha, C. Junqueira, E. Gambin, A. Vicente, A. Culhaoglu, E. Kemptner, “A free space measurement approach for dielectric material characterization”, SBMO/IEEE MTT-S International Microwave & Optoelectronics Conference (IMOC), pp.1 – 5, 2013.

[2] O. Siddiqui, R. Ramzan, M. Omar, M. Amin, “Phase sensing- A novel material characterization method”, International Conference on Electrical and Computing Technologies and Applications (ICECTA), pp. 1– 4, 2017.

[3] X. Hao, L. Weijun, G.Qiulai, “A new dual-channel measurement method for accurate characterization of low-permittivity and low-loss materials”, IEEE Transactions on Instrumentation and Measurement (Early Access), pp.1–10, 2018.

[4] M. H. Umari, D. K. Ghodgaonkar, V. V. Varadan, V. K. Varadan, “A free-space bistatic calibration technique for the measurement of parallel and perpendicular reflection coefficients of planar samples”, IEEE Transactions on Instrumentation and Measurement, pp. 19 – 24, 1991.

[5] L. Pometcu, A. Sharaiha, R. Benzerga, R. D. Tamas, Ph. Pouliguen, “Method for material characterization in a non-anechoic environment”, Applied Physics Letters, American Institute of Physics (AIP), vol. 108, 2016.

[6] R.D. Tamas, D. Deacu, G. Vasile, C. Ioana: “A method for antenna gain measurements in nonanechoic sites”, Microwave and Optical Technology Letters, John Wiley & Sons Inc. (SUA), vol. 56, No.7 pp.1553-1557, July 2014.

[7] C. A. Balanis, Antenna Theory – Analysis and Design, 3rd edition, Wiley, New York, 2005, pp. 94-96.

[8] L. Anchidin, R. D. Tamas, A. Androne, G. Caruntu, “Antenna Gain Evaluation Based on Weighting Near-Field Measurements”, IEEE International Workshop on Antenna Technology (IWAT 2017), 1-3 March 2017.

[9] L. Ridenour, Radar Systems Engineering, McGraw-Hill, 1947, pp. 18-62.