Antenna Efficiency Measurements without Reference Antenna in RC: Application to Textile PIFAs

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***Abstract*— A new method for antenna efficiency measurement in reverberation chamber (RC) is presented, it is based on the acquisition of the electrical field strength (E-field). This E-field method is to the RC what the gain/directivity radiation pattern method is to anechoic chambers. The advantage is that there is no need for reference antenna. The paper is primarily intended to mobile antenna designers who have to characterize their antenna efficiency in multipath and stochastic environments.**

Keywords-component; Antenna efficiency, reverberation chamber, PIFA antennas

I. INTRODUCTION

The radiation efficiency value of antennas mounted on RFID (Radio Frequency IDentification) equipment, cellular mobile phones or wireless communication equipment such as Bluetooth or Wifi (Wireless fidelity) is an important component of the link budget. The higher the efficiency, the larger the communication range, the longer the battery lifetime, and the lower the communication errors. Antennas such as the PIFA (Planar Inverted-F antenna), short whip or RFID tags exhibit an approximate efficiency of 65 % and operate within the 800-2400 MHz frequency range.

Several methods are used to measure the efficiency, like the one proposed by Wheeler in 1959 [1]. Integrating the measured antenna gain over all 4π steradians of a spherical surface, and dividing by 4π is another way to find the antenna efficiency. This method is called gain/directivity or radiation pattern method and gives good results if we accept an accuracy of ± 20 % in comparison to ± 2% with the Wheeler one, and the costly measurement platform.

Remembering that communication equipment is mostly used in urban areas or indoor environments where a lot of waves are coming in from almost all directions on the antenna, the use of a reverberation chamber becomes evident.

II. THEORY

A. *Definition*

Antenna efficiency is defined as the total radiated power divided by the total input power, when the antenna is assumed to be impedance matched [2]:

$$\eta = \frac{P_r}{P_r + P_l} \tag{1}$$

where:

- P_r is the total radiated power;
- P_l is the power lost in conductors and dielectrics;
- $P_r + P_l$ is the total power at the antenna terminals.

It is important to make the distinction with the *total antenna efficiency* which takes into account the impedance mismatch :

$$\eta_T = \eta \times (1 - S_{11}^2) \tag{2}$$

where S_{11} is the reflection coefficient of the antenna (and the well-known scattering parameter). $(1 - S_{11}^2)$ is called the impedance mismatch efficiency and is ≥ 90 % for satisfactory antenna impedance matching ($S_{11} \leq$ -10 dB).

B. *Relative method (with Reference antenna)*

The average power received by an impedance-matched reference antenna given by Hill [3], can be generalized to an antenna for which $S_{11r} \neq 0$ as follows:

$$\left\langle P_{Rr} \right\rangle = \frac{\left\langle E_0^2 \right\rangle}{Z_0} \times \frac{\lambda^2}{8\pi} \times \eta_r \times \left(1 - S_{11r}^2\right) \tag{3}$$

where :

- $\left\langle P_{Rr} \right\rangle$ is the ensemble average of the power received at the Reference antenna terminals;
- $\left\langle E_0^2 \right\rangle$ is the ensemble average, over one stirrer scan, of the square electric field in the RC;

- Z_0 is the free space plane wave impedance (=377 Ohm);
- λ is the operating wavelength;
- S_{11r}^2 is the square reflection coefficient of the Reference antenna.

For the unknown antenna (with $S_{11u} \neq 0$), we have :

$$\langle P_{Ru} \rangle = \frac{\langle E_0^2 \rangle}{Z_0} \times \frac{\lambda^2}{8\pi} \times \eta_u \times \left(1 - S_{11u}^2\right) \quad (4)$$

where :

- $\langle P_{Ru} \rangle$ is the ensemble average of the power received at the unknown antenna terminals;
- S_{11u}^2 is the square reflection coefficient of the unknown antenna.

By dividing (4) by (3), we obtain:

$$\eta_u = \frac{\langle P_{Ru} \rangle}{\langle P_{Rr} \rangle} \times \frac{\left(1 - S_{11r}^2\right)}{\left(1 - S_{11a}^2\right)} \times \eta_r \quad (5)$$

For further computation of our radiation efficiency, equation (5) will be used.

C. E-field method (without Reference antenna)

Solving (4) for η_u gives:

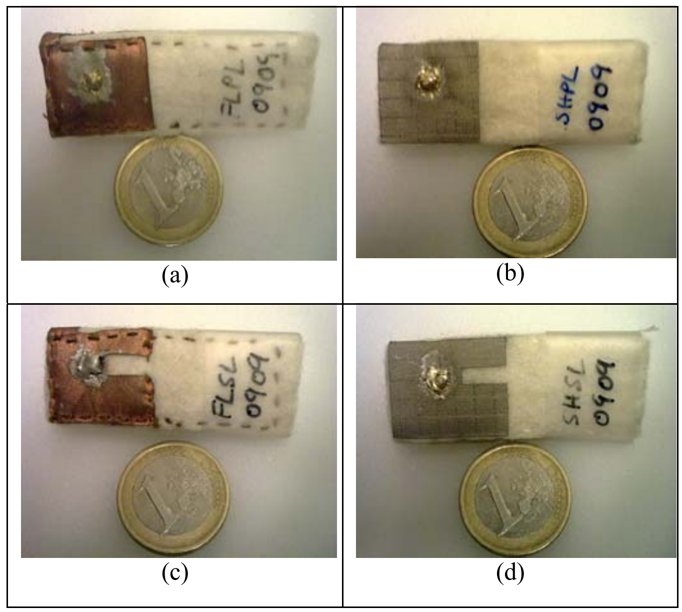
$$\eta_u = \frac{\langle P_{Ru} \rangle}{\langle E_0^2 \rangle / Z_0} \times \frac{1}{\lambda^2 / 8\pi} \times \frac{1}{\left(1 - S_{11u}^2\right)} \quad (6)$$

The discussion about (6) is the following: the radiation efficiency is presented as the ratio of the average power received at the antenna terminals divided by the average scalar power density $\langle E_0^2 \rangle / Z_0$ in the space occupied by the antenna. This gives a result in square meters. If we divide this result by the effective area (in square meters) of the antenna $\lambda^2 / 8\pi$ taking into account a polarization mismatch factor of ½, as justified in [4] and with G=1 (the antenna is considered isotropic in a reverberating multipath environment), we obtain a dimensionless value, just as the radiation efficiency is. This means that measuring and averaging the E-field makes it possible to obtain the radiation efficiency without the need of any Reference antenna.

III. MEASUREMENT SET-UP

We choose to measure the efficiency of some PIFA antennas made from ShieldIt (SH) and Flectron (FL) conductive textiles. Both are sourced from LessEMF USA, and possesses surface resistivities, R_s, of less than 0.05 Ω/sq. Both textiles are polyester-based fabric coated using copper (Flectron) and both copper and nickel (for ShieldIt fabric). The thickness, *t*, of Flectron is estimated at 0.08 mm, and ShieldIt is about twice of the former, 0.17 mm. The PIFAs' design, optimization and simulated efficiencies are gathered from CST Microwave Studio.

Two topologies of the antennas were tested in this work. One is PIFA with a plain radiator (labeled as SHPL for ShieldIt fabric and FLPL for Flectron), while another incorporates a notched radiator (labeled as SHSL for ShieldIt and FLSL for Flectron). The operating frequencies of these antennas are at 2.4 GHz, which is also the frequency of efficiency measurements. The summary of the topologies are given in Fig.1.



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

Fig. 1: (a) Plain Flectron PIFA (FLPL); (b) Plain ShieldIt PIFA (SHPL); (c) Slotted Flectron PIFA (FLSL) and (d) Slotted ShieldIt PIFA (SHSL)

We use the 2.48x2.48x2.48 m^3 RC of LEMA, with a LUF (Lowest Usable Frequency) of 800 MHz. The source-mode tuner consists of two rails. The horizontal one is 2.48 m long and the vertical one is 2.08 m long . On each rail a transmitting LPDA (Log Periodic Dipole Antenna) directed towards the walls of the chamber is moving. [5] gives an extensive description of the RC. The spatial uniformity is 2 dB for less for 150 samples and, maximum 2.5 dB for 24 samples.

A. General considerations

a) The reference and the unknown antennas have been placed inside a parallelipipedic volume (1.2 m long, 0.9 m wide and 0.6 m high). It is at a distance of least 0.6 m from the vertical walls, 1 m from the floor and 0.88 m from the ceiling, so the separation distance is kept higher than λ/4, i.e. 9 cm at 800 MHz.

b) Polarization imbalance is reduced as the two transmitting antennas are orthogonally polarized. Moreover, Reference and unknown antennas are placed sequentially in three identical orthogonally polarized positions.

c) In order to compensate for spatial lack of uniformity, we do a swap, that is to say, we place the unknown antenna in the former spatial position of the Reference antenna, and we place the Reference antenna in the former spatial position of the unknown antenna.

d) The reading difference between the two spectrum analyzers is compensated.

B. Procedure for Relative method

We use a wideband double ridged horn antenna as the Reference antenna. Its efficiency is assumed to be 90%. The unknown antennas are the PIFAs presented and illustrated above. The unknown and the Reference antennas are each connected to their spectrum analyzer. They are placed in a first identical orthogonal polarization inside the working volume. The stirrer (horizontal and vertical rails) produces 51 samples (29 for the horizontal and 21 for the vertical). We, then, measure 2x51 values of received power. After that another orthogonal polarization is set and again received power measurements are done. Then, a third orthogonal polarization is set and power measurements are performed. Finally, a spatial swap is done and the three orthogonal polarizations are set sequentially. A total of 2x3x2x51 power measurements are done. The mean value of the received power is computed. Then, we use the formula (5) to obtain the efficiency.

C. Procedure for E-field method

The E-field meter and the unknown antenna are placed in the working volume. The unknown antenna is connected to a spectrum analyzer. The E-field, the received power of the unknown antenna, and information about the stirrer steps are acquired automatically by internally-developed LabVIEW software. Again, there are 51 stirrer steps. The unknown antenna is placed sequentially in three orthogonal polarizations within the working volume. The signal is amplified by a power amplifier, E-fields around 10 V/m are measured. The formula (6) is used to compute the efficiency.

IV. Measurement Results

Four results are given, first the result of simulation with CST, second the measurement result in another laboratory using the gain/directivity method, third, the result of the E-field method, and finally the result of the relative method. All the results are summarized in Table 1.

Analyzing the results, difference between simulated and measured FLPL PIFA is about 0.4 dB. The simulation calculation seems to be slightly over-optimistic, considering ideal materials and simulation environments. For SHPL PIFA, the difference between the E-field method and the gain/directivity are -0.2 dB and 0.4 dB, respectively, compared to the relative method. On the other hand, difference SHSL efficiency measured using the E-field method and measured result obtained in another laboratory according the gain-directivity method is -0.5 dB. This difference is 0.5 dB for the relative method.

Table 1: Comparison of simulated and measured efficiencies for different types of PIFA tolopologies and materials.

Method	Sim	Gain/Dir	E-field	Relative
FLPL	82.2	67.1	72.6	66.0
FLSL	76.5	60.6	60.9	60.3
SHPL	78.3	79.0	82.5	71.4
SHSL	81.1	76.4	86.2	68.6

V. Conclusions

A new E-field method for the measurement of the antennas' efficiency in a reverberation chamber is designed and verified. This method provided a maximum difference of 0.5 dB or 10 % compared to the conventional gain-directivity or relative method. The measured reproducibility is 7.5 %. The benefit is that there is no need for a reference antenna. The accuracy can be improved by doing a larger number of stirrer steps, but the 45 minutes measurement time is, then, increased.

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