A modified version of the Radiation Pattern Integration Method for the Measurements of the Radiation Efficiency of Electrically Small Magnetic Antennas

Riccardo Stefanelli[1], Daniele Trinchero[2],

iXem Labs – Politecnico di Torino, Department of Electronics
corso Duca degli Abruzzi, 24, Torino, Italy

[1]Riccardo.Stefanelli@polito.it
[2]Daniele. Trinchero@polito.it

Abstract

The radiation efficiency of an antenna is always critical to characterize experimentally. In this paper four methods are reviewed and analyzed: the Wheeler method, Q method, radiometric method and radiation pattern integration method. Among them, a modified version of the last is introduced, in order to obtain a more efficient and faster measurement procedure, applicable to the characterization of small magnetic antennas. The simulation results demonstrate that using this method an improvement of 80% of the time and calculation effort can be reached. Nevertheless, the method introduces an acceptable uncertainty, never larger than 0.5 dB.

1. Introduction

The design of an antenna involves the characterization and experimental verification of several parameters; one of them is represented by the antenna efficiency, defined as the ratio between the radiated power and the input power,. This parameter becomes significantly important, when dealing with resonating antennas or short radiators, as in these cases the amount of losses grows significantly in correspondence with the resonance of the system. Moreover, the estimation of the radiation efficiency by simulations cannot be very accurate, since it strongly depends on the materials and the manufacturing process. For this reason, the measurements phase is strategically important. The literature reports several methods to measure this parameter. The most significant ones are listed in the present paper, and their applicability to the characterization of the efficiency of small antennas is discussed: the Wheeler method, the Q method, the radiometric method, and the radiation pattern integration.

1.1 The Wheeler Method

In 1959 Wheeler published a paper in which he described a method to measure the radiation efficiency of an antenna [1]. The method is based on a differential measurement of the antenna's impedance in two conditions.
Starting from the well known [2] definition of the radiation efficiency, the ratio between the radiated power and the input power:

$$\eta = \frac{P_{rad}}{P_{in}} = \frac{P_{rad}}{P_{rad} + P_{loss}} \tag{1}$$

where P_{rad} is the radiation power, P_{in} the input power and P_{loss} the power dissipated in ohmic losses; and assuming that the antenna can be modeled as a series RLC circuit close to the resonant frequency, the input power and the loss power can be written as (2)

$$P_{rad} = \frac{1}{2} R_{rad} I^2 \quad ; \quad P_{loss} = \frac{1}{2} R_{loss} I^2 \quad ; \quad P_{in} = \frac{1}{2} R_{in} I^2 = \frac{1}{2}\left(R_{rad} + R_{loss}\right) I^2 \tag{2}$$

where R_{in} takes into account the radiation resistance plus loss resistance and R_{loss} only the loss resistance. It follows that

$$\eta = \frac{P_{rad}}{P_{rad} + P_{loss}} = \frac{P_{in} - P_{loss}}{P_{in}} = \frac{\frac{1}{2} R_{in} I^2 - \frac{1}{2} R_{loss} I^2}{\frac{1}{2} R_{in} I^2} = \frac{R_{in} - R_{loss}}{R_{in}} \tag{3}$$

The determination of the antenna's efficiency, as written in (3) is still difficult because it is not easy to measure the Prad and Ploss. To overcome this problem Wheeler proposed to measure the impedance in normal condition and again with the antenna enclosed in a metal cap. In this way, in the first measurement the resulting impedance is Rin, while in the

second measurement is only Rloss because, if the cap is located at a certain distance, the Rrad is short-circuited. In [1] Wheeler calculated the distance of the metal cap for an electrically small antenna, obtaining that $\lambda_0/2\pi$ is the optimum value.
Following his calculations, other authors investigated that the exact distance of the cap is not important as well the shape of the cap [3], [4]. On the contrary, as emphasized in [5], the metal contact between the cap and the ground plane is more critical and may significantly affect the results.

1.2 The Q Method

The Q method [3] is based on the ratio between the Q factor for the real antenna and the Q factor for an ideal antenna. The two antennas, real and ideal, are the same except for the fact that the conductors in the ideal case have no losses. The Q factor for the real radiator is defined as:

$$Q_{real} = \frac{\omega \times \text{power stored}}{\text{power radiated} + \text{power dissipated}} \tag{4}$$

The Q factor for an ideal radiator is:

$$Q_{ideal} = \frac{\omega \times \text{power stored}}{\text{power radiated}} \tag{5}$$

It follows that the antenna's efficiency is:

$$\eta = \frac{Q_{real}}{Q_{ideal}} = \frac{\text{power radiated}}{\text{power radiated} + \text{power dissipated}} \tag{6}$$

Obviously the Q factor for the ideal antenna can be determined only by simulations. The Q factor for the real one can be measured, since this parameter is also defined as the inverse of the frequency resonance multiplied by the bandwidth. Hence, it can be easily determined, by measuring the input impedance of the antenna and the bandwidth with a network analyzer.

1.3 The Radiometric Method

This method, presented first in [6], is mainly based on a differential measurement of the effective temperature of the antenna under test when it points a warm and a cold target. To implement that method a radiometer must be connected to the antenna. The effective temperature (T_e) at the terminals of the antenna can be calculated with the formula (7):

$$T_e = T_a\left(1-\eta\right) + T_t\eta \tag{7}$$

where T_a is the physical temperature and T_t the temperature of the target. The output of the radiometer is:

$$U = C\left(T_e + T_{int}\right) \tag{8}$$

where T_{int} is the internal noise temperature of the instrument and C a constant. Let's write U_c and U_w the radiometer's output respectively when the antenna is pointing the cold target and warm target, it is easy to derive:

$$\varepsilon = \frac{U_w}{U_c} = \frac{T_{int} + T_a\left(1-\eta\right) + T_w\eta}{T_{int} + T_a\left(1-\eta\right) + T_c\eta} \tag{9}$$

The parameters T_{int}, T_a, T_w and T_c are known, so the parameter η can be calculated.
Some authors in [7] presented a modified method, more accurate and flexible, varying the temperature of the antenna. In this way the errors introduced by the measurements of the target temperature are avoided, obtaining a more accurate result.

The main drawback of the traditional method is that for wideband antennas, it is difficult to be sure that in the radiation space there aren't external uncontrolled sources, especially in the cold measurements. The modified method overcome this drawback but an expensive instruments (radiometer) is required.

1.4 The Radiation Pattern Integration Method

Since the radiation efficiency is the ratio between the radiated power and the input power, the radiated power is calculated by integrating the radiated field. From theory:

$$\eta = \frac{P_{rad}}{P_{in}} = \frac{\int_S E \times H^* dS}{P_{in}} = \frac{\int_\Sigma \frac{dP}{d\Sigma} d\Sigma}{P_{in}} \tag{10}$$

It means that a precise measurement of the radiated power in the radiation sphere should be done. In this context a typical measurements campaign consists up to 30.000 points, it requires a controllable rotor and it is time consuming, up to four hours.

2. A modified Integration Method

Electrically small magnetic antennas are nowadays employed in a growing number of applications, mainly for the realization of wireless sensors in complex environments. To measure the efficiency of such an antenna, in principle, all listed methods could be applicable, but the first could require a large caps (especially for sensors working in lower frequency ranges), the second requires temperature managements, and cannot be applied in any laboratory; the third requires efficient and reliable simulations, critical to obtain when the bandwidth is very small, as in the case under study.

In this chapter a modified integration method is introduced, to measure the efficiency of an electrically small magnetic antenna, by significantly reducing the number of the measuring points that are typically necessary with the traditional method, and accepting an additional measurement uncertainty.

As it can be found in the literature [2], the measurements of the radiated power should be performed at the far field distance that, for electrically small antennas, is typically set to 3λ. Since the operating frequency is low, to construct an experimental setup long enough it could be very hard. For this reason a set of simulations has been done in order to minimize the distance with the following main constraints:

1. maintaining a reliable separation between the respective near field regions of the transmitting and receiving antenna
2. maintaining an acceptable error on the characterization of the gain function, even if the distance reduction could affect its value
3. use the same antenna as transmitting and receiving ones, to minimize the error and avoid the use of wideband, large radiators, typically used for calibration or susceptibility measurements.

As it is shown in Fig. 1, in this paper, a loop antenna operating at 433 MHz with a diameter equal to 7.5 cm has been selected. Antenna design has been run accordingly to the design method reported in [8]. The results clearly show that for a distance equal to 1.5 λ the error is equal to 1 dB and can be considered acceptable.

Once the distance has been fixed, a set of measurements in the horizontal and vertical planes should be performed. The simulation results show, Fig. 2, that in the horizontal plane the radiation pattern is omnidirectional so, even one point in that plane could be enough. On the contrary, in the vertical plane another set of measurements has been done, about 50 points are necessary with an error equal to 0.5 dB.

5. Conclusion

In this several methods applicable to the measurement of the radiation efficiency of antennas are reviewed, in order to identify the most suitable one for electrically small magnetic radiators. As a consequence, a modified version of the pattern integration method is introduced. The method has been tested and validated with a loop antenna working at 433 MHz. The simulation results clearly show an advantage in terms of time consumed in the measurements with a reduced increment of the generated uncertainty.

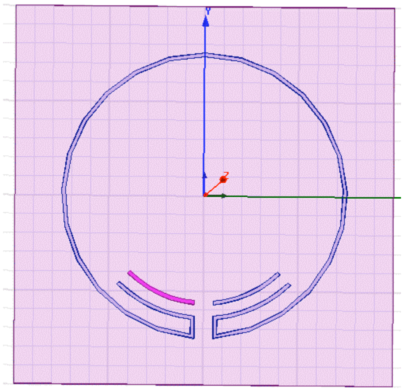

Fig.1 The antenna under test

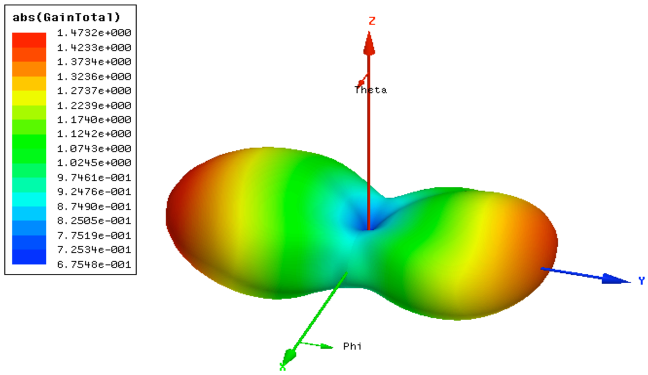

Fig.2 The 3d radiation diagram

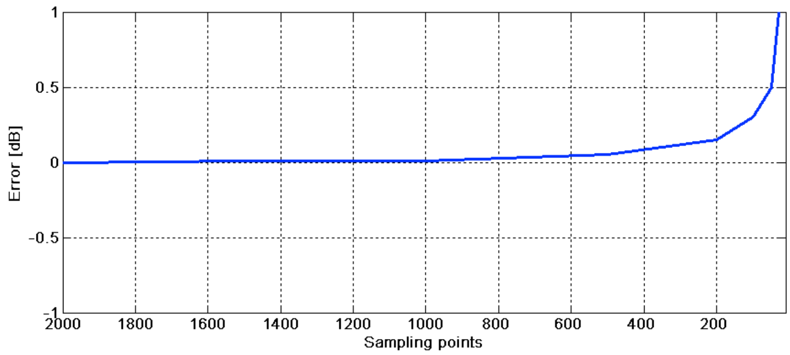

Fig.3 Error in the calculation of efficiency versus the sampling points

7. References

1. H. A. Wheeler, "The radiansphere around a small antenna," Proc. IRE. pp. 1325-1331, Aug. 1959

2. C. A. Balanis, "Antenna theory. Analysis and Design", Arizona State University, John & Sons, 1989.

3. E. Newman, P. Bohley, and C.H. Walter, Two method for the measurement of antenna efficiency, IEEE Trans Antennas Propagat 23 (1975), 457–461.

4. D. Agahi and W. Domino, Efficiency measurements of portable handset antennas using the wheeler cap, Appl Microwave Wireless 12 (2000), 32–34.

5. D. Pozar and B. Kaufman, Comparison of three methods for the measurement of printed antenna efficiency, IEEE Trans Antennas Propagat 36 (1988), 136–139

6. J. Ashkenazy, E. Levine, and D. Treves, "Radiometric measurement of antenna efficiency," Electron. Lett., vol. 21, no. 3, pp. 111–112, Jan. 1985.

7. N. J. McEwan, R. A. Abd-Alhameed, M. N. Z. Abidin, "A Modified Radiometric Method for Measuring Antenna Radiation Efficiency", IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION, VOL. 51, NO. 8, AUGUST 2003, 2099-2105

8. M. Marroncelli, R. Stefanelli, D. Trinchero, "Size-Reduction of Magnetic Radiators for RFID-Based Technology", URSI GA 2011, in submission