ACCURATE ANTENNA GAIN ESTIMATION USING THE TWO-ANTENNA METHOD

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Abstract

This paper demonstrates a simulation-assisted measurement technique to determine the gain of an antenna accurately in an open test site or anechoic chamber. The proposed technique is based on the two-antenna gain measurement method using Friis equation in far-field free-space conditions, with the actual measurement test setup modelled in CST Studio Suite for simulation. An LTE-reject UHF TV log-periodic dipole antenna is used to validate the gain measurement technique in this paper. The simulation of the two-antenna gain measurement method is used in order to estimate an appropriate minimum separation distance between the two antennas that needs to be used for actual measurements to ensure far-field free-space conditions. Determining this minimum separation distance using several simulations instead of actual measurements saves time and effort because it eliminates the need to perform measurements at various separation distances. The measured realized gain obtained using this technique provides a good agreement with the simulation and thus validates the accuracy of this technique.

1 Introduction

Measuring the gain of an antenna accurately is a very challenging task and is most commonly performed in an environment with non-reflecting characteristics like in an anechoic chamber or an open test site [1]. Measurements that are performed in anechoic chambers provide excellent free space antenna gain estimates, however, such measurements are expensive and also require the size of the chamber to be sufficiently large compared to the wavelength of the antenna under test (AUT). In addition to this, it also requires taking into consideration the type of absorbers that are used on the floor and on the walls, depending upon the frequency range of the measurements. This contributes in making the measurements in the anechoic chamber an expensive and time-consuming process [2]. Therefore, for such cases, a cheaper yet effective alternative to anechoic chamber measurements is to perform the measurements in an open test site. Performing the measurements at an open test site location requires to ensure that the selected site has low-noise. The reflections due to the ground may lead to inaccurate results and thus installing diffraction fences on the ground surface helps in reducing the ground reflections [2]. The IEC CISPR 16 on Electromagnetic Compatibility (EMC) describes the height scan measurement technique which involves determining the height where constructive interference occurs in order to reconstruct the direct wave using the measured values of constructive and destructive interference [3]. However, this technique is difficult to implement for directive antennas like log-periodic antennas because the vertical beam is narrow in this case. Another unique technique to eliminate the effects of ground reflections was proposed in [4], where time-domain pulses with duration and rise time of the order of 50 ps were generated in order to characterize the performance of antenna in the desired frequency range. The Antenna Time-Domain Measurement (ATDM) technique promises to reduce the duration of measurement compared to the frequency-domain measurements and the hardware implementation of this technique is described in [4]. Another alternative to reduce the effect of ground reflections is to perform an inverse Fourier transform on the data obtained through frequency-domain measurements as described in [5] and [6]. However, these techniques are not applicable in case the AUT is a narrow-band antenna. The reason behind this is that narrow band antennas produce time-domain responses that are much longer than the propagation delay of reflections. As a solution to this, a study in [7] suggested that narrow-band antennas could be measured in reverberation chambers with the help of statistical model of propagation. One of the accurate and cost-effective ways of measuring the gain of an antenna is by using two-antenna method combined with a distance scan method. This method has been implemented to determine the gain of UHF log-periodic directional antennas in [8], that were designed to be used for a transhorizon propagation measurement campaign [9]. The idea of the distance scan method was introduced after a helicopter measurement campaign was performed in order to characterise VHF broadcasting antennas in [10]. However, finding the appropriate distance for the separation between two identical antennas in order ensure far-field conditions as well as to minimise ground reflections is a challenging and time-consuming task. Therefore, in this paper, an accurate antenna gain estimation technique is proposed as a modification of the two-antenna method, where the appropriate distance between the two antennas is determined using the simulation of the test setup performed in CST Studio Suite. Furthermore, the accuracy of the antenna gain measurements can be improved by considering the exact phase centre of the antenna [11]-[12], which may depend on frequency. The gain determination of an LPDA by considering the phase centre is demonstrated in [13]. Additionally, the numerical investigation of the field regions of wire based antenna systems and the study of boundaries of near and far field regions in the simulations is described in [14] and [15] respectively.

2 Two-antenna method

The two-antenna method is a measurement technique that uses the Friis transmission equation to determine the gain of an antenna [16] in the far-field. This technique requires two samples of test antennas that are geometrically and electrically identical. The two identical antennas are separated by a distance in such a way that they face each other and are at the same height from the ground. One of the antennas will act as a radiating antenna and the other antenna will act as a receiving antenna. It should be made sure that the antennas are well matched in terms of impedance and polarization. A Rohde & Schwarz FSH8 portable spectrum analyzer was used to determine the power transferred from Antenna-1 to Antenna-2. The Friis Transmission equation is used to determine the gain of the antenna using the measured transferred power as shown in:

$$\frac{P_r}{P_t} = \left(\frac{\lambda}{4\pi R}\right)^2 G_t G_r \tag{1}$$

where, $G_t = G_r = G$

G_t= gain of the transmitting antenna
G_r= gain of the receiving antenna

This equation can be re-written in terms of dB as:

$$G_{dB} = \frac{1}{2}\left[\underbrace{20\log_{10}\left(\frac{4\pi R}{\lambda}\right)}_{FSPL} + \underbrace{10\log_{10}\left(\frac{P_r}{P_t}\right)}_{S_{21}}\right] \tag{2}$$

where,
G_{dB}= Gain of AUT in dB
R= distance between two antennas
P_t= transmitted power
P_r= received power
λ= wavelength
FSPL= Free-Space Propagation Loss

The S_{21} recorded by the spectrum analyzer and the accurate distance between the antennas will provide the gain of the antenna using equation (2). However, the only drawback of this technique is the estimation of the minimum distance between the antennas in the far-field that will provide less ground reflections and thus more accurate results. Inappropriate estimation of this distance may lead to inaccurately measured gain. Therefore, usually several measurements are recorded varying distance by moving one of the antennas away from the other. The measurements performed in [8], involved recording several measurements by varying the distance between the two antennas from 2 meters to 20 meters. This is a time-consuming process. The technique proposed in this paper provides a modification to this two-antenna method, where this distance can be estimated correctly using simulations of the test setup in CST Studio Suite, thereby reducing the overall time of measurements.

3 Antenna under test

To validate the measurement using the two-antenna method, a 10-dipole log-periodic antenna (LPDA) was used as a test case. This log-periodic antenna is a directional antenna that is used for ultra-high frequency (UHF) TV reception and has an operating frequency range from 470 MHz-790 MHz. This LDPA is a modified version of a traditional 10-dipole LPDA that has the capability to reject the LTE-800 MHz band and GSM-900 MHz band. The rejection capability was obtained by optimizing the traditional 10-dipole LPDA, and the design procedure is demonstrated in [17]. This optimized design is used in this paper to demonstrate the two-antenna method for determining the realized gain of the antenna. The CST model of the antenna is shown in Fig. 1. Another variant of LPDA has also been proposed in [18] using Particle Swarm Optimization with velocity mutation algorithm (PSOvm).

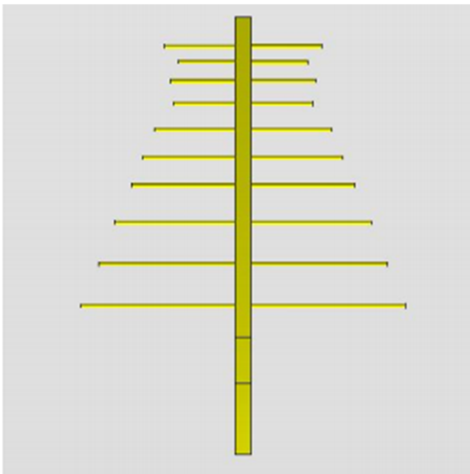

Fig. 1. CST model of a 10-dipole LPDA used as the AUT.

However, this antenna was further optimized using the Trusted Region Framework (TRF) algorithm [19] in CST Studio Suite and described in [20].

4 Proposed simulation-assisted antenna gain measurement

In order to validate the two-antenna method and find the appropriate far-field distance R (in meters) between the two antennas for the two-antenna method, an identical setup was created in the simulation software. This was done by creating an identical model of the AUT and placing it at a distance R. The top view of the test setup in the simulation software is shown in Fig. 2.

The model of this setup consists of hexahedral meshing with a minimum of 2,244,156 mesh cells and a maximum of 4,838,556 mesh cells for 1m and 5m separation distance between the two antennas respectively. The simulation was performed in the time domain in order to obtain the power transferred from one antenna to the other. Several simulations were performed by varying the distance R between the two antennas from 1m to 5m in order to obtain a good estimation of the minimum distance that would provide accurate free-space far-field results.

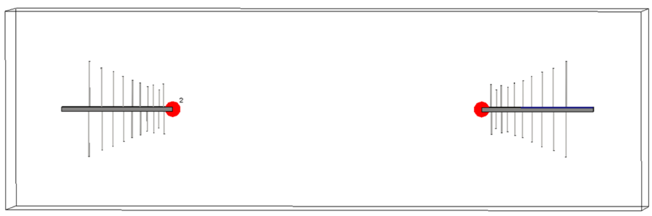

Fig. 2. Top-view of the measurement test setup modelled in CST simulation software.

After estimating the distance R between the two antennas in simulation, the actual measurement setup for the two-antenna method was created. A distance of 1.5 meters was considered for the distance between the two antennas to be used for the actual measurement setup. The two-identical antennas were mounted on two separate wooden stands and were placed at the same height in such a way that both the antennas faced each other. The wooden stands with the antennas were separated by R=1.5 meters, that was obtained from simulation. The power transferred from antenna-1 to antenna-2 was measured using an FSH8 Rohde & Schwarz spectrum analyzer. The value obtained from the spectrum analyzer was then used to calculate the realized gain of the antenna using equation (2).

Fig. 3 shows the comparison of the measured and the simulated S21 or the power transferred from antenna-1 to antenna-2. The plot is an evidence of the good agreement obtained between the measured and simulated results. The values from this plot were then used to calculate the realized gain of the antenna. Fig. 4 shows the comparison of the simulated and measured realized gain of the AUT. The plot shows good agreement between the measurement and simulation results. The graphs present reasonably high gain in the UHF reception range from 470 MHz to 790 MHz. The antenna demonstrates a high-rejection capability in the LTE-800 MHz and GSM-900 MHz band as expected.

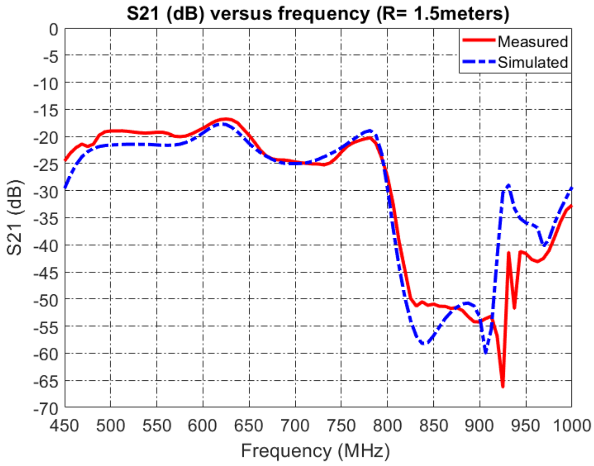

Fig. 3. Measured and simulated S21 of the AUT.

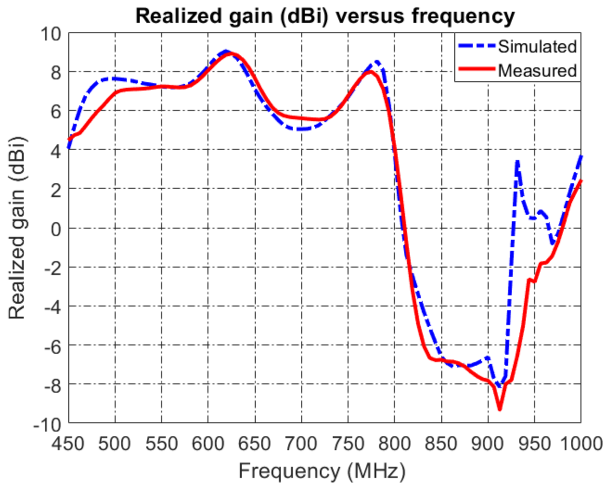

Fig. 4. Measured and simulated realized gain of the AUT.

5 Conclusion

An improvement of the two-antenna method is presented in this paper using measurements and simulations. This paper also proposes a useful technique using CST simulation to estimate the distance between the identical antennas to be considered for the measurement setup in order to achieve accurate measurement results. The realized gain of the AUT obtained using simulation and measurement demonstrates a good agreement.

6 References

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