Technical E-Paper

7

Using an ANECHOIC CHAMBER in the design of antennas

PART TWO: antenna measurements in an anechoic chamber.

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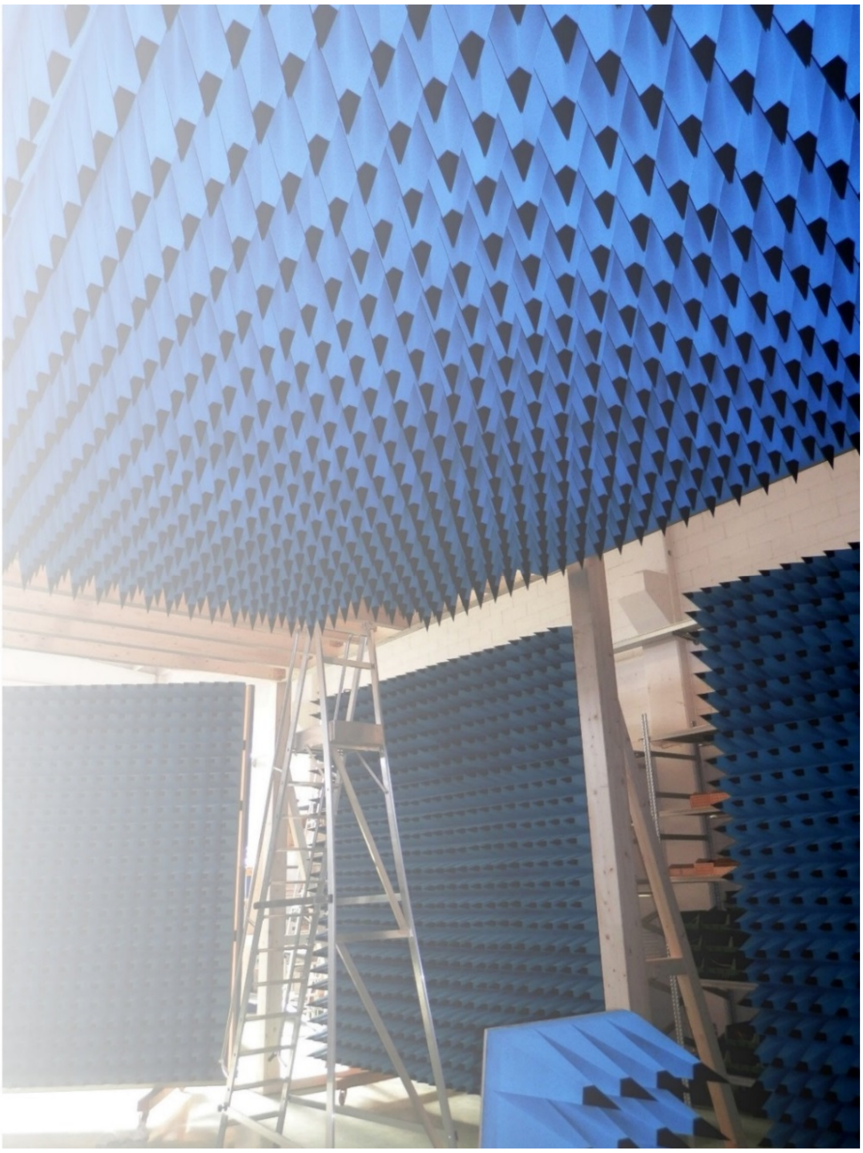
Let's continue with part two in which we will look at one of the most important pieces of equipment used in the research and development of antennas: the *anechoic chamber*.

PART ONE:
What is an anechoic chamber and how does it measure the electrical parameters of antennas?

PART TWO:
What steps can be taken to obtain reliable measurements when designing a new antenna?

PART THREE:
What other laboratory equipment is required to measure the radiation parameters of antennas?



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...continued from **PART ONE**:

5. Far-field measurement.

5.1. The setup.

The most traditional (and universal) use of the anechoic chamber is that of taking measurements from a *far field condition*; that is, by simulating a typical radio link in free space inside it between two antennas placed at a distance ***R***, for which the following condition is valid:

$$R \geq 2\frac{D^2}{\lambda} \quad [1]$$

this depends on both the maximum size ***D*** of the antenna and the wavelength λ; that is, the operating frequency. For antennas with dimension ***D*** of less than λ, in the far-field the following relation must always be valid:

$$R \gg \lambda \quad [2]$$

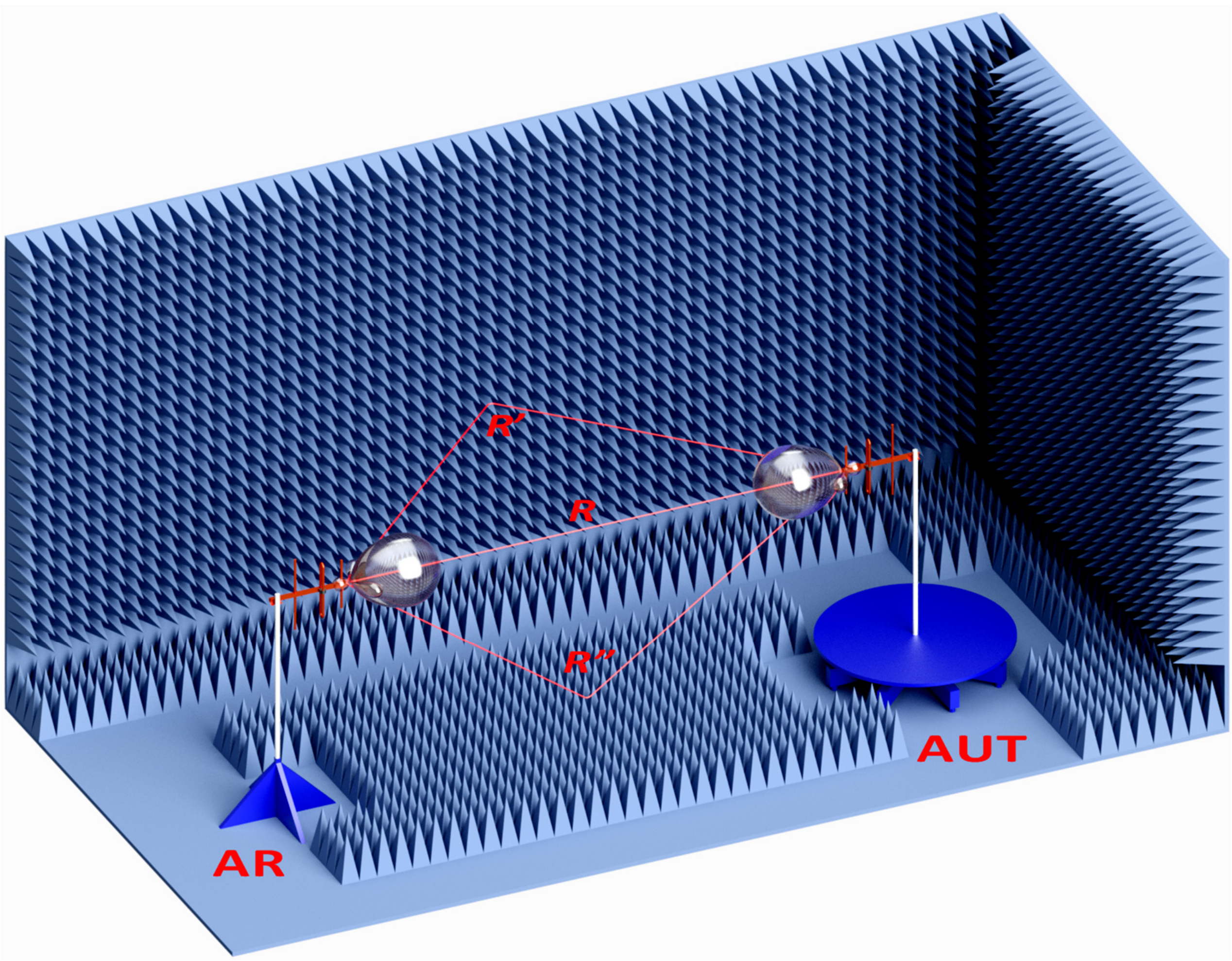

Figure 5
Far-field measurement setup.

Figure 5 shows this type of measurement in an anechoic chamber, where the antenna being measured (***AUT***) and the reference one (***AR***), located at the other end of the link, can be seen.

The diagram also shows the direct ray that travels a minimum distance ***R*** between the two antennas, as well as the main rays reflected off the vertical and horizontal walls of the chamber, whose paths are ***R'*** and ***R''*** respectively.

The purpose of an anechoic chamber is to create a certain region of space within it in which the energy reflected by any incident electromagnetic beam on the floor, walls and ceiling, is much more attenuated than the direct beam ***R***.

Therefore, at a certain frequency or frequency range, a so-called *quiet zone in* the chamber is identified.

Besides the reflectivity characteristics of the absorbent material and the type of structure (conductor or dielectric) with which the chamber is made, the radiation characteristics of the reference antenna (***AR***) also usually contribute to distinguishing the reflected rays from the direct one.

The best condition is therefore the one where **a gain measurement** has to be made between two directional antennas: in this case, the two antennas (***AUT*** and ***AR***) are directed at each other and both of their directional functions (shown in the figure) act as a spatial filter for all the reflected paths arriving at ***R*** from different directions.

In radiation patterns measurements, the ***AUT*** is mounted on a rotating table that turns the antenna 360° in azimuth for data acquisition and, consequently, its main lobe illuminates various surfaces of the chamber with different incidence angles, creating reflected rays that, in principle, tend to alter the measurement in a more consistent way than in the previous case.

In fact, in the limit case where the ***AUT*** radiation pattern shows zero values, the maximum observable depth of these minimums will depend on the energy level associated with the reflected rays, however picked up by the reference antenna ***AR***.

5.2. Gain measurement.

The first measurement performed in an anechoic chamber is certainly the gain measurement. As we will see in the following paragraph, with two calibrated antennas (i.e. with known gain curves) available, the performance of the chamber can be estimated rapidly by means of this type of measurement, by comparing the measured gain curve of the setup with the known gain of the calibrated antennas.

The radio link in ***Figure 5*** can be identified as a two-port network in which the reference sections (*port 1* and *port 2*) are the connectors of the two ***AUT*** and ***AR*** antennas respectively. It is therefore possible, using a vector network analyzer (VNA), to perform an insertion loss measurement ***IL(f)*** [dB] between these two ports, acquiring the curve $|S_{12}(f)|$ (o $|S_{21}(f)|$) [dB] in the operating frequency band.

Barring special cases, the system is reciprocal and the following relationship is therefore valid:

$$IL(f) = -|S_{12}(f)| = -|S_{21}(f)| \qquad [dB] \qquad [3]$$

that is, the ***AUT*** can be used indifferently, either as a transmitting or receiving antenna.

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From this measurement it is possible to calculate the antenna's gain curve G_{AUT} [dBi] using the expression:

$$G_{AUT}(f) = A_{SL}(f) - IL(f) - G_{AR}(f) \qquad \text{[dBi]} \qquad [4]$$

in which $G_{AR}(f)$ [dBi] is the gain curve (known) of the reference antenna, while $A_{SL}(f)$ [dB] is *the free-space attenuation*, given by:

$$A_{SL}(f,R) = -20 \cdot \log_{10}\left(\frac{\lambda}{4\pi \cdot R}\right) \qquad \text{[dB]} \qquad [5]$$

in which $\lambda = c/f$ [m] is the wavelength and ***R*** [m] is the distance between the two ***AUT*** and ***AR*** antennas.

If a reference antenna is not available for the desired frequency band, a gain measurement can be made using two identical antennas, i.e. by placing in [4] $G_{AUT} = G_{AR}$. In this case, the calculation is simplified, averaging any errors on the two antennas, and equation [4] becomes:

$$G_{AUT}(f) = \frac{1}{2}[A_{SL}(f,R) - IL(f)] \qquad \text{[dBi]} \qquad [6]$$

5.3. Practical controls of the reliability of a measurement.

There are studies, procedures and regulations that can be used to define the quiet zone of an anechoic chamber and to estimate its actual characteristics so as to calculate any correction factors to be applied in the measurements of a given setup. This subject is complex and outside the scope of this article.

I will therefore attempt to address the topic in a more practical way, given that the main need of an antenna design and manufacturing company is to characterize its new products, or the prototypes being developed, in the most rapid and reliable way possible.

A technician who works in a laboratory, using the same piece of equipment or instrument every day, necessarily becomes well-acquainted with his tools and develops empirical rules that allow him to quickly assess the reliability and accuracy of a measurement.

Not being an accredited test laboratory, in a company it may also happen that, to test certain products, the anechoic chamber has to be used to the limit of its operating capacities, for example at frequencies lower than the band in which the absorbers are most efficient. Of course, even in this case, you must always be able to provide the customer with a product whose specifications can be identified and verified, also by means of an independent validation test conducted by any accredited laboratory.

Let's now look at some methods that allow us to empirically evaluate the effectiveness of the quiet zone, in which a measurement is to be made.

- ***Comparison of the gain curves measured on planes E and H.***

Assuming that we are working with antennas with linear polarisation, inside a non-ideal anechoic chamber there are reflections with different mechanisms on the two main planes. The gain curves can therefore be measured on the two orthogonal planes E and H $G_E(f)$ and $G_H(f)$ and compared against each other.

For example, when developing an integrated antenna for which it was necessary to measure gain and radiation diagrams in the two horizontal and vertical linear polarizations, two reference antennas, identical to each other, operating in the 800 ÷ 1000 MHz band were designed and built ad hoc.

Each of these antennas, with a beam width of around 60°, is fitted with two identical radiating elements with orthogonal polarization (horizontal and vertical) that can be switched remotely by means of special RF relays regulated by a control voltage.

In this way it is possible to directly measure the two insertion losses $IL_E(f)$ and $IL_H(f)$ from which, using [6], the two gain curves $G_E(f)$ and $G_H(f)$ on the two orthogonal planes are then deduced. To accomplish this measurement, the ***AUT*** is rotated 90° around its main radiation direction to get the gain figures with the E-plane and H-plane oriented respectively parallel to ground.

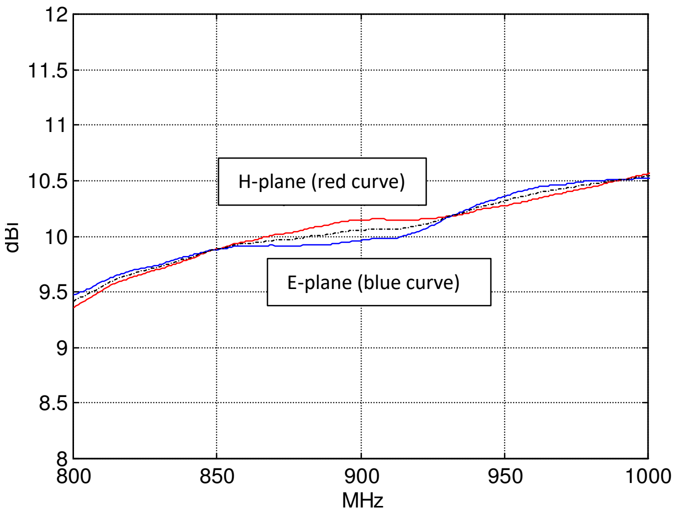

Figure 6
Gain curves on planes E and H of the switchable double polarization antennas, measured on the two planes E and H respectively.

Figure 6 shows the measurement of both curves, in red (plane H) and in blue (plane E), with the trend of the average gain added (dashed line).

In this case, the result is more than good, since the maximum deviation is less than 0.4 dB and this error also takes into account any construction tolerances between the two pairs of orthogonal radiating elements inevitably present in the two antennas.

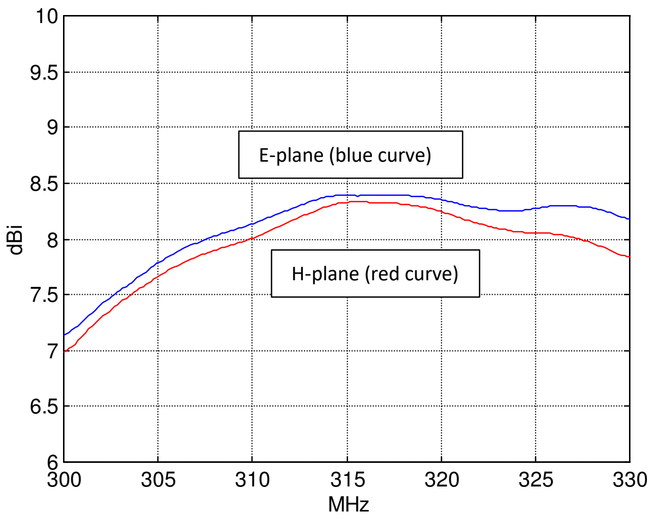

Figure 7
Gain curves in planes E and H of two identical Yagi antennas, in the 300÷330 MHz band, measured in the two planes E and H, respectively.

A second example is shown in ***Figure 7*** and refers to the same gain curves for a pair of Yagi antennas in the 300÷315 MHz band, where the chamber absorbers inevitably have a worse performance than the previous case. Compared to the latter, although the beamwidths are comparable, both antennas had to be physically rotated by 90° to change the plane on which the measurement was made. Nevertheless, it was possible to obtain a deviation of less than 0.5 dB, undoubtedly due to the dielectric structure of the anechoic chamber.

Following these measurements, a maximum difference of 0.5 dB can be considered an acceptable value.

The same measurements of as ***Figure 7***, conducted in an identical anechoic chamber, with the same size of absorbers but of a shielded type, would certainly have given a worse result.

- ***Comparison of the gain curves measured at different distances.***

If we think in a more pragmatic way, compared to the strict definitions, we can define the maximum extension of the quiet zone of our anechoic chamber based on the frequency and type of antenna being measured.

Assuming that the far-field condition is always verified, the closer I get to the two antennas ***AUT*** and ***AR***, the better the distinction of the reflected rays from the main beam. Indeed, as ***R*** decreases:

- The insertion loss of the radio link decreases;
- The radiation diagram of the reference antenna ***AR*** (and possibly also of the ***AUT***, if it is a directional one) manages to better distinguish the reflected rays from the main one;
- The rays that are reflected at the midpoint of the radio link have a greater incidence angle so the attenuation of the absorbers is better.

A valid method is therefore to perform the gain measurement at different ***R*** distances, naturally within a range compatible with the physical size of the chamber and without getting too close to the absorbers, which could interact with the near-field of the antenna.

With this method, the reliability of the gain measurement can be verified fairly quickly and unequivocally. If we imagine using two identical reference antennas with known gain $G_{AR}(f)$, positioning ourselves at the distance ***Ri***, we should be able to acquire the insertion loss curve given by:

$$IL(f,R_i) = A_{SL}(f,R_i) - 2 \cdot G_{AR}(f) \qquad \text{[dB]} \qquad [7]$$

If, for example, even without knowing the gain curves $G_{AR}(f)$ of the antennas I use, I make the gain measurement at two different distances R_1 and R_2 [m], in ideal conditions I should find a difference between the insertion loss curves $IL(R_2,R_1)$ [dB] given by:

$$\Delta IL(R_2,R_1) = IL(f,R_2) - IL(f,R_1) = 20 \cdot \log_{10}\left(\frac{R_2}{R_1}\right) \qquad \text{[dB]} \qquad [8]$$

Therefore, with each doubling of the distance, the insertion loss (always understood here as a positive value) must increase by 6 dB, simply by translating the acquired curve within the measuring band.

Although being a simple method, the presence of any reflections appears evident when, as ***R*** varies, the ***IL(f)*** curve deforms, giving rise, in the worst case scenario, to real minimums at certain frequency values, indicating the presence of a destructive interference between direct and reflected rays.

Also in this case, the rule of thumb establishes a maximum tolerance of 0.5 dB with respect to that indicated in [8].

- ***Symmetry of radiation patterns.***

If symmetrical (i.e. geometric and electrical symmetry) radiating elements are to be measured, it is logical to expect a symmetrical shape of the radiation patterns actually acquired.

Nowadays, this behaviour is also consolidated by the fact that there are many electromagnetic analysis software tools that enable precise modelling of the antenna and its feeding system, and, therefore, an estimation of its radiative behaviour with good accuracy can be estimated.

This type of symmetric antennas, which often has to be designed, allow indirect verification of the performance of an anechoic chamber. Although this may be a bit of an overstatement, I would like to take this opportunity to give the example of an omnidirectional UWB antenna operating in the 3.25÷4.25 GHz band, which we were recently commissioned. In this case, being in a rather high frequency band in which the chamber absorbers offer excellent performance, the radiation diagrams shown in ***Figure 8*** were obtained, for planes E and H respectively, and which represent an example of symmetry that meets the rotational symmetry of the radiating element structure.

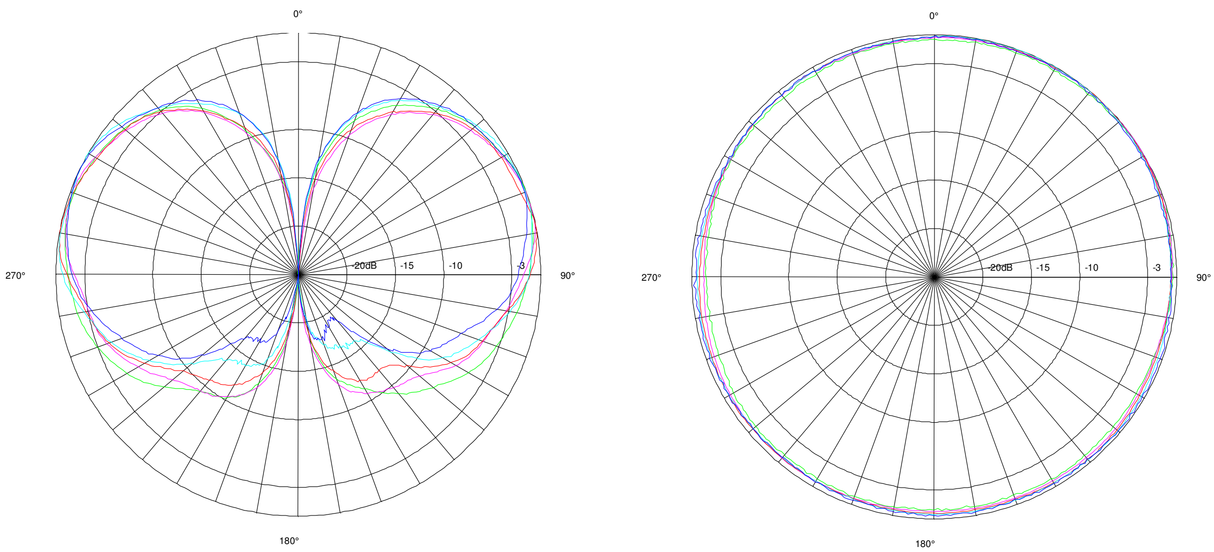

Figure 8
Radiation diagrams of an omnidirectional UWB antenna on planes E (left) and H (right), measured for five frequency values in the 3.25÷4.25 GHz band.

- ***Measurements on large antennas.***

It is not always possible to make a measurement in conditions similar to those of the diagrams shown in **Figure 8**; that is to say, in conditions that we can call consider as optimal.

However, there are antennas that can be effectively measured even at the limit of the performance of an anechoic chamber, both in terms of the characteristics of the absorbers and the useful dimensions of the chamber itself.

An interesting example is that of a SATCOM antenna in the 243÷318 MHz band: a directional panel with a size ***D*** of 1.3 meters (***Figure 9***).

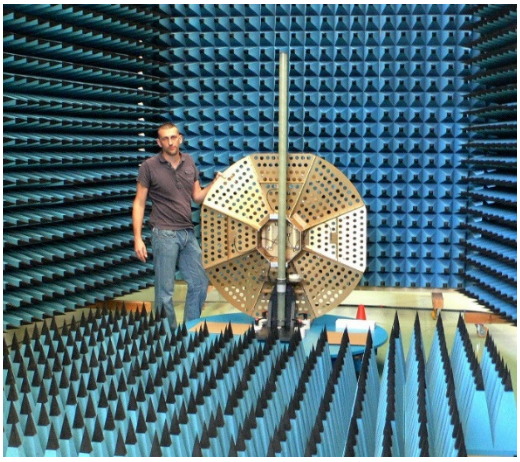

Figure 9
Setting measurements of a large antenna.

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Once the far field condition given by [1] was calculated, the measurements were carried out at a distance of about 6λ at the start of the band (*f=243 MHz*, or *λ=1.23 m*): this was possible because the anechoic chamber was built specially with mobile walls, so as to be able to move the bottom of the chamber a few meters away and gain enough space to accommodate both antennas (*AUT* and *AR*) without interfering with the absorbers.

Since in this case the polarization of the *AUT* is right circular, the radiation diagrams of the directional antennas involved in the measurement have contributed to effectively distinguishing the reflected rays from other directions, especially the rear one and, at the frequency of 243 MHz, the radiation diagram shown in ***Figure 10*** was obtained.

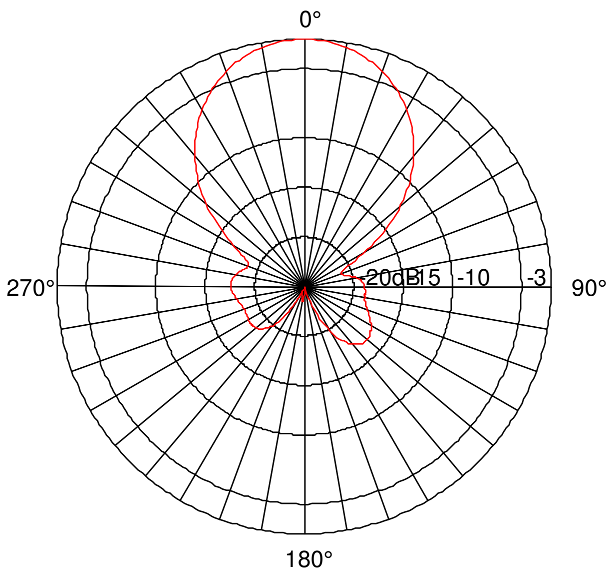

Figure 10
Radiation diagram of a SATCOM antenna, acquired at a frequency of 243 MHz.

The measurement, repeated at different distances (even greater ones) gave similar results, in perfect accordance with the antenna design specifications.

- ***Measurements on small antennas.***

Another way in which it is possible to go a little beyond the limits of an anechoic chamber is when measuring a so-called electrically small antenna, that is with dimension ***D*** that verifies the relationship:

$$D \leqq \frac{\lambda}{2\pi} \qquad [m] \qquad [9]$$

It was also decided to carry out the measurements at a single frequency or in any case in a narrow band, indicatively less than one percent.

Although these two limits are rather unusual, it is not uncommon to operate in these conditions when developing antennas incorporated in the 169 MHz *ISM* band: this is the case, for example, of antennas for gas meter remote reading devices.

Imagine that there are reflections in the chamber, associated with a number of electromagnetic rays that connect the two *AUT* and *AR*, antennas, along R_i paths that are different from the direct radius that covers the minimum *R<Ri* distance.

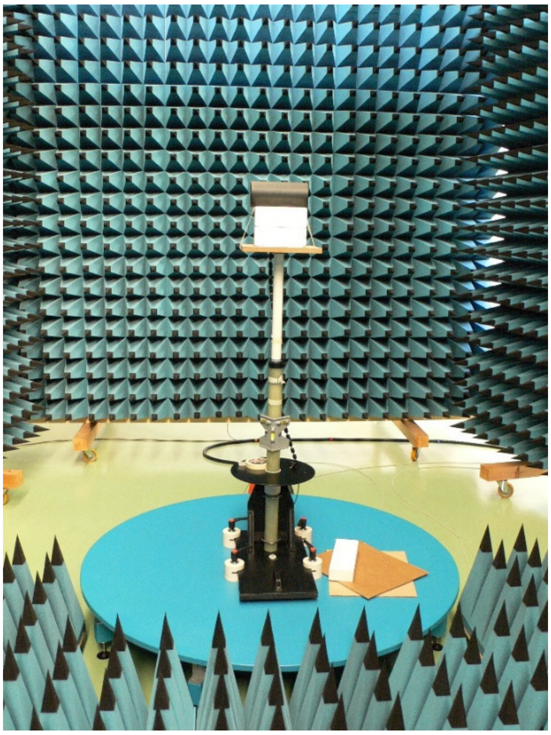

Figure 11
EP60012L biconical antenna.

In principle, it is possible to empirically find a position *(X_0,Y_0,Z_0)* of the *AUT* for which the vector sum of the reflected signals (each with its own phase) has a negligible effect on the direct radius. Of course, since the phases depend both on the distances *Ri* and on λ, the approximations described above apply.

The position *(X_0,Y_0,Z_0)* is determined in practice using a second reference antenna, positioned in the place of the *AUT*: in this case, our model *EP60012L* , that is, a biconical antenna with dimension *D≈20 cm* was used. For this antenna, *SIT* calibrated by an external certifying body, the gain value $\boldsymbol{G_{cal}}$ at 169 MHz is equal to -15.25 dBi.

Figure 11 shows this antenna in position: this calibration procedure was carried out with a previous version of the anechoic chamber, not yet fitted with all absorbers.

Figure 12 shows some 169 MHz gain measurements carried out on both the main planes E and H at various distances from the reference position which was then found to be the optimal one, here normalized to zero. The horizontal line (green in the figure) shows the value of the actual gain of the calibrated antenna *EP60012L*.

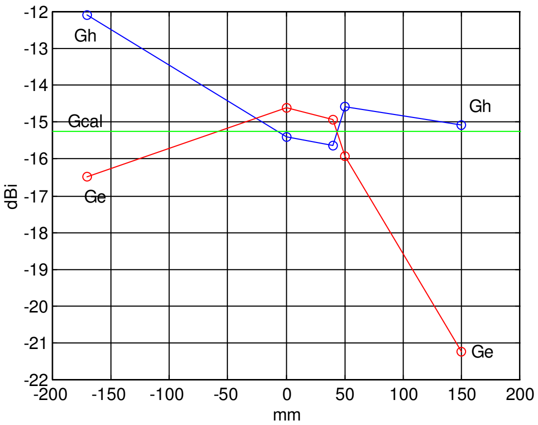

Figure 12

$\boldsymbol{G_e}$ and $\boldsymbol{G_h}$ gain values at 169 MHz of the biconical calibration antenna (ordinate), measured respectively on planes E and H, as a function of the variation of the measurement distance ***R*** (abscissa).

Figure 12 shows how, by moving the ***AUT***, it is often possible to determine an optimal position, (about 0±50 mm) at which reliable measurements can be conducted, with an estimated error in this example of around ±0.5 dB.

Figure 13 shows the corresponding radiation diagrams on plane E acquired at the frequencies of 164 MHz and 169.5 MHz: as a result of this optimization, they are very regular and symmetrical, compliant with the radiation characteristics of the *EP60012L* antenna.

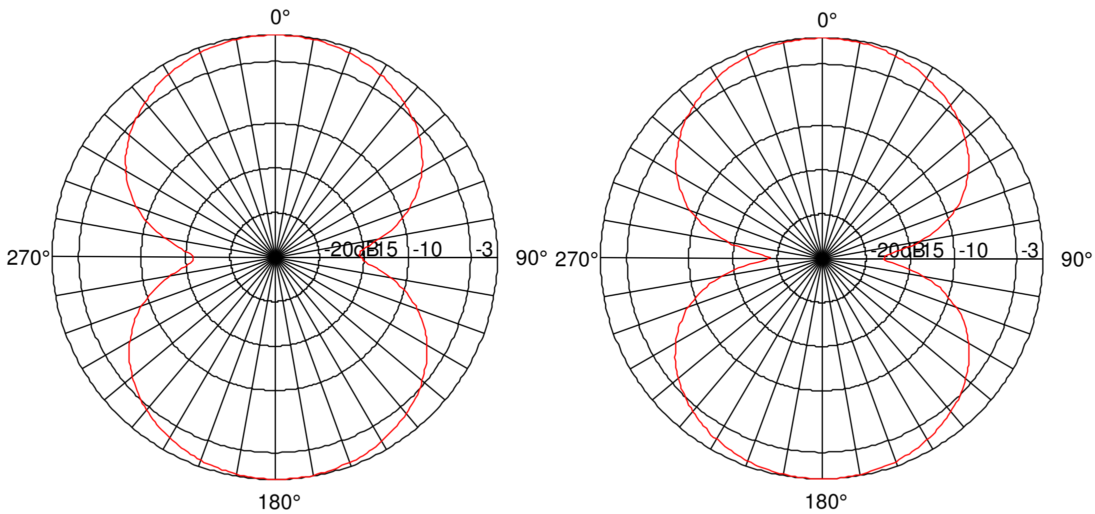

Figure 13

E-plane radiation patterns of the EP60012L calibration antenna, measured at 164 MHz (left) and 169.5 MHz (right) respectively.

The empirical procedure mentioned here, whose principle is applied in some more rigorous methodologies to verify the quiet zone of an anechoic chamber, has the purpose of making it clear that under certain conditions it is possible to obtain reliable pre-certification measures even in sub-optimal measurement conditions.

All the information and experiences reported in this article are the result of the **design, development and construction of professional custom antennas** *by ElettroMagnetic Services Srl using the AntennaCustomizer method.*

For **questions, clarifications or further information** *about this or other topics regarding* **professional antennas, write to** *bollini@elettromagneticservices.com*

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