CHARACTERIZATION OF MEASUREMENT SYSTEMS THROUGH EXTENSIVE MEASUREMENT CAMPAIGNS

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ABSTRACT

Within the European Union network "Antenna Center of Excellence" – ACE (2004-2007), two intercomparison campaigns among different European measurement systems, using the 12 GHz Validation Standard (VAST12) antenna, were carried out. These campaigns are described in the companion paper “Dedicated measurement campaign for definition of accurate reference pattern of the VAST12 antenna”.

The second campaign was performed by Technical University of Denmark (DTU) in Denmark, SAAB Microwave Systems in Sweden and Technical University of Madrid (UPM) in Spain. This campaign consisted of a large number of measurements with slightly different configurations in each of the three institutions (2 spherical near field systems and one compact range). The purpose of this paper is to evaluate the accuracy of the different facilities using this large number of acquisitions. The acquisitions were performed systematically varying in applied scanning scheme, measurement distances, signal level and so on.

The results are analyzed by each institution combining the measurement results in near or far field and extracting from these measurements: a “best” pattern, an evaluation of possible sources of errors (i.e. reflections, mechanical and electrical uncertainties) and an estimation of the items of the uncertainty budget.

Keywords: accuracy, standards, reference, uncertainty, intercomparison.

1. Introduction

During the period 2004 to 2007, European Union supported the “Antenna Centre of Excellence (ACE)” [1] as one of the Networks of Excellence financed within the VI European Frame Program. One of the activities of this network was dedicated to Antenna Measurements, and several universities, research institutes and privates companies along Europe were involved. In 2004 and 2005, the First Facility Comparison Campaign was carried out with the VAST12 antenna, involving 9 different measurement facilities. The results of the campaign are documented in the report [2] available from the Antennas Virtual Centre of Excellence portal [3]. The VAST12 was designed and manufactured at the Technical University of Denmark in 1992 under the contract from the European Space Research and Technology Center [4]. The main purpose of the VAST12 antenna is to facilitate antenna test range intercomparisons for the European Space Agency (ESA). The characteristics of this antenna have been detailed in the contribution “Dedicated Measurement Campaign for Definition of Accurate Reference Pattern of the VAST12 Antenna”.

One of the challenges of this first campaign was the establishment of a reference pattern with all the measurements collected, since each measurement was performed in a different system, with a different uncertainty budget, and even with a different measurement technique.

In 2006, SAAB Microwave Systems in Sweden, DTU in Denmark and UPM in Spain decided to carry out a second intercomparisons campaign with the same antenna. In this case, the main goal of the campaign was to achieve the best reference pattern for each institution, to get a precise uncertainty budget in order to be able to combine the results achieved in each institution to establish a common reference pattern. For this purpose, extensive measurement campaigns in a Compact Range (SAAB Microwave Systems) and in two Spherical Near Field

Systems (DTU and UPM) were performed during 2007 and beginning of 2008.

This paper details the procedure carried out to achieve the reference pattern and the corresponding uncertainty budget in each institution. For the uncertainty budget, in ACE a list of uncertainty contributions were detailed [6], extending the ones defined by Newell in [7]. Here, some of those contributions are reduced averaging different far field patterns.

2. Reference pattern establishment at DTU

DTU performed 14 different acquisitions modifying some parameters: inclusion of a extension flange, scan in θ or scan in ϕ, variation of the measurement distance and introduction of a 3 dB attenuator. The measurement setups are shown in Fig. 1. The AUT, in this case the VAST12 antenna, was measured in two configurations: in configuration 1 it was mounted directly to the mounting flange on the antenna tower, whereas in configuration 2 it was mounted to the antenna tower through the extension flange of 150 mm length. In both cases the origin of the measurement CS was located 280 mm forward from the front flange (visible under reflector in Fig. 1). In order to obtain this in the configuration 2, the antenna tower was translated backward by 150 mm, as compared to the configuration 1.

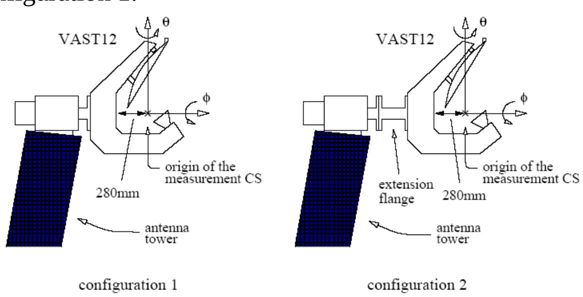

Figure 1. Configuration for measurements at DTU.

The antenna tower provides two axes of rotation: a vertical axis (θ-axis) and a horizontal axis (ϕ-axis). The near-field of the AUT can hereby be measured in any (θ,ϕ)-direction at a constant distance, i. e. a full sphere measurement, using the probe mounted on the probe tower. Two orthogonal components of the near-field are measured. The RF system comprises a Scientific Atlanta SA2180 signal source and a Scientific Atlanta SA1795 vector measurement receiver. The measurement is automated and controlled by a computer programme developed at the facility. The near-field to far-field transformation is performed with the SNIFTD software [5]. Prior to making any measurements of the AUT, pattern and polarization calibrations of the probe are performed. Before the last step of the polarization calibration is performed, the probe is placed in its final position on the probe tower. The probe is then not removed before all the measurements of the AUT are completed. The measurement procedure is outlined below:

- Mechanical alignment of the antenna tower and the probe tower.
- Pattern and polarization calibration of the probe.
- Mounting and alignment of the AUT on the antenna tower in the configuration 1.
- Eight full sphere measurements of the AUT (see Table 1).
- Re-mounting and alignment of the AUT on the antenna tower in the configuration 2.
- Six full sphere measurements of the AUT (see Table 1).

The alignment of the AUT in each configuration included a series of the flip-tests with the aim to check and correct the following errors: intersection between the horizontal and vertical axes of the antenna tower, horizontal and vertical pointing of the horizontal axis of the antenna tower. The measurements in Table 1 are designated with two-digit numbers: the first digit denotes the configuration, while the second digit denotes the running number for the measurement. The measurement parameters for the VAST12 antenna are given in Table 2.

Measurement	Description
	Configuration 1
11	Scan in θ, 0≤ϕ<180º, measurement distance 1
12	Scan in θ, 180≤ϕ<360º, measurement distance 1
13	Scan in ϕ, 0≤θ≤180º, measurement distance 1
14	Scan in θ, 0≤ϕ<180º, measurement distance 2
15	Scan in θ, 180≤ϕ<360º, measurement distance 2
16	Scan in ϕ, 0≤θ≤180º, measurement distance 2
17	Scan in ϕ, 0≤θ≤180º, meas. distance 2, 3 dB attenuator
18	Scan in ϕ, 0≤θ≤180º, meas. distance 2, 3 dB attenuator
	Configuration 2, 3 dB attenuator
21	Scan in θ, 0≤ϕ<180º, measurement distance 1
22	Scan in θ, 180≤ϕ<360º, measurement distance 1
23	Scan in ϕ, 0≤θ≤180º, measurement distance 1
24	Scan in θ, 0≤ϕ<180º, measurement distance 2
25	Scan in θ, 180≤ϕ<360º, measurement distance 2
26	Scan in ϕ, 0≤θ≤180º, measurement distance 2

Table 2. Description of the full sphere measurement

Measurement frequency:	12 GHz, single frequency
Measurement type:	Full sphere measurement
Measurement distance 1:	6070 mm
Measurement distance 2:	6063.75 mm
Scan angle range, increment:	0 ≤ θ ≤ 359.5º, 0.5º
Step angle range, increment:	0 ≤ ϕ ≤ 179º, 1º
Probe	Dual channel probe X3
Probe pattern correction:	Included. Probe pattern measured using SGH with identification BL159.
Probe polarization correction:	Included. Three antenna polarization calibration using SGH's with identifications BL152 and BL159.

Table 2. Measurement parameters for the VAST12 antenna

An optimum averaging procedure would require N pairs of the far-field results with the effect of some uncertainty being opposite in the two results of each pair. In addition, the number N should be equal 2^n, such that the averaged results are then also averaged in pairs. The available data do not satisfy this requirement completely, since the number of the pairs of the far-field results is not equal 2n. It is easy to identify several possible averaging scenarios, but due to the above difficulty the final averaging procedure is a bit complicated.

The following assumptions were made in the chosen averaging procedure:

1. The results at two measurement distances are affected by multiple reflections in essentially opposite way.
2. The results at two measurement configurations are affected by support structure in essentially opposite way.
3. The results from the two θ-scanning schemes are affected by mechanical uncertainties in essentially opposite way.
4. The support structure interference and the receiver non-linearity are independent uncertainties.
5. The results from the ϕ-scanning scheme and from any of the two θ-scanning scheme are affected equally by mechanical uncertainties.

The third assumption means that after averaging the results from the two θ-scanning schemes the mechanical uncertainties are considered to be compensated. However, there is no such complementary pair for the available result from the ϕ-scanning scheme as indicated in the last assumption. Therefore, it was decided to use the results from the ϕ-scanning scheme and from the θ-scanning schemes with approximately equal weights.

The final averaging procedure is as follows:

1. The results from the measurements with two measurement distances are averaged. This forms 6 results, which are designated: T_{11}, T_{12}, P_1, T_{21}, T_{22}, P_2. T stands for the θ-scanning scheme, P stands for the ϕ-scanning scheme, first number is for the configuration, while the second number indicates the limits of the θ-scanning scheme.
2. The results from the θ-scanning schemes are averaged: $T_1=(T_{11}+T_{12})/2$ and $T_2=(T_{21}+T_{22})/2$.
3. The results from the different scanning schemes are averaged as follows:

$$AV_1 = \left(\frac{T_1 + P_1}{2} + T_1\right) / 2$$

$$AV_2 = \left(\frac{T_2 + P_2}{2} + T_2\right) / 2$$

   In this way, e.g. the results T_{11} and T_{12} have weights 3/8, while P_1 has weight 2/8.
4. The results AV_1 and AV_2 are averaged in between.

The averaging was done in the linear scale between the corresponding field components. It is noted that the absolute phase is slightly different in the obtained results. This is partly due to drift and partly due to the different measurement distance. It is also noted that the phase pattern is sensitive to the location of the origin of the measurement CS and it is thus critical to reproduce its location in the second measurement configuration as compared to the first one. Comparison of the result AV_1 vs. AV_2, done after the step 3 of the averaging procedure above, has shown that there is certain progressive phase deviation between these, which can be essentially removed by moving the origin of the CS for the AV_2 by 2 mm along z-axis. Both AV_1 and AV_2 were then normalized such that the phase of the co-polar component is equal to 0 on-axis and averaged as described in step 4.

The second purpose of this measurement campaign is the estimation of the influence (and reduction if possible) of the following uncertainties sources:

- Axes intersection and pointing of the mechanical setup
- Amplitude and phase drift and noise
- Receiver non-linearity
- Probe polarization and channel balance
- Multiple reflections between the AUT and probe
- Mounting structure interference

Right now, the compilation of the uncertainty estimates is still on-going at DTU facility.

3. Reference pattern establishment at SAAB Microwave Systems

The measurements at SAAB MS (compact range facility) consisted of in total 12 directly measured far-field patterns as cuts in the main and diagonal planes, which were aimed at estimate of influence and at reduction of the following uncertainties:

- Wall reflections
- Edge diffraction at the compact range reflector
- Multiple reflections between the AUT and the compact range

The final result is formed as a complex far-field average of all 12 available patterns.

The measurements at UPM (spherical near-field facility) consisted of in total 18 full-sphere near-field acquisitions, which were aimed at estimate of influence and at reduction of the following uncertainties:

- Mechanical uncertainties of the setup
- Chamber reflections
- Mounting structure interference
- Receiver non-linearity
- Multiple reflections between the AUT and probe
- Amplitude and phase drift and noise

4. Reference pattern establishment at UPM

The measurements at UPM (spherical near-field facility) consisted of in total 18 full-sphere near-field acquisitions:

Acq. number	SCAN	STEP	Measurement Conditions
01	θ	0 ≤ φ ≤ 179	R=544cm
02	φ	0 ≤ θ ≤ 179	R=544cm
03	φ	181 ≤ θ ≤ 360	R=544cm
04	θ	181 ≤ φ ≤ 360	R=544cm
05	θ	0 ≤ φ ≤ 179	R=544cm
06	φ	0 ≤ θ ≤ 179	R=544cm, with absorber
07	θ	0 ≤ φ ≤ 179	R=544cm, with absorber
08	φ	181 ≤ θ ≤ 360	R=544cm, with absorber
09	φ	0 ≤ θ ≤ 179	R=544cm, 6dB att.
10	θ	0 ≤ φ ≤ 179	R=544cm, 6dB att.
11	φ	0 ≤ θ ≤ 179	R=544cm, λ/4 probe displacement
12	θ	0 ≤ φ ≤ 179	R=544cm, λ/4 probe displacement
13	φ	0 ≤ θ ≤ 179	R=544cm, centre of rotation displaced
14	θ	0 ≤ φ ≤ 179	R=544cm, centre of rotation displaced
15	φ	0 ≤ θ ≤ 179	R=295cm
16	θ	0 ≤ φ ≤ 179	R=295cm
17	φ	181 ≤ θ ≤ 360	R=295cm
18	θ	181 ≤ φ ≤ 360	R=295cm

Table 3. Description of the full sphere measurement at UPM

Acquisition 01 and 05 were repeated with the same configuration to check the repeatability of the measurement procedure. The standard measurement distance is 544 cm, although some scans were repeated at a smaller distance (295 cm). Different scan configurations in ϕ and in θ were carried out (lower sphere, upper sphere, right and left hand side). These configurations allow us to evaluate the effect of mechanical errors and chamber reflections effects. In acquisitions 06 to 08, the antenna structure and support was partially covered with an absorber to reduce the effect of AUT scattering contribution. Measurements 09 and 10 were performed including a 6 dB attenuator in order to reduce the effect of non linearity amplitude effects. Acquisitions 11 and 12 were performed to be able to average with cases 02 and 05 to cancel the effect of the reflections. Finally, acquisitions 13 and 14 modify the contribution of the mechanical errors on the radiation pattern.

The procedure to establish the UPM reference pattern is done following the next criteria:

- The individual measurements are processed and the worst cases are excluded.
- A first average of the selected scans is done, and a first reference value is obtained.
- The complex average of the far field is done in pairs, in order to estimate only one effect at each time. For instance:
    - 02 is averaged with 11, and it is assumed that the average compensate the multiple reflections.
    - 02 is averaged with 03 and 04 with 05. These scans are performed with different mechanical errors and different chamber reflections. We assume that the average improves both effects.
    - 02 is compared with 06 to establish the effect of AUT support scattering. In this case, we assume that both measurements only differ in the contribution of the support scattering, and in case 06 this contribution can be neglected.
    - 02 is compared with 09 to establish the effect of receiver non linearity. We assume that the effect of non-linearity is worse in the first case (at least for the peak directivity).

This large number of acquisitions allows us to repeat the evaluation of some uncertainty sources. Other uncertainty sources (i.e. noise, leakage, thermal drift and cable and rotary joints variations) are evaluated through simulations according to [8].

- The uncertainty for the peak directivity of each of the previous scans or averages of scans is calculated comparing the peak directivity value of each set of scans or set of averages with the first reference value. This allows us to solve simple equations to derive each uncertainty source value.
- Five sets of four comparable acquisitions are complex averaged, and their uncertainty is calculated using the results obtained previously. This estimation has been performed assuming that some source of errors in the average can be considered negligible. These five sets include 12 full sphere acquisitions (so, some of them are repeated).

- The uncertainty of each set is calculated adding the variance of the values of the uncertainty sources obtained before.
- The UPM reference value is obtained using the same expressions that will be explained in the next section.

5. Establishment of the Final Reference Pattern

Although compilation of the uncertainty estimates is still on-going at the facilities, the final reference pattern will be established by averaging the results from different facilities with weights inversely proportional to the estimated uncertainties, according to [9]:

$$\bar{d}_w = \sum_{i=1}^{3} \frac{d_i}{u^2(d_i)} \times u^2(\bar{d}_w)$$

where:

- "$\mathbf{d_i}$" represents the directivity of each of the contributions ("dir_{DTU}", "dir_{SAAB}", "dir_{UPM}"),
- "$\mathbf{u^2(d_i)}$" designates the square of the standard uncertainty for each contribution,
- "$\mathbf{u^2(\bar{d}_w)}$" denotes the square of the uncertainty in the Weighted Reference Value (WRV), which is given by:

$$u^2(\bar{d}_w) = 1 \Big/ \sum_{i=1}^{3} \left(\frac{1}{u^2(d_i)} \right)$$

6. Conclusions

Antenna Centre of Excellence has been working on intercomparisons for antenna measurement in order to improve the measurement accuracy of the involved institutions. The existence of an accurate reference pattern of a reference antenna allows benchmarking of the antenna test ranges and estimating their measurement uncertainties. A dedicated measurement campaign carried out in 2007-2008 for definition of the highly accurate reference pattern of the VAST12 antenna has been described in this paper. This paper has shown three different approaches to calculate the reference pattern and to estimate the uncertainty budget at three different European measurement facilities.

7. REFERENCES

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8. ACKNOWLEDGMENTS

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