# Facility Comparison Campaigns Within EurAPP

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*Abstract*— **An important activity within the past Antenna Centre of Excellence (ACE) network was dedicated to facility comparison campaigns as reported in [1-7]. The activities spanned the frequency range from L-Ka band using different antennas (VAST12, SATIMO SH800 and SATIMO SH2000). The vast amount of data from different measurements institutions within Europe and US has been used to establish a reference pattern for each of the high accuracy reference antennas. The reference patterns and the data from the facility comparison activities are considered important instruments to verify the measurements accuracies for antenna measurement ranges as well as to investigate and evaluate possible improvements in measurement set-ups and procedures. This paper gives an overview of the ongoing activities in the frame of the EURAPP working group on antennas measurements and the first considerations on useful criteria for comparing and evaluating large amount of measured antenna data.**

## I. Introduction

Several facility comparison campaigns have been carried out during the last years in the framework of the different European Activities regarding to Antenna Measurements. The Antenna Measurement Activity of the Antenna Centre of Excellence [8] of the VI Frame program of the UE, in the period of 2004 to 2007, began to define some reference antennas to be used for these purposes. A high directive reflector antenna, DTU-ESA 12 GHz VAST12 [9], and two dual ridge horns, SATIMO SH800 [10] in L, S and C band (SH800) and SATIMO SH2000 in Ku and Ka bands, were employed. After finishing the works of this network of excellence, the different tasks related to this topic have been continued in the frame of the COST ASSIST (IC0603) [11] and now, included in the Antenna Measurement Working group of the EurAAP [12], where a specific task for Antenna Measurement Intercomparisons has been approved.

The main lesson of these campaigns is that comparative measurements based on high accuracy reference antennas and involving different antenna measurement systems are important instruments in the evaluation, benchmarking and calibration of the measurement facilities. Regular inter comparisons are also an important instrument for traceability and quality maintenance. These activities promote and document the measurement confidence level among the participants and are an important prerequisite for official or unofficial certification of the facilities.

In this paper, we will review the work realized with the three first reference antennas, emphasizing in the achieved conclusions. Then, the last intercomparison campaign for a new reference antenna, the SATIMO BTS 1940 for cellular telephony base stations, is explained. The first results for this campaign are also presented. The next sections will introduce the activities proposed for the Antenna Measurement Intercomparison task in the Antenna Measurement WG of the EurAPP. Finally, some conclusions and future lines are extracted.

## II. Previous Antenna Measurement Campaigns in the Frame of Antenna Centre of Excellence

### A. DTU-ESA 12 GHz VAST12 campaigns.

For the first campaign a very high quality antenna with a very directive radiation pattern was selected. This antenna was the VAST-12 (Fig.1). This antenna was designed and manufactured at the Technical University of Denmark in 1992 for the European Space Agency (ESA) [9]. VAST12 was designed to serve as a reference antenna for the purpose of comparison and validation of antenna measurement facilities. The antenna is an offset shaped reflector with a circular aperture fed by a conical corrugated horn with a polarizer, although for this configuration linear polarization is selected. This configuration provides a complex pattern with low side lobes and a high ellipticity of the main beam. The mechanical construction of the VAST-12 antenna is based on a light-weight carbon fiber reinforced polymer support structure (CFRP), making the antenna structure mechanically and thermally very stable. These electrical and mechanical characteristics make this antenna very suitable for comparison purposes.

The VAST-12 comparison campaign took place during 2004 and 2005, with 8 facilities of 6 different institutions providing results (Saab Microwave Systems, France Telecom R&D, RUAG Aerospace Sweden, Technical University of Catalonia, Technical University of Denmark and Technical University of Madrid). The measurements were carried out in compact ranges (CR), far field (FF), spherical near field systems (SNF) and planar near field systems (PNF). DTU leaded this process and two measurements at the beginning and the end of the campaign were performed there.

Fig. 1 The DTU-ESA 12 GHz VAST 12 Antenna.

TABLE I
VAST-12 1ST INTERCOMPARISON CAMPAIGN

| Participant | Facility type | Peak Dir (dBi) | Peak gain (dBi) | On axis gain (dBi) |
|---|---|---|---|---|
| SAAB | CR | 30.72 | 30.43 | - |
| FRTD | FF | 31.1 | 30.4 | - |
| RUAG | SNF | 30.67 | 30.41 | 30.40 |
| UPC | SNF | 30.87 | - | - |
| DTU (1) | SNF | 30.71 | 30.35 | 30.33 |
| DTU (2) | SNF | 30.72 | 30.59 | 30.56 |
| UPM | SNF | 30.65 | 30.39 | 30.36 |
| UPM | PNF | - | 30.38 | 30.33 |
| UPM | CR | - | - | 30.39 |

For the comparison of the pattern different techniques were analysed [13], using linear or logarithmic differences and various choices of weighting functions.

A second campaign [14], involving the SAAB compact range and the DTU and UPM spherical near field systems, was carried out in 2007 and 2008. In this case, a very intensive measurement campaign was performed; where each institution should accomplish a large number of measurements (12 to 18 measurements in each facility) in order to reduce as much as possible the uncertainties. In this case the comparison considered the uncertainties calculated by each institution using a unified procedure. In this case, the objective was to obtain a very accurate reference pattern for the VAST-12 antenna, in order to be used as reference for future campaigns.

## *B. SATIMO SH800 and SH2000 campaigns.*

Two wideband dual ridge horns were selected in these cases. In this case, the campaigns were headed by SATIMO. Due to the ridge, ridge horns are much smaller and less bulky that the corresponding standard gain horn at comparable frequencies. Carefully designed dual ridge horns have excellent return loss, cross polar and flat gain response (typically 7-15 dBi) in a 1:15 frequency range. Therefore, very few horns are require to cover the operative range of an antenna testing facility. High quality designs are based on numerically controlled and precision fitted mechanical parts, so very little performance difference can be observed between similar horns.

The Satimo Dual Ridge SH800 (0.8-12GHz) Horn as shown in Fig. 2 is widely used as a broadband reference antenna. The horn is connectorized and essentially an open, flared ridge waveguide with lateral bars designed to harmonize the gain with frequency curve. At low frequencies, the bars appear as a closed surface and increase the boresight gain of the horn, whereas at high frequencies the bars are electrically transparent and the effective gain decreases.

Fig. 2 The SATIMO SH800 Dual Ridge Horn (0.8-12 GHz).

This activity on comparative measurements was performed involving different test facilities. Measurements were performed in the DTU-ESA spherical near-field antenna test facility at the Technical University of Denmark (DTU), in both of the SATIMO multi probe spherical near field systems (SG-64) in Atlanta (USA) and Paris (France), in the spherical near field system of technical university of Madrid (Spain) and the combined farfield/spherical near field test range of Saab Ericsson Space (Sweden) and the far field ranges of IMST (Germany) and National Centre for Scientific Research (Greece). The data collection and processing was conducted by SATIMO in cooperation with the other participants and documented in an ACE report. The traditional comparison of data involved the comparison of boresight gain and directivity values for different frequencies; however, the measurement differences and their sources are often better understood by direct inspection and comparison of the patterns. Since the direct comparison of large amount of measured pattern data is unfeasible by inspection of pattern differences alone, a statistical approach was implemented that allows the comparison of data in a simple form.


Fig. 3 Participants for the SATIMO SH800 Intercomparison Campaign.

Different results were published in ACE report and symposiums [1]. Fig. 4 shows the results from some institutions for the gain difference with respect to the weighted mean value (reference). The reference data can be calculated as the simple mean or weighted mean of each data entry where the weights are proportional to the estimated uncertainty. This reference value and its uncertainty were obtained using the measured values and their uncertainties (1).

$$X_{typ} = \frac{\sum_{i=1}^{N} \left( \frac{x_i}{u_i^2} \right)}{\sum_{i=1}^{N} \left( \frac{1}{u_i^2} \right)} \qquad u_{typ} = 1 + \sqrt{\frac{1}{\sum_{i=1}^{N} \frac{1}{(1-u_i)^2}}} \tag{1}$$

The uncertainty associated with the weighted mean is "improved" if the measurements are truly independent. The previous formulas give RSS values corresponding to the 1σ value, with 69% confidence level assuming a normal distribution.

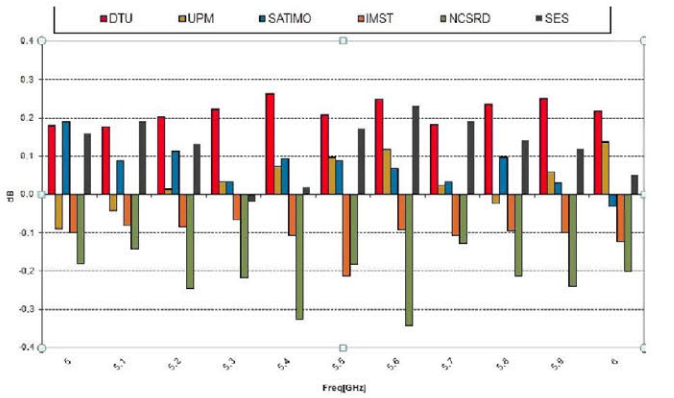


Fig. 4 Gain difference from "weighted mean value" reference for the SH800 Intercomparison campaign.

The next antenna, the SH2000 (2-32GHz) is dual ridge horn that combines a stable gain performance and low VSWR with wide band frequency operation. The horn is single linearly polarized with high cross-polar discrimination and is often used as a reference antenna for gain calibration of antenna measurement systems or as a wideband probe in classical far field test ranges. The horn is specifically designed to avoid excitation of higher order modes in the aperture and to maintain a well-defined smooth radiation pattern in the direction of the boresight axis throughout the operational bandwidth. The horn is equipped with a high precision female 3.5 mm connector intermateable with SMA and K connectors.

Experiences from previous facility comparisons [1-5] had shown that the measured results are sensitive to the measurements configuration and, in particular, the type of positioner. To improve the correlation and independence from measurements configurations, the test antenna was equipped with a small absorber plate (250 x 250mm) covering the mechanical interface as shown in Fig. 5.

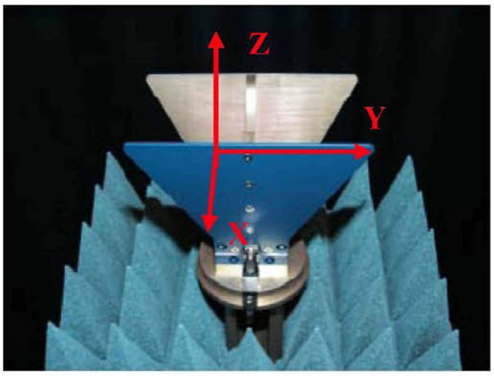


Fig. 5: SATIMO SH2000 Dual Ridge Horn with an absorber plate.

For the SH2000, 8 frequencies were selected in Ku and Ka bands and 11 different test facilities were involved (Table II). The comparison of such a large amount of measured data is unfeasible by inspection of pattern differences and should not be limited to studying boresight or peak differences alone [15]. Different approaches were implemented to overcome this problem.

TABLE II
PARTICIPATING INSTITUTIONS, ACRONYM, COUNTRY OF ORIGIN AND MEASUREMENT CONFIGURATION.

| *Acronym* | *Name* | *Country* | *System* |
|---|---|---|---|
| SATIMO | SATIMO | France | SNF |
| DTU | Technical University of Denmark | Denmark | SNF |
| UPM | Technical University of Madrid | Spain | SNF |
| UPC | Technical University of Catalunya | Spain | SNF |
| SES | SAAB Ericsson Space | Sweden | SNF |
| FTR&D | France Telecom | France | FF |
| GTRI | Georgia Tech Research Institute | USA | FF |
| IMST | IMST GmbH | Germany | FF |
| XLIM | University of Limoges/CNRS | France | C |
| THALES | Thales Alenia Space | France | C |
| SAAB | SAAB Group | Sveden | C |

From the reference pattern, the standard deviation of the differences for each measurement and in each direction was calculated. This value expresses the effective variation over the 45° forward cone giving an indication of the measurement error level in a single value. The procedure is expressed in (2), where directivity data for each angular position in linear scale is normalized respect the boresight value and the reference value:

$$f(\theta) = \left( \frac{Dir_{co,xp} - Dir_{ref\_co,xp}}{Dir_{ref\_co,xp}} \right) \cdot \left( \frac{Dir_{co,xp}}{Dir_{co,boresight}} \right) \tag{2}$$

The resulting number express the equivalent signal-to-noise level in which all deviations with respect to the reference pattern has been converted into an equivalent "noise". The calculated copolar standard variation for each facility with respect to the weighted mean reference pattern is shown in Fig. 6. The standard deviation σ is very useful to quantify the range in which measurements errors are distributed. It expresses the 68.3% confidence that the measurements errors are within this level (the 99.7% confidence level is 3σ). The standard deviation expresses only the variation, but it does not consider a general shift. This also means that this value "cleans" the comparison from differences caused by pattern difference in the antenna back-lobe (usually due to differences in the measurement set-up). The impact of this is often very small in high gain measurements, but can be a significant contribution for medium and low gain antennas, as in this case.

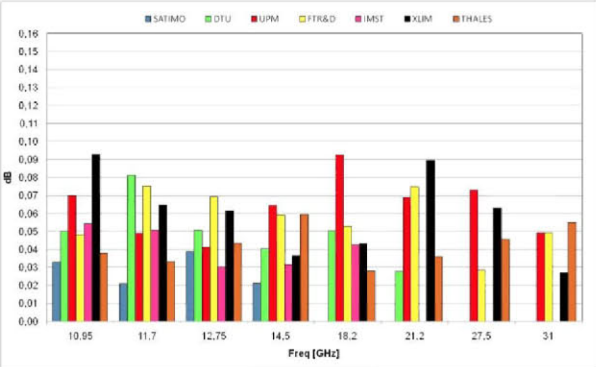


Fig. 6: Copolar standard deviation calculated from weighted mean reference patterns in 4 cuts in forward 45° cone.

## III. Intercomparison Campaign for the SATIMO BTS1940 Antenna

In 2009, a new intercomparison campaign began. In this case, the AUT is a BTS array working in GSM1800 and UMTS frequency bands (1710 to 2170 MHz). The BTS1940 is a linear array reference antenna with dual slant +45°/-45° or H/V polarized. This antenna is ideal as reference for calibration of antenna measurement systems. The array is specifically designed to achieve excellent crosspolar discrimination and to maintain a well defined radiation pattern in the direction of the boresight axis throughout the operational bandwidth. The BTS1940 antennas are equipped with high precision female N type connectors for superior repeatability and durability. The nominal impedance is 50 ohm with return loss values better than -15 dB (VSWR < 1.5).

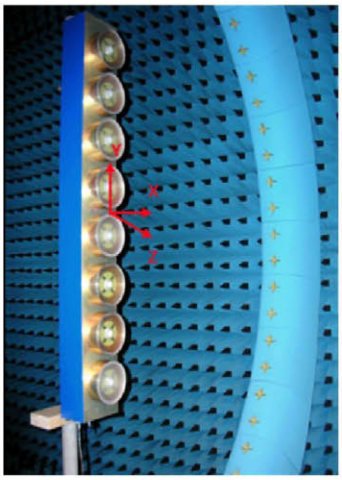


Fig. 7: SATIMO linear array antenna 1710-2170MHz (BTS1940) in test configuration. The reference coordinate system is shown on the antenna.

The SATIMO linear array antenna BTS1940 has been measured in the reference coordinate system shown on the antenna in Fig. 7.

Until now, the BTS1940 has been measured in SATIMO, Technical University of Madrid (UPM), SAAB, University of Oviedo (UNIOVI), Technical University of Valencia (UPV) and Huawei. The first results show the radiation pattern comparisons at 1920 MHz for the first three facilities and the comparison in peak directivity directivity for five facilities. The results show a good concordance among all the facilities.

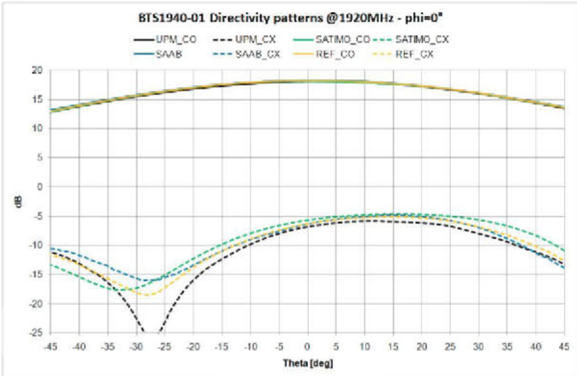


Fig. 8: BTS 1940 horizontal pattern at SATIMO, UPM and SAAB compared with weighted reference value.

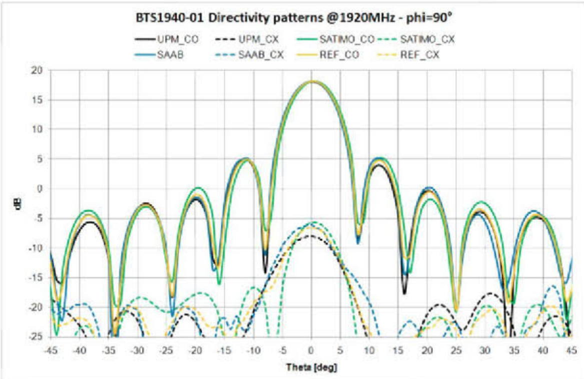


Fig. 9: BTS 1940 vertical pattern at SATIMO, UPM and SAAB compared with weighted reference value.

TABLE III

Boresight Directivity of the Participant Facilites for BTS1940

| | Boresight Directivity [dBi] | | | | |
|---|---|---|---|---|---|
| | UPV | UPM | SAAB | Huawei | SATIMO |
| Freq [MHz] | *SNF* | *SNF2* | *CR* | *SNF3* | *SNF4* |
| 1710 | 17,40 | 17,28 | 17,35 | 17,38 | 17,34 |
| 1795 | 17,77 | 17,62 | 17,73 | 17,68 | 17,63 |
| 1880 | 18,14 | 18,02 | 18,05 | 18,01 | 18,02 |
| 1920 | 18,33 | 18,17 | 18,22 | 18,17 | 18,15 |
| 2170 | 18,81 | 18,76 | --- | 18,93 | 18,87 |
| 2200 | 18,79 | 18,77 | --- | --- | 18,85 |

## IV. ACTIVITIES TO BE CONDUCTED IN THE FRAME OF THE ANTENNA MEASUREMENT INTERCOMPARISON TASK OF EURAAP

The previous campaigns have been very useful for different purposes, as validation of new antenna measurement systems, detection of problems in existing facilities, accreditation purposes (i.e. ISO17025). Regarding this last item, there are several European facilities that are already accredited (SATIMO, IMST, SAAB Microwave Systems, UPM) or beginning the process, in the case of DTU. Under EurAAP frame, a new task 'Antenna Measurements Intercomparison (AMI)' has been created following the next objectives:

- To organize and manage the European Antenna Measurement Facilities Intercomparison campaigns during the next years.
- To create reference values (antenna pattern, gain,…) for the antennas involved in the previous and future campaigns, agreeing on the general rules of the intercomparison campaigns, on the way of calculation of the reference values and uncertainties.
- To plan and carry out one or more campaigns and to report the results of these campaigns.
- To manage the service of measurement of these antennas by other laboratories and to send a report with the comparison of the measured results with the reference values. During the first year, the Task members will agree regarding the fee for this kind of service.

Antenna measurement facilities are invited to participate in this task.

## V. CONCLUSIONS

These campaigns gave us a set of important conclusions to be considered during the antenna measurement intercomparison processes, summarized in:

- A very precise definition of the setup is necessary in order to assure that all participants are performing the measurements in the same way.
- The organization of the campaigns requires the exact definition of the objectives to be pursued, in order to prepare in advance the test plan, test procedure and the procedure for giving the results.
- A unified procedure for getting the uncertainty for a specific measurement has to be agreed.
- In any case, this exercise is very useful for improving the quality of the facility (detecting errors) and the measurement capability of the participants.
- These campaigns have become very useful for the facilities that have the ISO17025 accreditation or are in the process. Also, regular inter comparisons are also an important instrument for traceability and quality maintenance.
- The reference value has to be obtained considering the uncertainty of each measurement and facility.


## ACKNOWLEDGMENT

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