FACILITY COMPARISON AND EVALUATION USING DUAL RIGDE HORN

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ABSTRACT

Facilities comparisons involving high accuracy reference antennas are key instruments for the evaluation, benchmarking and calibration of antenna measurements systems. Regular inter comparisons between accredited measurement facilities are also an important instrument for the measurement traceability and quality maintenance.

In the frame of Activity 1.2 *"Antenna Measurement Techniques and Facility Sharing"* of the EU network "Antenna Center of Excellence" (ACE) an activity on comparative measurements has been performed. The ongoing activity involves different test facilities and a 0.8-12GHz dual ridge horn. The facility comparison activities will be extended to more facilities within and outside Europe in the following two years.

The participating facilities in this campaign where: SATIMO, the technical university of Denmark (DTU), The technical university of Madrid, Spain (UPM) and Saab Ericsson Space, Sweden (SES).

**Keywords**: Antenna measurements, comparison, validation, reference antennas.

1. Introduction

Comparative measurements at 25 frequencies have been performed on a dual ridge horn involving four different test facilities in the 1.55-6GHz range. The comparison of large amounts of measured data is unfeasible by inspection of pattern differences and should not be limited to studying boresight differences alone. Therefore a statistical approach has been implemented for the fast evaluation of large amounts of measurement data.

In the following, the measurement systems employed by each institution are briefly described.

2. SATIMO measurement facility

The SATIMO SG-64 measurement facility in Atlanta, USA is a spherical near field range as shown in Figure 1. The Satimo SG systems, that are now installed worldwide, consists of a probe array based on advanced Modulated Scattering Techniques (A-MST) and a passive combining network [1]. Such arrays have been installed covering frequencies from 70MHz to 18GHz. The electronic scan of the probe array provides outstanding measurement speed and the geometry of the set-up with only a Styrofoam column in the vicinity of the Antenna under test (AUT) ensures minimum interference and low ripple on the measured radiation patterns.
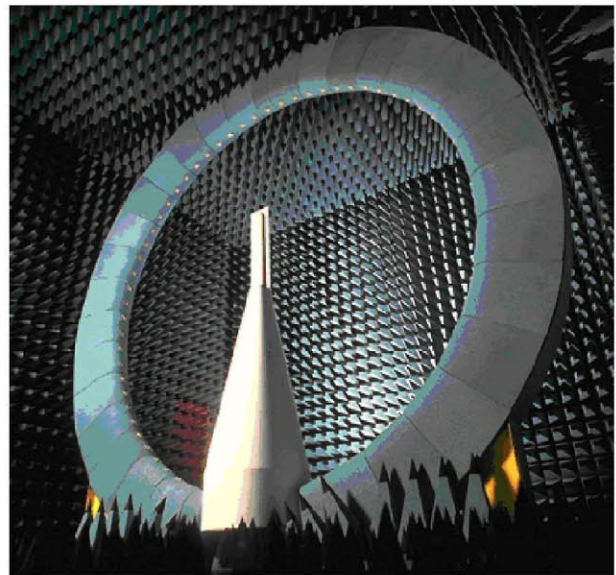
Figure. 1: Satimo SG-64. The AUT is placed on top of the pedestal, in the centre of the system.
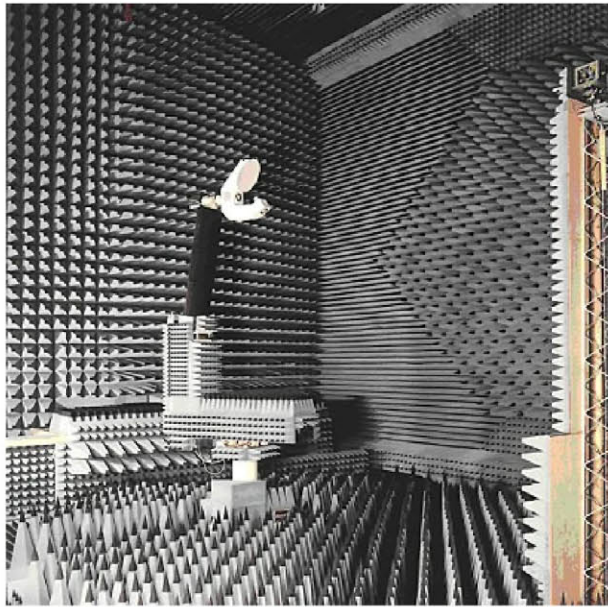
Prior to the measurement, the AUT is aligned using electrical or mechanical alignment based on a

permanently mounted laser cross beam illuminating the centre of the range.

The gain of the AUT is determined by the gain-transfer or substitution method in which the unknown power gain of the test antenna is measured by comparing it to that of a gain-standard antenna [2].

2. DTU-ESA measurement facility

The DTU-ESA measurement facility located at the Technical university of Denmark (DTU) is a single probe spherical near field system as shown in Figure 2.

Figure 2: DTU-ESA Spherical Near-Field Antenna Test Facility.

Prior to the measurement, the measurement set-up is carefully aligned using a theodolite permanently mounted on the probe tower, optical mirrors and precision levels. Careful probe calibration is then carried out to take full advantage of the probe correction inherent in the near-to-far field transformation algorithm. Probe calibration is of particular importance for the measurement of antenna gain, directivity and cross-polar patterns.

The radiation pattern measurement is carried out in two steps. First, two orthogonal components of the near field of the Antenna Under Test (AUT) are measured in amplitude and phase in a number of points on a regular grid on a full sphere. This is accomplished in the DTU-ESA Facility by using a fixed probe and rotating the AUT with a high-precision roll-over-azimuth antenna tower shown to the left in Figure 2. The dual-polarized probe, a conical horn excited by a circular waveguide with the TE$_{11}$ mode, is mounted on the probe tower positioned about 6 m from the vertical axis of the antenna tower.

Next, the near field is transformed to the corresponding far field using SNIFTD software based on a spherical wave expansion of the near field [3]. During the transformation, a value for the total radiated power is also found. The directivity in any direction is then found as the ratio between the power densities in that direction and the average radiated power density. A detailed treatment of the spherical near-field measurement technique can be found in [4].

For a general AUT the gain measurement is performed using the gain-transfer or substitution technique, where the amplitude of the AUT near field is compared with the amplitude of the near field of a Standard Gain Horn (SGH). Combined with the knowledge of the near- and far-fields of the two antennas, obtained from full-sphere measurements of both, the ratio between the gains of the AUT and the SGH can be determined. The input reflection coefficients of the AUT, the signal source, and the SGH are also measured and accounted for to accurately determine the gain of the AUT according to the IEEE definition. A detailed treatment of the gain determination technique can be found in [5], pp. 210-214.

For a smooth wall SGH, the gain has been determined by subtracting the calculated loss from the directivity. The directivity is found from a full sphere measurement, while the loss in the waveguide and in the pyramidal section is estimated using well known formulas for the ohmic loss in a rectangular waveguide (see e.g. [6], p. 423). It is assumed that only the TE$_{10}$ mode is propagating in any part of the SGH. The loss in the pyramidal section is calculated by modelling it by a large number of short regular waveguide sections with each section having cross sectional dimensions slightly larger than the preceding section. This loss calculation is approximate, but since the loss is very small and less than the accuracy of the directivity measurement, this is considered as an adequate technique.

3. UPM measurement facility

The UPM measurement facility, located at the Technical university of Madrid, Spain is a single probe spherical near field system as shown in Figure 3

The radiation pattern measurement is carried out in two steps: first, the near field of the Antenna Under Test (AUT) is measured in a number of points in a full sphere. Next, the near field is transformed to the corresponding far field using spherical wave expansion of the near field using SNIFTD [3]. During this transformation, a value for the total radiated power is also found.

Figure 3: UPM, Spherical Near-Field Antenna Test Facility. AUT Positioner on longitudinal table and Roll over Azimuth Polarization Positioner.

The directivity in any direction can be found as the ratio between the power density in that direction and the average radiated power density.

The gain measurement is performed using a substitution technique, where the amplitude of the AUT near field is compared with the amplitude of the field of a Standard Gain Horn at the same distance. Combined with the knowledge of the near and far fields of two antennas, obtained from full-sphere measurement of both, the ratio between the gains of the AUT and Standard Gain Horn (SGH) can be determined. The gain of the SGH is found by subtracting the loss from its directivity. The directivity is found from a full sphere measurement. The losses of the SGH are estimated. The reflection of both SGH and AUT are considered for gain calculation.

4. SES measurement facility

The Saab Ericsson Space indoor dual mode test range A6 (SES) is located in Gothenburg, Sweden The test range is a dual mode facility where the AUT can be either a passive antenna or an active antenna. It is used for applications that range from far-field measurements of small antennas to near-field testing of directive reflector and array antennas.

The anechoic chamber is a 5 (width) x 5 (height) x 9 (length) m³ rectangular chamber lined with pyramidal absorbers as shown in figure 4. To protect the measurements from external disturbances, or to protect the outer environment when active antennas are tested, the facility is RF shielded. The level of shielding is better than 90 dB. Access to the test object is via a drawbridge, as shown in Figure 5.
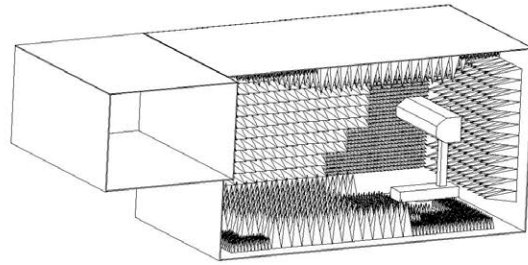

Figure 4: Outline of the SES facility.

The frequency range covered is 0.8 – 40 GHz and the measurement distance is 6 m. The quiet zone diameter is 0.5 m for far-field measurements and more than 1.2 m for near-field measurements.

The RF subsystem is based on an HP8530 microwave receiver with distributed mixers. The signal and LO sources are of the HP8360 family. The range antennas used are two dual linearly polarised wide band horns for 0.8 – 4.5 GHz and 2 – 18 GHz and two standard gain horn antennas for 18 – 26 GHz and 26 – 40 GHz. It is possible to measure four ports on the AUT and two polarisations on the range antenna.

The positioner system features a high precision roll over slide over azimuth system with a tower between the slide and roll positioner. The roll axis is interchangeable between a high precision high load positioner (100 kg load) and an extremely low profile positioner (10 kg load) for measurement of small antennas. The positioner control is accomplished by an Orbit/FR AL-4146-2 power amplifier and a DSP card in the range computer.
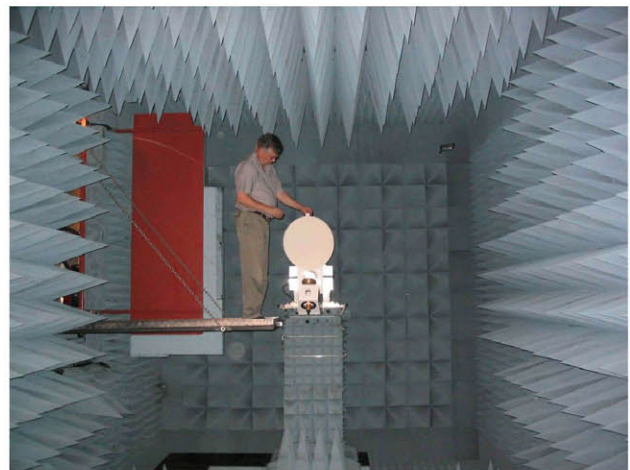

Figure 5: SES test range for active and passive testing. Access to the antenna test object is via a drawbridge.

5. Dual ridge horn

The SATIMO 0.8-12GHz dual ridge horn as shown in figure 6 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 reference antennas for gain calibration of antenna measurement systems or as wideband probes in classical far field test ranges.

The horn is specifically designed to avoid any 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. Thanks to the lightweight design in corrosion resistant aluminium and high reliability manufacturing technology the horn is robust, low weight, easy to handle and have excellent performance repeatability.

The horn is equipped with a high precision female 3.5mm connector intermateable with SMA and K connectors, for superior connector repeatability and durability. The nominal impedance is 50Ohm with return loss values better than -10dB (WSVR < 1.9) throughout the operational bandwidth.
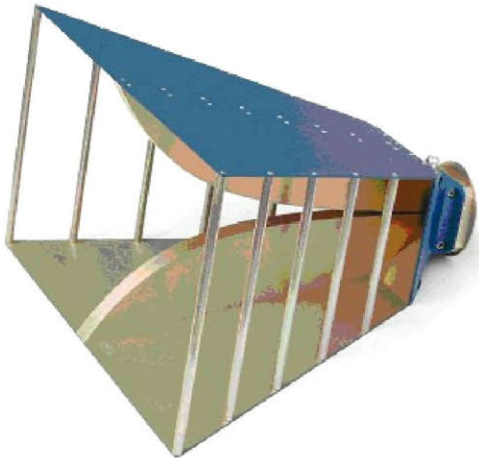
**Figure 6: SATIMO SH800-SN044 horn used for the facility comparison.**

6. Boresight pattern comparison

The measured boresight gain and directivity values from the four facilities at 25 frequency points in the 1.55 – 6 GHz range are shown in table 1.

For each measured frequency a reference directivity value has been determined as the geometric mean of the 4 measurements where the globally most distant of the 4 measurements has been discarded for each frequency. The difference of each measurement with the reference has been illustrated graphically in Figure 7 and Figure 8.

Freq	DTU Dir	DTU Gain	SATIMO Dir	SATIMO Gain	UPM Dir	UPM Gain	SES Dir	SES Gain
1.55	9.97	9.93	9.78	9.70	10.01	10.01	9.87	9.84
1.60	10.22	10.04	10.06	9.98	10.03	10.19	10.05	9.95
1.71	10.73	10.67	10.43	10.34	10.56	10.57	10.69	10.7
1.75	10.8	10.72	10.48	10.39	10.57	10.49	10.85	10.88
1.80	10.49	10.4	10.26	10.17	10.3	10.2	10.49	10.38
1.88	9.41	9.32	9.45	9.35	9.35	9.39	9.65	9.45
1.92	9.35	9.26	9.29	9.20	9.23	9.38	9.43	9.27
1.96	9.67	9.57	9.56	9.47	9.36	9.54	9.55	9.57
2.00	9.86	9.74	9.79	9.69	9.63	9.59	9.72	9.59
2.11	10.14	10.05	10.03	9.94	10.24	9.73	9.82	9.75
2.17	10.44	10.38	10.20	10.11	10.37	10.17	10.37	10.41
2.40	11.1	11	11.03	10.93	11.1	11.19	11.07	11.06
2.45	11.15	11.06	11.10	11.01	11.17	10.96	11.13	11.06
2.50	11.21	11.11	11.21	11.11	11.23	11.12	11.17	11.03
5.00	12.39	12.32	12.49	12.33	12.23	12.05	12.45	12.3
5.10	12.66	12.55	12.62	12.46	12.54	12.33	12.71	12.56
5.20	12.85	12.74	12.80	12.65	12.75	12.55	12.93	12.67
5.30	13.03	12.93	12.89	12.74	12.9	12.74	12.91	12.69
5.40	12.96	12.86	12.84	12.69	12.92	12.67	12.86	12.62
5.50	12.66	12.56	12.60	12.44	12.7	12.45	12.77	12.52
5.60	12.65	12.54	12.51	12.36	12.68	12.41	12.78	12.52
5.70	12.7	12.6	12.60	12.45	12.61	12.44	12.66	12.61
5.80	12.77	12.66	12.67	12.52	12.65	12.4	12.62	12.56
5.90	12.76	12.64	12.58	12.42	12.63	12.45	12.77	12.51
6.00	12.69	12.57	12.48	12.32	12.65	12.49	12.67	12.4

Table 1: Measured boresight directivity and gain values at the four facilities.
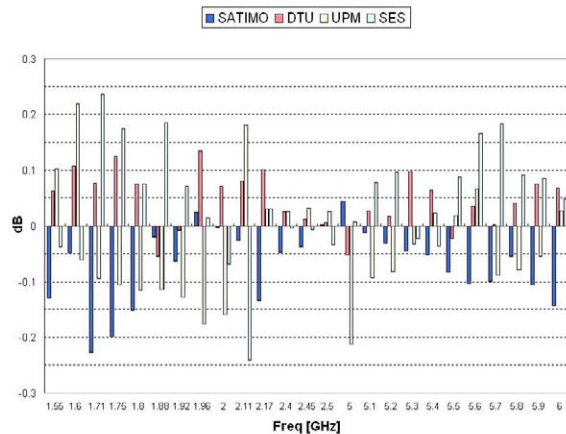

Figure 7: Boresight Directivity, difference to geometric mean of all measurements excluding the most distant sample.
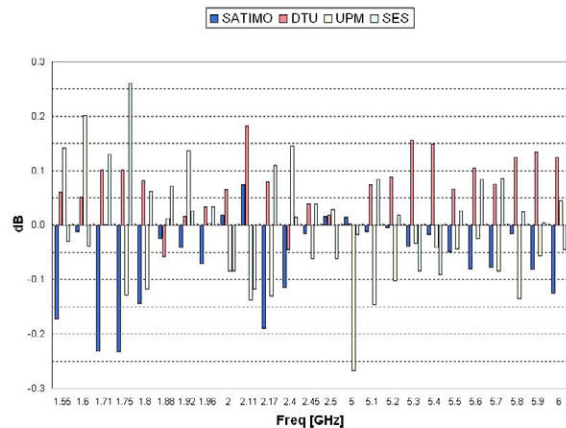

Figure 8: Boresight Gain, difference to geometric mean of all measurements excluding the most distant sample.

The measured boresight directivities are all in good agreement with deviation within 0.15/0.20 dB. UPM and SATIMO directivities are slightly below the mean value with SES and TUD slightly above. This is probably due to the measurement set-up where each facility provided the necessary absorbers to cover the antenna positioner. The SATIMO measurement set-up is without absorbers as shown in Figure 9 and as such included slightly more power in the antenna back-lobe lowering the overall directivity and gain values.
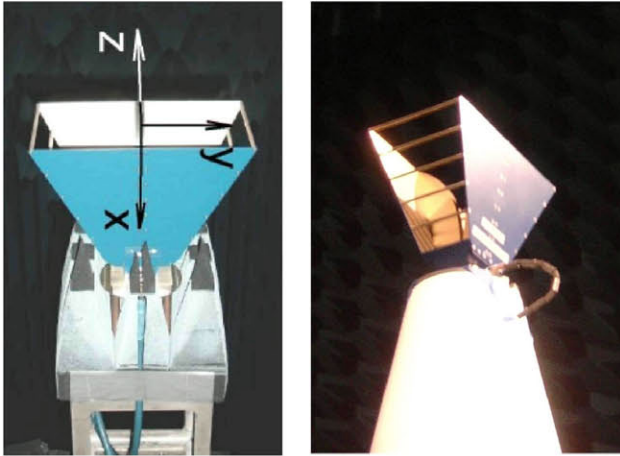
Figure 9: Difference in antenna mounting. Styrofoam positioner (right) in the Satimo range and Absorber covered positioner in the DTU range (left).

The measured antenna loss of is defined as the measured directivity minus the antenna gain using the IEEE definition [2]. The comparison is shown in Figure 10. The correlations of the measured losses are quite good with mean values around 0.1-0.15dB with TUD and SATIMO in good agreement and slightly lower than UPM and SES.
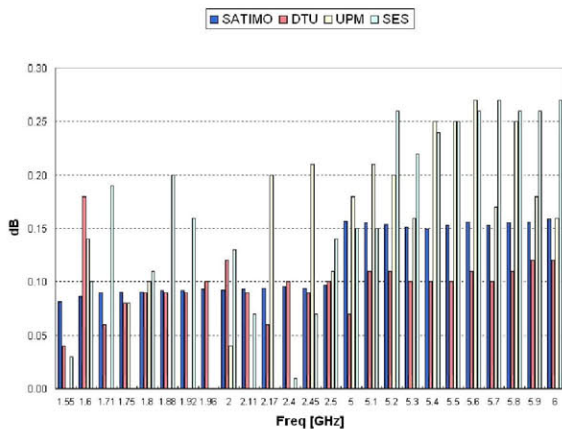

Figure 10: Measured antenna loss defined as directivity minus antenna gain.

7. Statistical approach

The traditional comparison of data involves the comparison of boresight gain and directivity values [6]. Measurement differences and their sources are often better understood by direct inspection and comparison of the patterns. However, the comparison of large amount of measured data is unfeasible by inspection of pattern differences alone. Therefore a statistical approach has been implemented that allow the comparison of large amount of data in a simple form.

The statistical approach concerns the 60° forward cone of the radiated co and cross-polar patterns. This angle has been determined somewhat arbitrary but include field levels from 9 to 25 dB below the peak. For each measured frequency a reference pattern has been determined as the geometric mean of the 4 measurements for each frequency excluding the most distant sample. The Ludwig III [7], co and cross polarised components are treated separately since the cross polar values include 2 cuts in 45˚ and 135˚ while the copolar values include 4 cuts each 45˚. From the reference pattern the standard deviation of the weighted differences for each measurement is calculated. This value expresses the effective variation over the 60˚ forward cone giving an indication off the measurement error level.

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 error is 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 mean that this value "clean" the comparison from differences caused by pattern difference in the antenna back-lobe that are often 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 when comparing medium and low gain antennas as in this case.
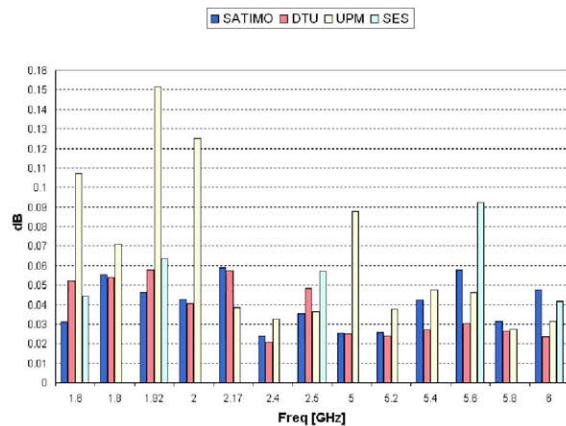
Figure 11: Copolar standard deviation from reference pattern in 4 cuts in forward 60˚ cone.
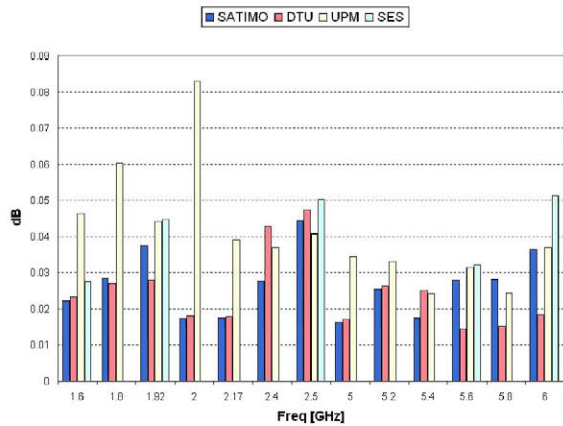
Figure 12: Cross-polar standard deviation from reference pattern in 2 cuts in forward 60° cone.

8. Pattern comparisons

Measured pattern from each facility in the 45° cuts are compared with the calculated reference pattern in Figure 13 and Figure 14.
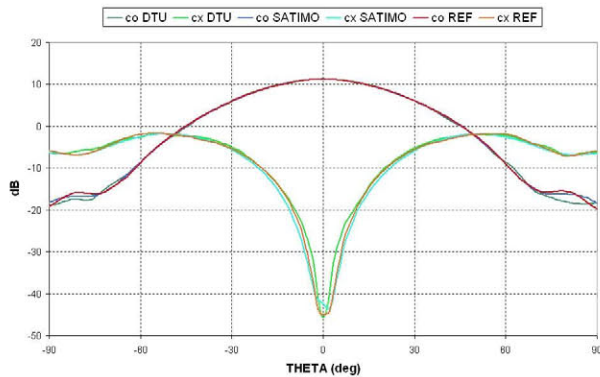

Figure 13: Measured directivity patterns @ 2.5GHz. Reference, SATIMO and TUD measurements.
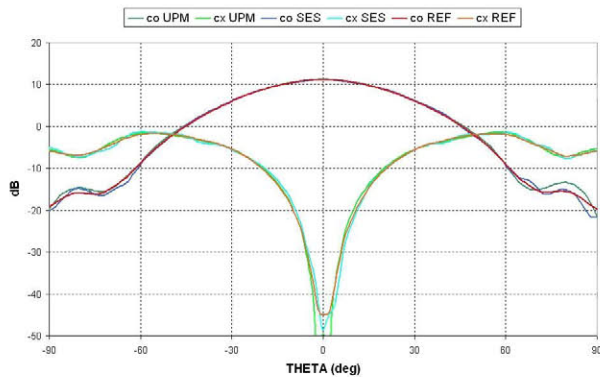

Figure 14: Measured directivity patterns @ 2.5GHz. Reference, SES and UPM measurements.

7. Summary

Comparative measurements have been performed on a dual ridge horn involving four different test facilities in the 1.55-6GHz range. The comparisons show an excellent agreement between the ranges for directivity measurements and very good agreements for the IEEE gain measurements. All reported differences are well within the estimated measurements accuracies of each system and the impact of variations in the measurements set-up.

A statistical approach has been presented for the fast evaluation of large amounts of measurement data. This approach gives an indication of the measurements error "cleaning" the comparison from differences caused by difference in the antenna back-lobe that are often due to differences in the measurement set-up. These differences are often small in high gain measurements but can give a significant contribution when comparing medium and low gain antennas as in this case.

The facility comparison activities will be extended to more facilities within and outside Europe in the following two years.

8. References

[1] P.O. Iversen, Ph. Garreau, et al, "Real Time Spherical Near-field Antenna Test Range for Personal Communications Applications", AMTA 1999.

[2] IEEE Standard Test Procedures for Antennas, ANSI/IEEE Std 149-1979.

[3] TICRA Engineering Consultants, www.ticra.com

[4] Hansen J. E. (ed.), *Spherical Near-Field Antenna Measurements,* Peter Peregrinus, Ltd., on behalf of IEE, London, 1988.

[5] Ramo S., Whinnery J.R., Van Duser T. *Fields and Waves in Communication Electronics,* John Wiley and Sons, New York, 3rd edition, 1993.

[6] Stubenrauch, C.F.; Newell, et al "International intercomparison of horn gain at X-band" IEEE Transactions on Antennas and Propagation, Volume: 44, Issue: 10,Oct. 1996, Pages:1367 - 1374

[7] A. C. Ludwig, "The Definition of Cross Polarization", IEEE Transactions on Antennas and Propagation, vol. AP-21, pp. 116-119, Jan. 1973.

9. Acknowledgements