Recent Developments in International Facility Comparison Campaigns

M.A.Saporetti, L.J. Foged
Microwave Vision Italy (MVI)
Pomezia, Italy
(lars.foged, maria.saporetti)@microwavevision.com

A. A. Alexandridis
Institute of Informatics & Telecommunications, National Centre for Scientific Research "Demokritos" (NCSRD),
Athens, 15310, GREECE
aalex@iit.demokritos.gr

Y. Alvarez-Lopez,
Area de Teoría de la Señal y Comunicaciones,
Universidad de Oviedo
alvarezyuri@uniovi.es

C. Culotta-López
RWTH Aachen University,
Germany
culotta@ihf.rwth-aachen.de

B. Svensson
Saab AB,
Gothenburg, Sweden
bengt.i.svensson@saabgroup.com

I. Expósito
University of Vigo,
Vigo, Spain
iexpositop@uvigo.es

F. Tercero
Yebes Observatory,
Yebes, Spain
f.tercero@oan.es

M. Sierra Castañer
ETSI Telecomunicación,Un. Politécnica de Madrid (UPM)
Madrid, Spain
mscastaner@gr.ssr.upm.es

***Abstract*— The EurAAP (the European Association on Antennas and Propagation) [1] Measurements working group (WG5), constitutes a framework for cooperation to advance research and development of antenna measurements. An important on-going task of this group is to sustain the Antenna Measurement Intercomparisons.**

The comparison of each facility measurement of the same reference antenna in a standard configuration results in important documentation and validation of laboratory expertise and competence, allowing to validate and document the achieved measurement accuracy and to obtain and maintain accreditations like ISO 17025.

An additional outcome is the improvement in antenna measurement procedures and protocols in facilities and contributions to standards, which is one of the long-term objectives of the EurAAP WG5. Several participants among Europe but also USA and ASIA have joined the activity.

These campaigns will also serve for a new task, recently approved within the WG5, of self-evaluation from comparison of the measurement results.

An important on-going campaign involves a X/Ku/Ka-band high gain reflector antenna MVI-SR40 fed by SH4000 Dual Ridge Horn. In this paper we report the results here for the first time.

The medium gain ridge horn, MVI-SH800, equipped with an absorber plate to enhance the correlation in different facilities has been the reference antenna of another campaign. In [2] the preliminary results were shown. In this paper we present the final validation.

The comparison is reported plotting the gain/directivity patterns and computing the equivalent noise level and the Birge ratio with respect to the reference pattern obtained taking into account the uncertainty declared by each facility.

I. Introduction

The EurAAP (the European Association on Antennas and Propagation) [1] Measurements working group (WG5), constitutes a framework for cooperation to advance research and development of antenna measurements. The working group is organized in tasks. An important on-going task is to sustain the Antenna Measurement Intercomparisons.

The comparison of each facility measurement of the same reference antenna in a standard configuration results in important documentation and validation of laboratory expertise and competence, allowing to validate and document the achieved measurement accuracy and to obtain and maintain accreditations like ISO 17025 [3]. The main goal of the facility comparison activities is to provide a formal opportunity for the participants to validate and document their achieved measurement accuracy and procedures by comparison with other facilities. In fact, the measurement of any antenna performance parameter is considered to be incomplete without knowledge of the measurement accuracy ([4], [5]). An additional outcome is the improvement in antenna measurement procedures and protocols in facilities and contributions to standards.

Since 2004, comparison campaigns with different scopes have been conducted on antenna measurements within various European activities ([1], [6] ,[7], [8]). Several participants among Europe but also USA and ASIA have joined the activity. Due to the direct benefits to the participants, the activities have been very successful and partial results have been published in IEEE referenced papers during the years ([2],[9]-[10]).

These campaigns will also serve for a new task, recently approved within the WG5, of self-evaluation from comparison of the measurement results.

An important on-going campaign involves a X/Ku/Ka-band high gain reflector antenna MVI-SR40 fed by SH4000 Dual Ridge Horn. In this paper we report the results here for the first time. The medium gain ridge horn, MVI-SH800, equipped with an absorber plate to enhance the correlation in different facilities has been the reference antenna of another campaign. In [2] the preliminary results were shown. In this paper we present the final validation.

The comparison for both campaigns is reported plotting the gain/directivity patterns and computing the equivalent noise level and the Birge ratio with respect to the reference pattern obtained taking into account the uncertainty declared by each facility.

II. MEASUREMENTS INTERCOMPARISON

The determination of the reference pattern, obtained from several independent measurements, and the equivalent noise level, intended as the correlation between the reference pattern and each measurement, are needed for the intercomparison data elaboration and are described in this paragraph.

A. Reference Pattern

The reference pattern is computed using a weighted linear mean [2]:

$$\mu_{Lin} = \frac{\sum_{i=1}^{n} w_i x_{i\,Lin}}{\sum_{i=1}^{n} w_{i\,Lin}} \qquad (1)$$

where:
n = total number of participants (and of measurements),
i = measurement of the *ith* participant to the campaign,
x_{iLin} = linear measurement.

The value for the weight w_i associated to the ith measurement is given by:

$$w_{i\,Lin} = \frac{1}{\sigma_{i\,Lin}^{2}} \qquad (2)$$

where σ_{Lin} is the linear uncertainty computed starting from σ_{dB} that is the uncertainty, related to the measurement, declared by each facility.

B. Equivalent Noise Level

The correlation between each measurement and the reference pattern can be expressed through the equivalent "noise" level (EQN), evaluated, in dB, on a limited (±45° or ±60°) theta cone, with the following expression [2]:

$$EQN_{dB} = \left[RMSE\left(\frac{Dir_{co,xp} - Dir_{ref\_co,xp}}{Dir_{co,ref\_boresight}} \right) \right] \qquad (3)$$

where:
RMSE is the Root Mean Square Error,
$Dir_{co,cx}$= Directivity (Co or Cx) of the measured pattern,
$Dir_{ref\_co,cx}$ = Directivity of the reference pattern (Co or Cx), $Dir_{co,ref,boresight}$ = Directivity of the co-polar component of the reference pattern in boresight.

C. Birge ratio

A classic method of checking the consistency of a set of intercomparison results is the Birge ratio test [11]. A set of results that contains discrepant results is said to be inconsistent. The Birge ratio denoted by R_B is defined as:

$$R_B = \sqrt{\frac{\sum_i w_i (x_i - \mu)^2}{n-1}} \qquad (4)$$

where w_i is the weight, $x_1, \ldots, x_n$ are the measurements, μ is the weighted mean and n is the number of involved facilities.

If R_B is close to 1 or less , the measurements $x_1,\ldots, x_n$ are consistent. The values of R_B that are much greater than 1 suggest that the measurements $x_1,\ldots, x_n$ are inconsistent.

III. MVI SR40+ SH4000 CAMPAIGN

A. Test object

The campaign involving a gain reflector antenna MVI-SR40 fed by SH4000 Dual Ridge Horn is presented here for the first time. The SR40, shown in Figure 1, is a X/Ku/Ka-band high gain reflector antenna, linear polarized with high polarization purity with low return loss. It is precision machined with stiff and robust mechanical design. The feed is a SH4000, a dual ridge horn characterized by stable gain performance and low VSWR.

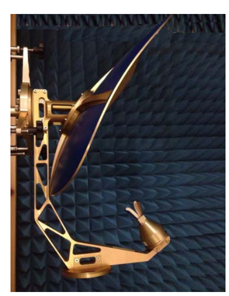

Figure 1. Reflector SR 40-A fed by SH4000 Dual Ridge Horn: Antenna during measurement

B. Measurement Campaign

The facilities that took part to the intercomparison and whose data are presented in this paper are:

- MVG Stargate64 in Paris, France
- Universidad de Oviedo, Spain (old chamber)
- Un. Politécnica de Madrid (UPM), Spain
- IMST, Germany
- RWTH Aachen, Germany
- Yebes Observatory, Spain.

Figure 2 shows the location of the facilities with the indication of the type of measurement system.

Figure 2. Involved facilities in the SR40+SH4000 campaign.

C. Preliminary Results

This paragraph shows the gain radiation patterns. The results shown are preliminary and no weighted reference pattern, and as a consequence, no equivalent noise level have been computed yet since the campaign is still on going. The measured co-polar and cross-polar gain patterns, at phi = 0° and 90°, at 28 GHz are shown in Figure 3 and Figure 4 while Table I shows the Peak IEEE Gain.

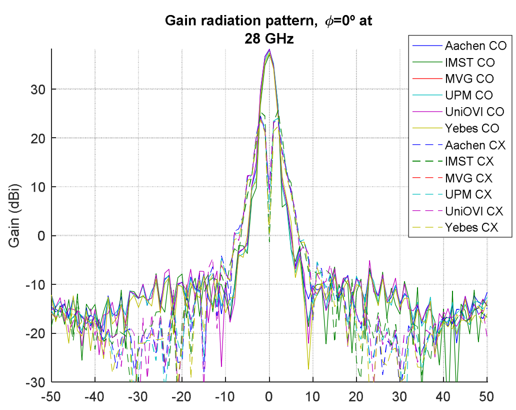

Figure 3. Gain radiation pattern at phi=0° @ 28 GHz: RWTH Aachen, IMST, MVG Paris, UPM, University of Oviedo,Yebes Observatory.

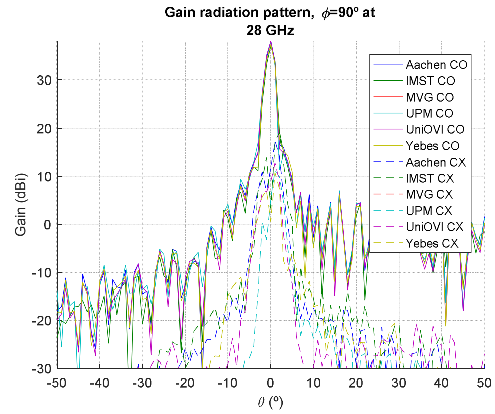

Figure 4. Gain radiation pattern at phi=90° @ 28 GHz: RWTH Aachen, IMST, MVG Paris, UPM, University of Oviedo,Yebes Observatory.

TABLE I. PEAK IEEE GAIN

Freq [GHz]	Peak Gain [dB]					
	Aachen	*MVG P*	*UPM*	*IMST*	*Yebes*	*OVI*
10.7	30.77	30.89	30.77	30.31	30.93	29.48
12.6	32.28	31.94	32.14	32.21	32.27	31.85
14.5	33.45	33.29	33.84	33.59	33.52	33.49
18	35.44	35.20	34.88	34.38	34.53	33.91
19	35.80	-	35.08	34.61	34.52	34.43
20	36.09	-	35.47	35.53	35.31	34.79
28	38.26	-	37.98	37.39	37.35	37.23
29	38.29	-	37.88	36.90	36.67	37.78
30	38.47	-	38.18	37.55	37.23	38.24
38	39.94	-	39.66	39.84	38.00	39.24

IV. MVI SH800 WITH ABSORBERS PLATE CAMPAIGN

A. Test object

The final validation of the campaign involving the medium gain ridge horn, MVI-SH800 is presented in this paper. The MVI SH800 is a Dual-Ridge Horn which combines stable gain performance and low VSWR. For the intercomparison campaign it has been equipped with an absorber plate to enhance the correlation in different facilities, as shown in Figure 5.

B. Measurement Campaign

The facilities that took part to the intercomparison and whose data have been presented in [2] are:

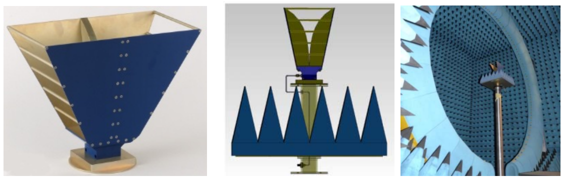

Figure 5. MVI SH800 with absorbers plate.

- MVG Stargate64 in Atlanta-USA
- MVG Stargate64 in Paris, France
- Universidad de Oviedo, Spain (old chamber)
- Un. Politécnica de Madrid (UPM), Spain
- IMST, Germany
- NCSR Demokritos, Institute of Informatics & Telecommunications (NCSRD), Greece
- RWTH Aachen, Germany.

In this paper we present the final validation considering also:

- University of Vigo (UVigo), Spain
- Saab AB, Sweden.

Figure 6 shows the location of the facilities with the indication of the type of measurement system.

Figure 6. Involved facilities in the SH800+absorbers plate campaign.

C. Results

1) Gain

The results that will be shown hereafter are referred to the gain patterns measured by: MVG SG64 Paris, MVG SG64 Atlanta, UPM, IMST, NCSRD, Oviedo, UVigo and SAAB. The weighted gain reference pattern has been computed according to the 2σ uncertainties reported in Table II excluding University of Oviedo, whose uncertainty is under revision. Measured co-polar and cross-polar gain patterns, at phi = 0° and 90°, at 2.5 GHz are compared with the weighted reference pattern, computed with (1), in Figure 7 and Figure 8. The EQN computed with offset gain patterns (4) in a ±45° θ cone is reported in Figure 9 and Figure 10 @1.8, 2.5, 4 and 5 GHz, computed at phi=0° and phi=90° planes for the co-polar component. The values of the peak IEEE gain are reported in Table III together with the difference (in red) with respect to the REF.

TABLE II. FACILITIES AND UNCERTAINTIES FOR THE REFERENCE GAIN PATTERN COMPUTATION

Facility	Gain Uncertainty 2 σ @ freq [MHz]			
	1800	2500	4000	5000
MVG SG64 Paris	0.6	0.6	0.6	0.6
MVG SG64 Atlanta	0.6	0.6	0.6	0.6
UPM	0.16	0.16	0.16	0.16
IMST	0.2	0.2	0.2	0.2
NCSRD	1.05	1.05	1.05	1.05
Oviedo	*	*	*	*
SAAB	0.4	0.3	0.25	0.25
UVigo	0.72	0.85	0.42	0.68

* under revision

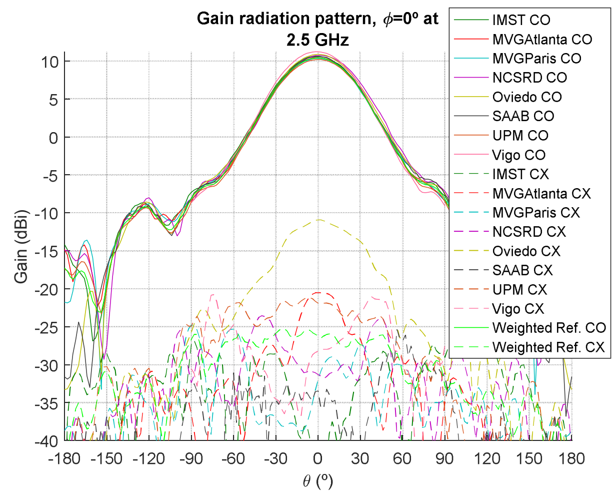

Figure 7. Gain radiation pattern at phi=0° @ 2.5 GHz: Weighted reference, MVG Paris, MVG Atlanta, UPM, IMST, NCSRD, Oviedo, UVigo, SAAB.

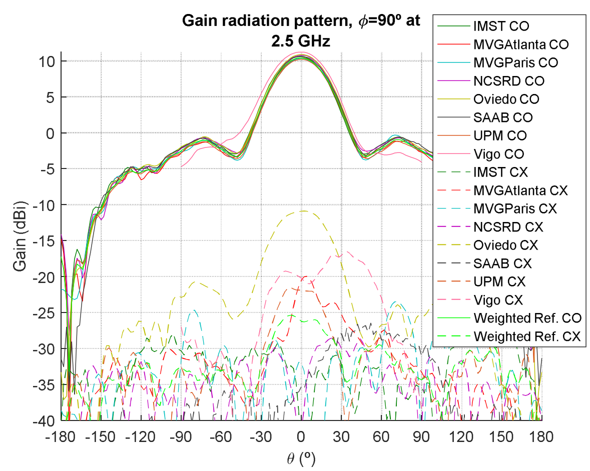

Figure 8. Gain radiation pattern at phi=90° @ 2.5 GHz: Weighted reference, MVG Paris, MVG Atlanta, UPM, IMST, NCSRD, Oviedo , UVigo, SAAB.

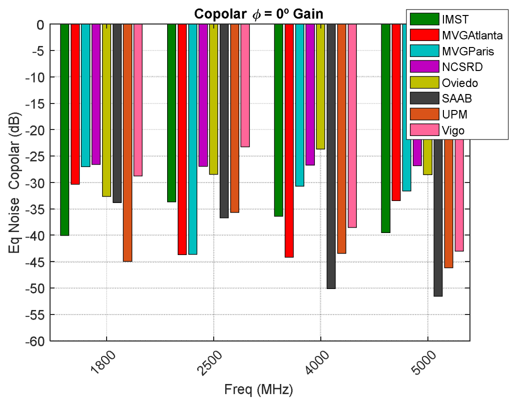

Figure 9. Equivalent noise level for the gain co-polar component at phi=0°.

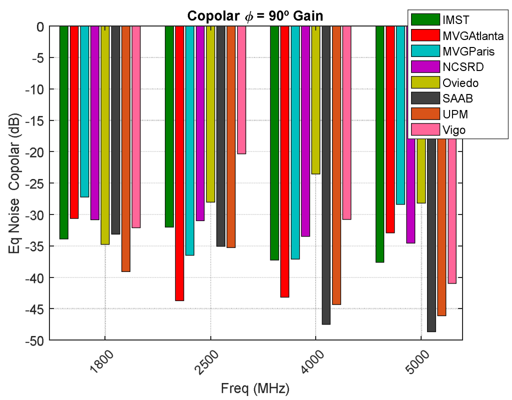

Figure 10. Equivalent noise level for the gain co-polar component at phi=90°.

TABLE III. PEAK IEEE GAIN

Freq GHz	Peak Gain [dB]								
	REF	*MVG P*	*MVG A*	*UPM*	*IMST*	*NCSRD*	*OVI*	*SAAB*	*UVigo*
1.8	9.98	9.52 -0.46	9.67 -0.31	9.91 -0.07	10.12 0.14	10.33 0.35	10.27 0.29*	10.21 0.23	10.32 0.34
2.5	10.41	10.35 -0.06	10.42 0.01	10.22 -0.19	10.63 0.22	10.74 0.34	10.89 0.48*	10.56 0.15	11.26 0.85
4	10.78	10.60 -0.18	10.81 0.03	10.73 -0.05	10.87 0.09	10.82 0.04	11.56 0.78*	10.84 0.06	10.58 -0.2
5	11.61	11.26 -0.35	11.47 -0.14	11.56 -0.05	11.72 0.11	11.69 0.08	12.09 0.48*	11.64 0.03	11.58 -0.03

*the REF has been computed excluding University of Oviedo

2) *Directivity*

The results that will be shown hereafter are referred to the directivity patterns measured by: MVG SG64 Paris, MVG SG64 Atlanta, UPM, NCSRD, Oviedo, RWTH Aachen and SAAB. The weighted directivity reference pattern has been computed according to the 2σ uncertainties reported in Table IV excluding Oviedo and UVigo, whose uncertainties are under revision/evaluation.

Measured co-polar and cross-polar directivity patterns, at phi = 0° and 90°, at 5 GHz are compared with the weighted reference pattern, computed with (1), in Figure 11 and Figure 12.

The EQN computed in a ±45° theta cone, using (3) is reported in Figure 13 and Figure 14 at 1.8, 2.5, 4 and 5 GHz, computed at phi=0° and phi=90° planes for the co-polar component. The values of the peak directivity are reported in Table V together with the difference (in red) with respect to the REF.

TABLE IV. FACILITIES AND UNCERTAINTIES FOR THE REFERENCE DIRECTIVITY PATTERN COMPUTATION

Facility	Directivity Uncertainty 2 σ @ freq [MHz]			
	1800	**2500**	**4000**	**5000**
MVG SG64 Paris	0.3	0.3	0.3	0.3
MVG SG64 Atlanta	0.3	0.3	0.3	0.3
UPM	0.1	0.1	0.1	0.1
RWTH Aachen	-	0.20	0.20	0.16
NCSRD	1.06	1.06	1.06	1.06
Oviedo	*	*	*	*
SAAB	0.3	0.2	0.15	0.15
UVigo	*	*	*	*

* under revision/evaluation

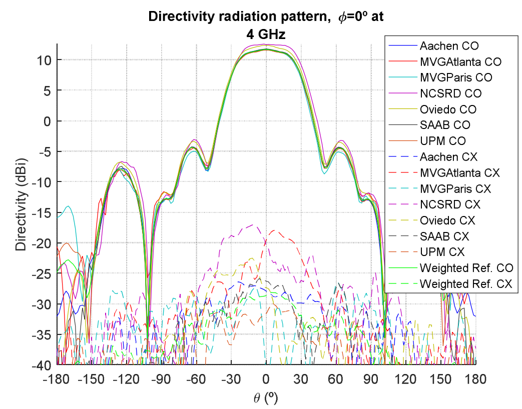

Figure 11. Directivity radiation pattern at phi=0° @ 4GHz: MVG Paris, MVG Atlanta, UPM, NCSRD, Oviedo, RWTH Aachen, SAAB.

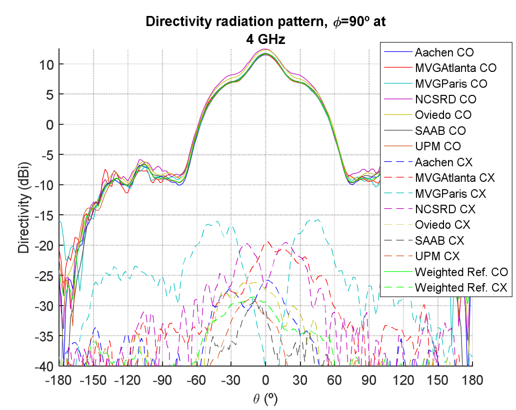

Figure 12. Directivity radiation pattern at phi=90° @ 4 GHz: MVG Paris, MVG Atlanta, UPM, NCSRD, Oviedo, RWTH Aachen, SAAB.

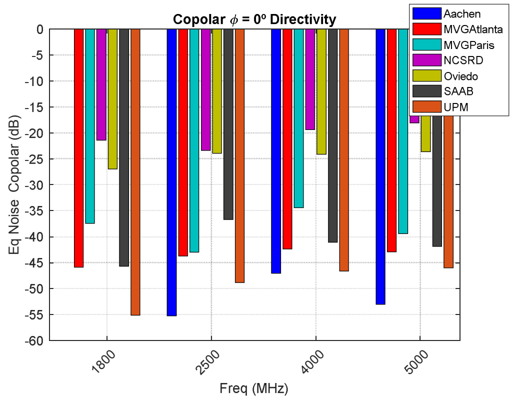

Figure 13. Equivalent noise level for the directivity co-polar component at phi=0°.

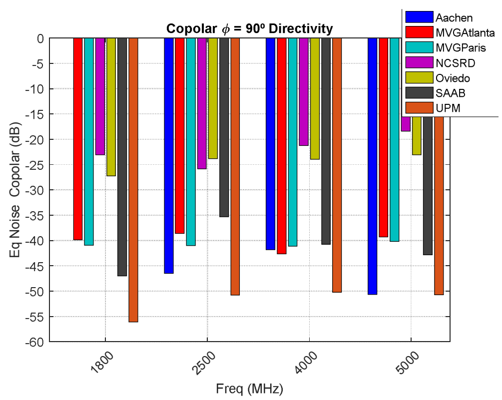

Figure 14. Equivalent noise level for the directivity co-polar component at phi=90.

TABLE V. PEAK DIRECTIVITY

Freq GHz	Peak Directivity [dBi]							
	REF	*MVG P*	*MVG A*	*UPM*	*Aachen*	*NCSRD*	*OVI*	*SAAB*
1.8	10.5	10.44 -0. 06	10.54 0.04	10.5 0	-	11.32 0.82	11.05 0.55*	10.45 -0.05
2.5	11.27	11.22 -0.05	11.33 0.06	11.23 -0.04	11.29 0.02	11.90 -0.63	12.04 0.8*	11.42 0.15
4	11.66	11.65 0.01	11.61 -0.05	11.6 -0.06	11.68 0.02	12.46 0.8	12.38 0.72*	11.79 0.13
5	12.56	12.63 0.7	12.65 0.12	12.49 -0.07	12.56 0	13.80 1.24	13.38 0.85*	12.66 0.1

*the REF has been computed excluding University of Oviedo and University of Vigo

3) Birge ratio

Figure 17 shows the Birge ratio for directivity and gain.

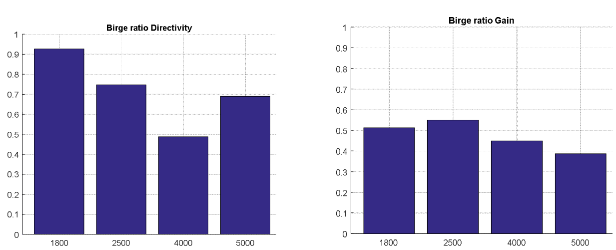

Figure 15. Birge ratio for directivity and gain.

V. CONCLUSIONS

The results concerning two intercomparison activities based on high accuracy reference antennas supported by EurAAP have been presented.

The preliminary results of a X/Ku/Ka-band high gain reflector antenna MVI-SR40 fed by SH4000 Dual Ridge Horn have been presented. The patterns and the peak gain measured from 7 different facilities have been shown. The visible pattern agreement seems good. The campaign is still on going, therefore no weighted reference pattern, and as a consequence, no equivalent noise level have been computed yet.

The final validation of a facility comparison campaign involving a medium gain ridge horn, MVI-SH800, working at L and C band frequencies and equipped with an absorber plate to enhance the correlation in different facilities, has been also presented. The antenna has been measured in 9 different facilities in Europe and USA. The measurements from the 9 different facilities are generally in very good agreement when compared to each other. The visible pattern agreement is confirmed by the equivalent noise level (pattern correlation) of less than ~ -30 dB. Very good agreement has been achieved also for performance parameters such as peak directivity and peak gain. The reliability of the results is confirmed by the Birge ratio, smaller than 1, especially for the gain measurements. Such results confirm the expected improvement with respect to the previous SH800 campaign (without absorber plate) where standard deviation errors were ~ 0.05 which corresponds to an EQN of - ~ 26 dB.

ACKNOWLEDGEMENT

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