L/S & C Band Medium Gain Ridge Horn Intercomparison Campaign Results

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***Abstract* - The measurements working group, WG5 of the European Association on Antennas and Propagation (EurAAP) [1], promotes cooperation to advance research and development of antenna measurements. An on-going task of this group is to support inter-comparisons of measurement facilities. The activities involve many participants in Europe. It has been extended to USA and participants from Asia is planned to enter at a later moment. The different campaigns also serve as input for a new task, recently approved in WG5, about self-evaluation from inter-comparison results.**

The L/S & C bands medium gain ridge horn, MVI-SH800, was selected as reference antenna for an EurAAP ACE campaign [2]. In order to enhance the correlation in different facilities, the MVI-SH800 has been equipped with an absorber plate and employed in a new extensive comparison campaign. In [3], we described the activities and showed preliminary results. In this paper we present the complete inter-comparison and draw final conclusions. The obtained results are in very good agreement and confirm the expected improvement with respect to the previous SH800 campaign without absorber plate [2].

***Index Terms*—antennas, Birge ratio, Equivalent Noise Level, intercomparison, measurements.**

I. INTRODUCTION

Since 2004, comparison campaigns have been conducted on antenna measurements within various European activities ([1],[4],[5],[6]). These activities involved many participants in Europe, and it is extended also to USA and Asia. Due to the direct benefits to the participants, the activities have been very successful and partial results have been published in IEEE referenced papers ([2],[3],[7]-[12]). The main objective of the facility comparison activities is to provide a formal opportunity for the various 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 incomplete without knowledge of the measurement accuracy ([13], [14]). By measuring the same reference antenna in a standard and repeatable configuration each institution can validate and document their declared measurement accuracy. Such documentation is an important input to obtain and maintain formal measurement accreditations like ISO 17025 [15]. An additional outcome of the campaigns is the improvement in antenna measurement procedures and protocols in facilities and contributions to standards.

The MVI-SH800, 800MHz-12GHz medium gain ridge horn is the reference antenna in the L/S & C bands inter-comparison campaign. In the comparison, the antenna has been equipped with an absorber plate to enhance the correlation in different facilities as seen in Fig. 1.

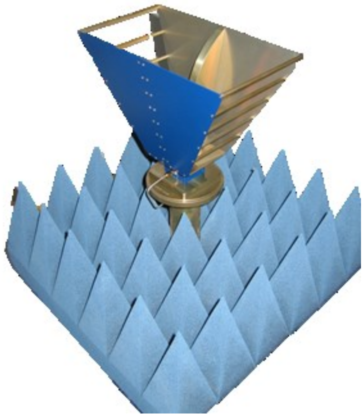

Fig. 1. MVI SH800 medium gain dual ridge horn with absorber plate.

II. INTERCOMPARISON DATA ELABORATION

The intercomparison data elaboration is based on the determination of:

- Reference Pattern
- Equivalent Noise Level.

The former is obtained from several independent measurements and its correlation with each measurement is expressed through the latter. Additional figures of merit that can enhance the comparison are the Birge Ratio and Escore. The formulas are detailed in the following.

A. *Reference Pattern*

The reference pattern is obtained as a weighted linear mean [2]:

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

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 provided by:

$$w_{i\,Lin} = \frac{1}{\sigma_{i\,Lin}^{2}} \tag{2}$$

where:
σ_{Lin} = linear uncertainty computed starting from σ_{dB}
σ_{dB} = measurement uncertainty 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 (ENL), evaluated, in dB, on a limited (±45° or ±60°) theta cone, with the following expression [2]:

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

where:
$RMSE$ = 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 [16]. A set of results that contains discrepant results is said to be inconsistent. The Birge ratio denoted by R_B is defined as:

$$R_B = \sqrt{\frac{\sum_i w_{iLin}(x_{iLin} - \mu)^2}{n-1}} \tag{4}$$

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

D. *Escore*

An alternative metric to check the consistency of a set of data is provided by the Escore. It checks if the declared uncertainty is correct or not:

$$Escore = \frac{|x_i - \mu|}{\sqrt{U_i^2 + U^2}} \tag{5}$$

where:
$U_i = 2\sigma_i$ being σ_i the uncertainty related to $x_1,\dots, x_n$ measurement,
$U = 2\sigma$ with $\sigma = \sqrt{\dfrac{1}{\dfrac{1}{(\sigma_1)^2} + \dfrac{1}{(\sigma_2)^2} + \dfrac{1}{(\sigma_3)^2} + \dots}}$.

If Escore is smaller than 1, then the declared uncertainty is correct, otherwise is underestimated.

III. MVI SH800 WITH ABSORBERS PLATE CAMPAIGN

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 Fig.1.

The facilities involved in the intercomparison, shown in the map of Fig.2, are:

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

Fig. 2. Map of the partecipating institutions of the SH800 intercomparison campaign.

A. *Directivity*

The results presented here include 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 I excluding Oviedo 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 Fig. 3 and Fig. 4.

The ENL computed in a ±45° theta cone, using (3) is reported in Fig. 5 and Fig. 6 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 II together with the difference (in red) with respect to the REF. The ENL as a function of θ at 4 GHz is shown for the co-polar components at phi=90° for all facilities in Fig. 7. Fig. 8 shows the Birge ratio for directivity and Fig.9 shows the Escore for directivity measurements at 2.5GHz.

TABLE I. FACILITIES UNCERTAINTIES FOR REFERENCE DIRECTIVITY PATTERN

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
SAAB	0.3	0.2	0.15	0.15

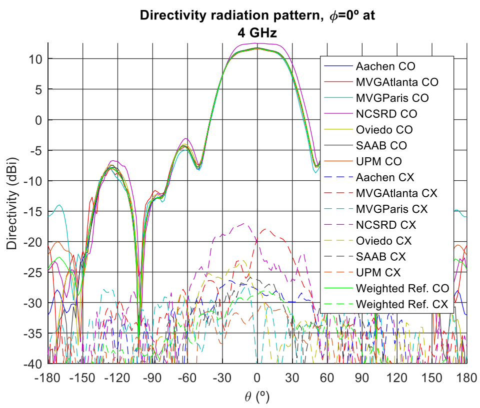

Fig. 3. Directivity radiation pattern at phi=0° @ 4GHz: MVG Paris, MVG Atlanta, UPM, NCSRD, Oviedo, RWTH Aachen, SAAB.

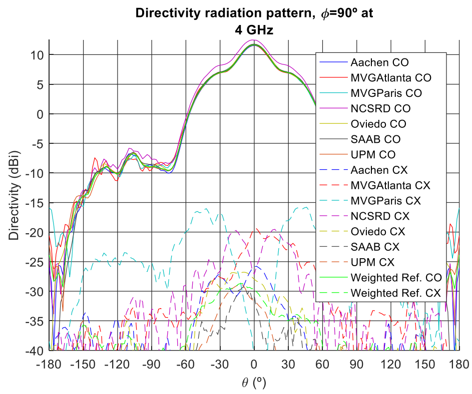

Fig. 4. Directivity radiation pattern at phi=90° @ 4 GHz: MVG Paris, MVG Atlanta, UPM, NCSRD, Oviedo, RWTH Aachen, SAAB.

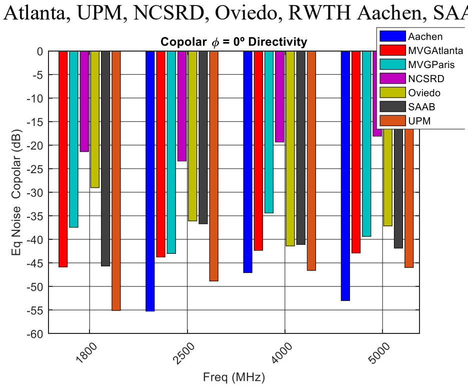

Fig. 5. ENL for directivity co-polar component at phi=0°.

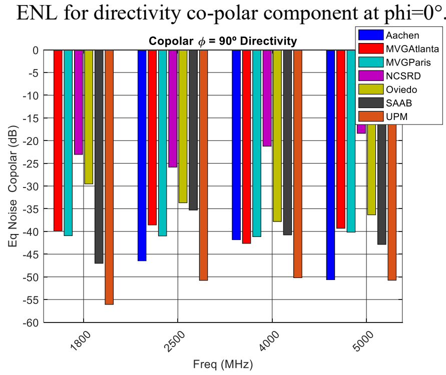

Fig. 6. ENL for the directivity co-polar component at phi=90°.

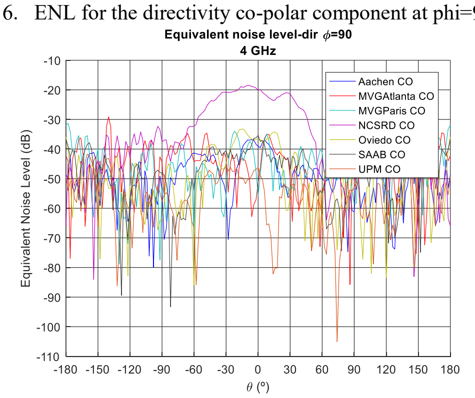

Fig. 7. ENL at 4 GHz, phi=90° w.r.t. θ for directivity co-polar component.

TABLE II. 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	10.94 0.44*	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	11.51 0.24*	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	11.77 0.11*	11.79 0.13
5	12.56	12.63 0.07	12.65 0.09	12.49 -0.07	12.56 0	13.80 1.24	12.73 0.17*	12.66 0.1

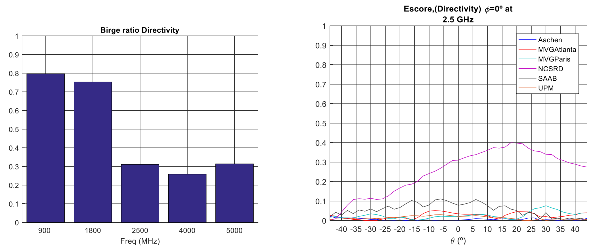

Fig. 8. Birge ratio vs frequency and Escore at 2.5GHz for directivity measurements.

B. Gain

The results presented here include 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 III 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 Fig. 9 and Fig. 10. The ENL computed with offset gain patterns (4) in a ±45° θ cone is reported in Fig.11 and Fig.12 @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. The ENL as a function of θ at 4 GHz is shown for the co-polar components at phi=90° for all facilities in Fig. 13. Fig. 14 shows the Birge ratio and the Escore for gain measurements at 1.8GHz.

TABLE III. FACILITIES UNCERTAINTIES FOR REFERENCE GAIN PATTERN

Facility	Gain Uncertainty 2σ Frequency [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
SAAB	0.4	0.3	0.25	0.25
UVigo	0.72	0.85	0.42	0.68

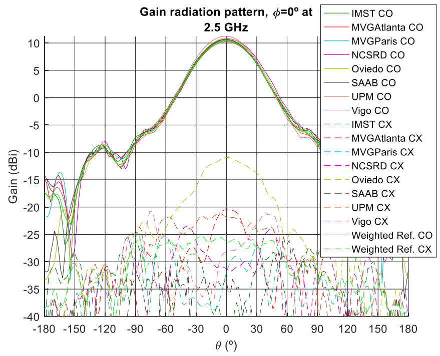

Fig. 9. Gain radiation pattern at phi=0° @ 2.5 GHz: Weighted reference, MVG Paris, MVG Atlanta, UPM, IMST, NCSRD, Oviedo, UVigo, SAAB.

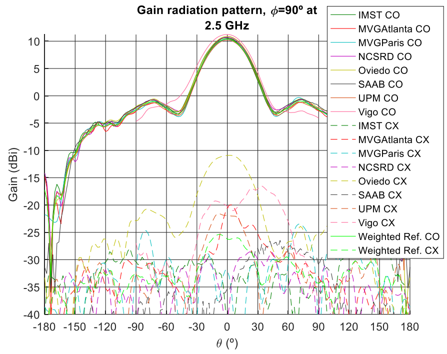

Fig. 10. Gain radiation pattern at phi=90° @ 2.5 GHz: Weighted reference, MVG Paris, MVG Atlanta, UPM, IMST, NCSRD, Oviedo , UVigo, SAAB.

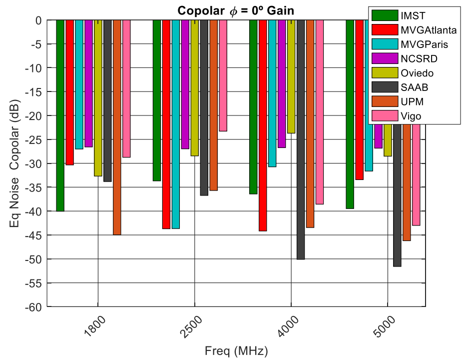

Fig. 11. ENL for gain co-polar component at phi=0°.

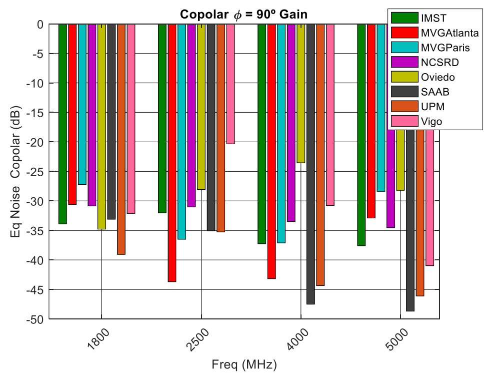

Fig. 12. ENL for gain co-polar component at phi=90°.

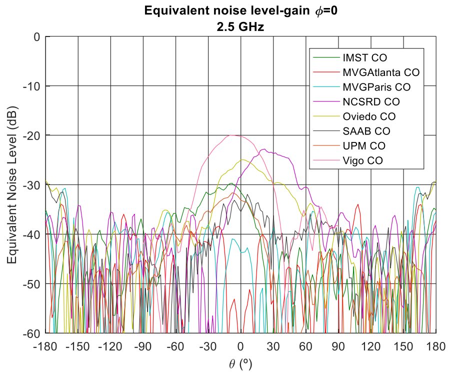

Fig. 13. Equivalent noise level at 2.5 GHz, phi=0° w.r.t. θ for the gain co-polar component.

TABLE IV. PEAK GAIN

Freq GHz	Peak Gain [dB]								
	REF	***MVGP***	***MVGA***	***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

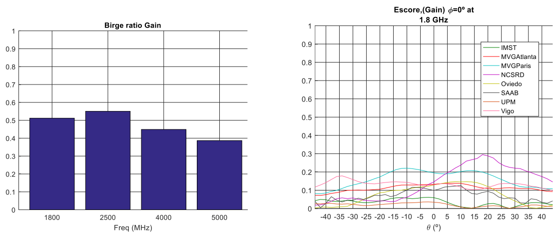

Fig. 14. Birge ratio vs frequency and Escore at 1.8 GHz for gain measurements.

IV. CONCLUSIONS

The final results of the EurAAP facility comparison campaign involving a medium gain ridge horn, MVI-SH800, working at L/S and C band frequencies has been presented. The measurements from 9 different facilities, in Europe and USA, are largely in very good agreement. The visible pattern agreement is confirmed by the equivalent noise level (pattern correlation) smaller 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 which is smaller than 1 at all the frequencies. The Escore, smaller than 1, confirms that the uncertainties declared by each facility are correctly estimated. Such results confirm the expected improvement with respect to the previous SH800 campaign (without absorber plate) [2] where standard deviation errors were ~ 0.05 which corresponds to an ENL of ~ -26 dB.

ACKNOWLEDGEMENT

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