# Experimental Validation of Linear Multiprobe Arrays for Fast and Accurate PNF Antenna Characterizations


F. Saccardi, *AMTA senior*, A. Giacomini, AMTA *Senior*, L. J. Foged, *AMTA Fellow*
Microwave Vision Italy SRL
Via Castelli Romani, 59, 00071 Pomezia Rome, Italy
francesco.saccardi@mvg-world.com

N. Gross, T. Blin
MVG Industries
13 Rue du Zéphyr, 91140 Villejust, France

P.O. Iversen, *AMTA Fellow*
Orbit/FR's Corporate HQ
650 Louis Drive,18974 Warminster, PA.USA

R. Braun, L. Shmidov
Orbit/FR Israel
24 Tsavei Hanahal St, Emek Hefer Industrial Park, Isreal

M. He, C. Chen, X. Bland
MVG Hong-Kong,
100 Cyberport Road, Pok Fu Lam, Hong Kong S.A.R., Hong Kong



***Abstract*—The application of multi-probe (MP) technology in near-field (NF) measurement scenarios is well-known for its ability to significantly reduce test time. This is achieved by electronically sampling the radiated field using different probes in the array, eliminating the need for mechanical probe movement. However, in planar near-field (PNF) measurements, the accuracy is contingent on probe correction (PC) during post-processing. Characterizing the pattern of each individual sensor in a PNF MP system presents an additional challenge, often being impractical or impossible. Previous publications have explored various approaches to address this challenge and achieve an accurate characterization of the MP equivalent pattern. In this paper, we focus on the average probe pattern (APP) technique, which involves the experimental determination of the MP pattern. To validate the effectiveness of the APP technique, we conducted experiments on a large PNF MP system equipped with a 4.65m probe array. Our measurements focused on an electrically large 1.5m diameter reflector antenna (MVG SR150 reflector, fed by a quad-ridge horn) operating in the 1.8–6.0 GHz frequency range. The validation process involved the comparison of MP measurements processed with the APP technique and conventional open-ended waveguide (OEW) PNF measurements. To ensure the reliability of the validation, we conducted the comparative tests within the same frequency range and test setup. This minimized the impact of measurement errors, enabling a robust and accurate comparison between the techniques. By validating the APP technique's effectiveness, we aim to establish its suitability for improving accuracy in PNF MP system measurements.**


## I. Introduction

Planar Near-Field (PNF) antenna measurement systems are an industry standard for accurate characterization of medium and high directive antennas [1]. The main drawback of such systems is the sampling requirement, needed to properly apply the Near Field to Far Field (NF/FF) transformation, which can lead to long acquisition times. Linear Multi-Probe (MP) systems, in which a fast electronic scanning of the probe array substitutes the slower vertical physical movement of the probe, are an effective solution to speed-up the PNF measurement process [2]-[5]. Depending on the implementation of the system (length and number of elements in the probe array) and the Antenna/Device Under Test (AUT/DUT), the measurement time reduction achievable with a MP system can range from 5- to 15-time with respect to a conventional single-probe (SP) system.

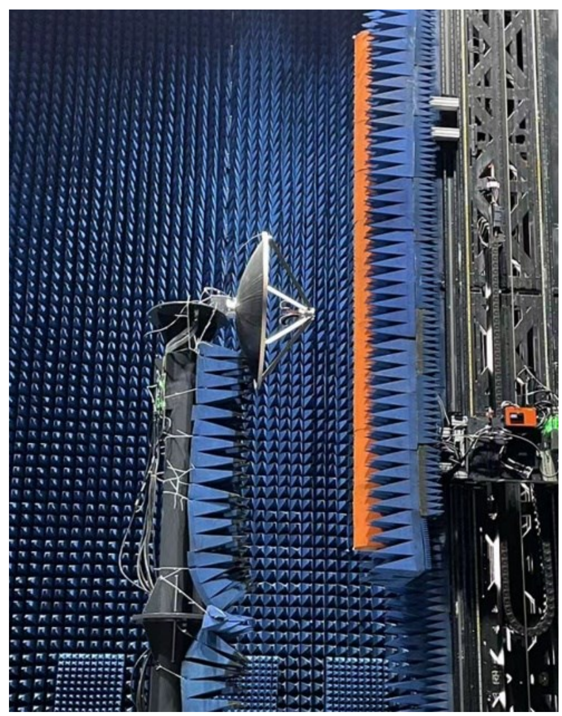

Figure 1. Linear multi-probe array measuring the SR150 onset reflector antenna.

Due to the manufacturing tolerances of the probes, MP systems require additional calibration. Probe array calibration (or orthomodal calibration) is a standard procedure for any multi-probes system (spherical, cylindrical and planar) and is used to compensate minor differences and imperfections of the different probes in the array, to equalize the amplitude, phase and polarization characteristic of the sensors [1]. While in spherical scanning geometry the orthomodal calibration is often sufficient to achieve accurate measurements performance even without the Probe pattern Correction (PC), in PNF systems the impact of the probe pattern is usually more pronounced and requires a proper compensation.

PC in PNF MP system is an additional challenge because is usually impossible or impracticable to characterize the pattern of each individual sensor. In previous publications different PC techniques for PNF MP systems have been presented and analyzed [4]-[5]. The Average Probe Pattern (APP) technique is based on the characterization of a number (≈10) of probes installed on a representative mockup of the MP array with at least three adjacent elements to include possible coupling effects. Despite its simplicity, it has been shown that such a technique is able to significantly improve the measurement accuracy. An alternative is the Equivalent Multi Probe Pattern (EMPP) technique which is based on the measurement of an antenna with known radiation pattern used to retrieve the equivalent probe pattern of the array. The main advantage of this latter technique is the possibility to retrieve the actual probe pattern response of a specific MP system instead of considering an averaged/typical one.

In this paper we will focus on the APP technique, and we will extend the experimental validation of the PNF MP system already presented in [4]-[5] considering a larger (1.5m diameter) reflector antenna (MVG SR150 fed by a quad-ridge horn) and a wider frequency range (1.8 – 6.0 GHz). The validation will be carried out comparing PNF measurements performed in a conventional SP system, and the MP system applying the APP technique. To ensure the reliability of the validation, both measurements have been conducted in the same test setup, exploiting the MVG T-dual scan [6], a hybrid system comprising of both SP and MP scanning technology. This allowed to minimize the impact of measurement errors that both systems have in common, enabling a robust and accurate comparison between the techniques.

## II. Linear MP Array System Description and Discussion of Error Sources

The considered linear MP system is shown in Figure 1. The probe array is 4.65m high and is composed of 47 proprietary linearly dual-polarized probes working in the 0.8-6.0 GHz frequency range. To reduce the mutual coupling between elements the probes are embedded in conformal absorbers. Horizontal scanning is performed mechanically by moving the probe array from left to right (x-scan). Vertical scanning (y-scan) is performed electronically by switching between the different probes. If further spatial sampling (less than that of the physical probe spacing) is required, a small vertical movement of the linear array is used to shift the relative probe positions to provide smaller spatial sampling. This technique is often referred to as oversampling capability.

Like in every MP system [1], probe array calibration (or orthomodal calibration) is applied to equalize the amplitude/phase on-axis response of the sensors and to compensate for their on-axis cross-polar.

To compensate for the effect of the probe pattern the Average Probe Pattern (APP) technique is considered in this validation. The APP technique is based on the pattern characterization of a sufficient number of different probes (≈10) which are then averaged. As explained in [5], the probes are measured in a representative environment such as mounted on a smaller array structure (mock-up) as the one shown in Figure 2. To include possible coupling effects, three adjacent elements are considered in the mock-up. Once the APP is computed, it is applied during the conventional NF/FF transformation [1],[7],[8].

Figure 2. 3-element linear array mock-up during measurement in the StarLab spherical NF system.

In accordance with the standard 18-term uncertainty analysis [9], the primary contributors to the PNF MP measurement uncertainty on antenna pattern in the considered 1.8-6GHz range have been identified. These include the probe/AUT coupling & room scattering, the measurement area truncation and the relative probe pattern.

Of these, the relative probe pattern has been identified as the major contributor to measurement uncertainty. The following significant contributor is the mutual coupling effect. Despite the MP being covered by multilayer absorber, its larger area makes it more susceptible to interactions compared to a single probe system with a traditional probe collar. Additionally, lesser sources of error have been recognized, such as leakage/crosstalk and random errors. The probe positioning errors are considered minor contributors as the MP array normally operates in stepped mode, involving movement and stopping of the probe array before each measurement. Addressing these identified sources of uncertainty is crucial for accurate and reliable measurements within the specified frequency range.

In this paper, our primary focus will be on reducing the measurement uncertainty associated with the relative probe pattern. To assess the success of our approach, comparative measurements using a traditional single probe setup with an OEW probe within the same frequency range are considered. Both SP and MP measurements utilize the same test antenna and test setup, minimizing the influence of measurement errors and facilitating a robust and accurate comparison. By employing this rigorous approach, we aim to demonstrate the effectiveness of our proposed method in achieving improved measurement accuracy and reducing uncertainties due to the relative probe pattern in MP array antenna pattern measurements.

## III. MEASUREMENT VALIDATION SETUP

The considered AUT for the validation is the SR150 onset reflector fed by the QH800 dual-polarized quad-ridge horn shown in Figure 1. The diameter of the reflector is 1.5m and, with such a feed, it can operate in the wide 0.8-12.0GHz band. In this validation the 1.8 – 6.0GHz sub-band have been selected. The nominal directivity in the chosen band ranges from approximately 25dBi to 31dBi.

The AUT has been measured both with the single probe and multi-probe scanner available in the same system (T-dual scan technology, [6]). The SP measurements have been conducted with the conventional rectangular open-ended waveguide (OEW) probes, hence dividing the considered band in three sub-bands as shown in Table I. Such SP measurements have been considered the reference for this analysis.

The considered scan size (horizontal-x-vertical) of the SP and MP measurements are reported in Table I. The vertical dimension of the MP scan is larger, because of the height of the probe array itself (4.65m). The AUT-scanner distance has been adjusted in each sub-band to keep the same validity region of the measured radiation pattern [1] (approx. +/-50°, considering the edge of the reflector as AUT surface). The conventional half-wavelength sampling step required by the Nyquist criteria has been adopted in both measurement systems [1].

It is pointed out that, to validate both orthogonal polarizations of the MP array, the AUT has been measured both in horizonal and vertical orientation by rotating it about its main axis.

TABLE I. SCAN DIMENSIONS AND MP TIME SAVING FACTOR

| | SP scan size [m] | MP scan size [m] | Time saving factor |
|---|---|---|---|
| 1.8 - 2.6 GHz | 4 x 4 | 4 x 4.65 | 10.4 |
| 2.7 - 3.9 GHz | 3.5 x 3.5 | 3.5 x 4.65 | 6.4 |
| 4.0 - 6.0 GHz | 3 x 3 | 3 x 4.65 | 6.2 |

In Table I. the time saving factor of the MP with respect to the SP measurement is also reported. Such factors have been normalized according to the total number of sampling points, being different in the SP and MP measurement.

The implementation of the "on-the-fly" scanning mode, which involves continuous movement of the probe along one scanning axis, has been instrumental in accelerating the measuring time of the SP system. Even with this approach, the MP system operating in the stepped mode achieves significantly reduced measurement times. To achieve further time savings in measurements, it is possible to explore operating the MP system in the on-the-fly mode as well. This additional optimization could potentially lead to even more efficient measurement times compared to the current stepped mode.

On the other hand, it's worth noting that the SP system utilizes a single-polarized probe, whereas the MP employs native dual-polarized probes. Had the SP measurements employed dual-polarized probes, the time-saving factor reported in the table would have been approximately halved.

## IV. MEASUREMENT RESULTS

In this section, we present and comment on the measured radiation patterns from the linear MP system validation campaign.

Figure 3. and Figure 4. show the comparison of the co-polar (solid traces) and cx-polar (dashed traces) normalized radiation pattern at 2.6GHz and 3.8GHz, respectively. The scenario with the horizontally polarized AUT has been chosen for this comparison and the reported pattern cuts are the vertical ones (along the MP array). The blue patterns are obtained from the NF/FF transformation of the SP measurements applying the conventional probe pattern correction, based on the numerical model of the rectangular OEW probe [10]. It is remarked that such patterns are the reference ones in this validation. The black patterns are computed with the NF/FF processing of the MP measurements without any probe pattern correction. As can be seen, significant deviations on the sidelobe levels are obtained. The oranges patterns are instead computed from the same MP measurement, but applying the probe correction, based on the APP method. In this case agreement with the SP measurement is significantly improved.

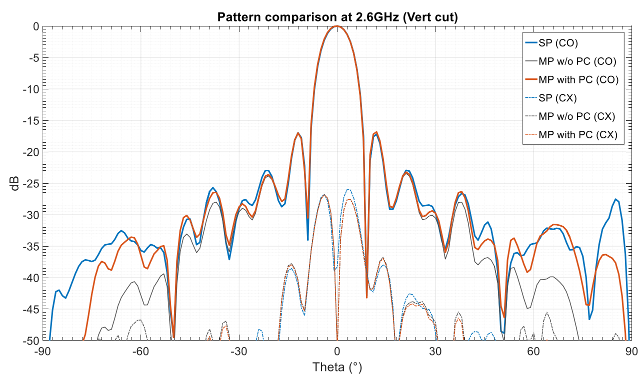


Figure 3. Normalized co-polar and cx-polar pattern comparison at 2.6GHz. Horizonally polarized antenna.

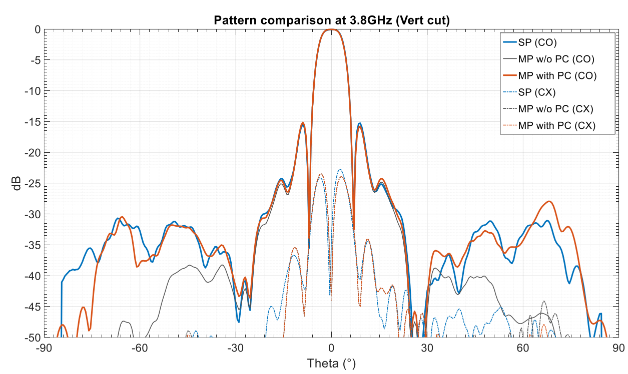


Figure 4. Normalized co-polar and cx-polar pattern comparison at 3.8GHz. Horizonally polarized antenna.

The directivity comparison over frequency is shown in Figure 5. The blue trace is the peak directivity obtained with the SP system applying the conventional PC. The orange and green traces are the peak directivities measured with the MP system with the AUT in horizontal and vertical polarization, respectively. In both cases the probe correction based on the APP method is applied. The agreement of the two MP measurements with the SP ones is excellent. The maximum deviation (approx. 0.3dB) is observed at the highest frequencies where the tapering effect introduced by the probe pattern is more pronounced, and hence more challenging to be compensated.

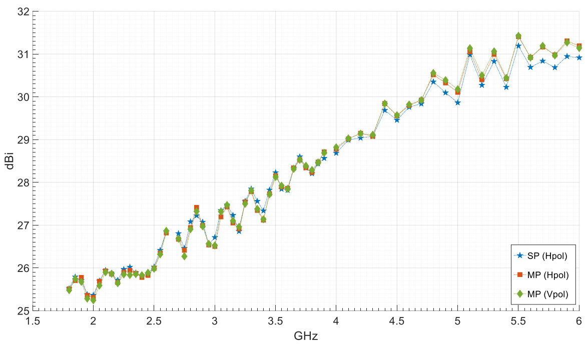


Figure 5. Directivity comparison among probe corrected SP and MP measurements.

To evaluate the overall agreement of the MP measurements with the SP ones, the Equivalent Noise Level (ENL), defined by the equation below is considered.

$$ENL = 20\log_{10}\left(RMS\left|\frac{E(\theta,\varphi) - \tilde{E}(\theta,\varphi)}{E(\theta,\varphi)_{MAX}}\right|\right)$$

In the equation $E(\theta,\varphi)$ and $\tilde{E}(\theta,\varphi)$ are the reference pattern (the ones from the SP measurements) and test patterns (the ones from the MP measurements), respectively.

Figure 7. shows the ENL for the horizontally polarized AUT. Such a metric has been computed both for the co-polar (left plot) and the cx-polar pattern (right plot) as well as for the processing without the probe correction (black traces) and with probe correction based on the APP method (orange traces). The computed ENL have been limited to a solid angle of +/-50° from the boresight direction. The improvements obtained with the considered probe correction technique are remarkable both for the co-polar and cx-polar patterns. As can been seen the application of the probe pattern correction is particularly relevant above 3.2-3.5GHz where indeed, the probe pattern becomes more directive.

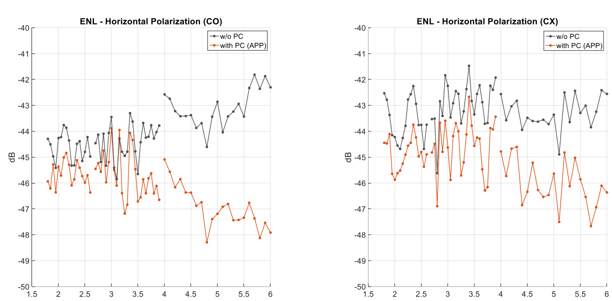


Figure 6. Comparison of copolar (left) and cx-polar (right) ENL between SP and MP measurements of the SR150 in horizontal polarization.

Figure 7. shows the same ENL comparison but applied to the vertically polarized antenna configuration. The achieved error levels are approximately the same of the one observed with the horizontally polarized configuration, meaning that the applied probe compensation works well for both polarizations of the MP array.

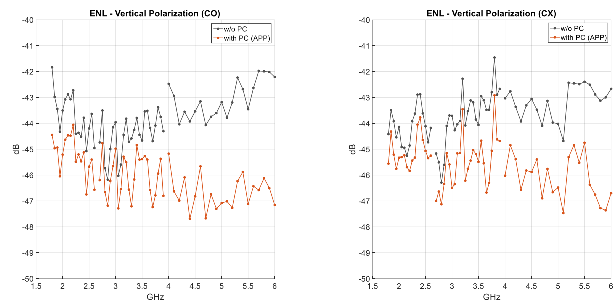


Figure 7. Comparison of copolar (left) and cx-polar (right) ENL between SP and MP measurements of the SR150 in vertical polarization.

Considering the computed ENL, we can make some observations about the measurement uncertainty of the MP system.

- Firstly, it is important to note that the measurement uncertainty of the SP system, which serves as the reference for the measurements, has been determined through a dedicated study [9], revealing an uncertainty, significantly better than the ENL reported here.
- Since both SP and MP measurements are conducted in the same environment and test setup, it is reasonable to assume that certain errors, like room scattering, are consistent for both systems.
- The uncertainty analysis performed in this study as expressed by the ENL values are primarily driven by two factors: the coupling between the MP array and the AUT, and the relative probe pattern of the MP array.
- The effect of the MP array-AUT coupling has been thoroughly studied in a separate campaign, involving multiple measurements at varying scan distances [9]. The results showed that the MP array-AUT coupling effect is on the order of -55 dB in a worst-case scenario.
- Examining the ENL values presented in Figure 6 and Figure 7, we observe that they range between -48dB and -44dB. Consequently, it can be inferred that these ENL values are primarily influenced by the relative probe pattern of the MP array.
- For these ENL values, the corresponding 1σ-uncertainty is bounded between 0.03dB and 0.05dB at the peak of the pattern. Similarly, the uncertainties of the -30dB sidelobes are approximately bounded between 1dB and 1.5dB.

By understanding these sources of uncertainty, we gain valuable insights into the accuracy and reliability of our measurement system.

## V. CONCLUSIONS

Linear multi-probe arrays allow to significantly reduce the test time of planar near field antenna measurements. Besides the mandatory probe array calibration needed to equalize the response of each probe, the probe pattern correction represents an additional challenge. The average probe pattern (APP) technique has been considered in this paper to compensate for the effect introduced by the probe. An extensive validation campaign based on the comparison between measurements of the same antenna performed in a single probe and a multi probe system installed in the same range has been presented in this paper. The considered antenna is a 1.5m reflector in the 1.8-6.0 GHz frequency range.

It has been shown that the proposed APP technique is capable of significantly reduce the errors introduced by the probe pattern, being far from an ideal isotropic source, especially at higher frequencies.

Considerations on the computed equivalent noise level, evaluated from the single probe measurement (assumed as reference) and the multi probe one, allowed to estimate the additional uncertainty introduced by the multi probe. This is bounded between 0.03dB and 0.05dB at the peak of the AUT pattern and between 1dB and 1.5dB at -30dB pattern level.

## REFERENCES


[1] IEEE Std 1720-2012 "Recommended Practice for Near-Field Antenna Measurements"

[2] L. Durand, L. Duchesne, L.J. Foged, Roni Braun, Reuven Konevky Lior Shmidov "Electronically scanned arrays for fast testing of large antennas" 2010 International Workshop on Antenna Technology (iWAT), 1-3 March 2010

[3] L. Durand et al. "Fast testing technique for multibeam antennas", 2011 IEEE Applied Electromagnetics Conference (AEMC), 18-22 Dec. 2011

[4] F. Saccardi et al., "Analysis of Probe Compensation Techniques for Fast Multi-Probe Planar Near Field Measurements," AMTA 2021, Daytona Beach, FL, USA, 2021.

[5] F. Saccardi, N. Gross, P.O. Iversen, K. Hassett, G. Pinchuk, R. Braun, L. Shmidov, M. He, L. J. Foged, "Probe Compensated Planar Near Field Measurements Performed with Mult-Probe Technology", EuCAP 2021, Dusseldorf, Germany

[6] https://www.mvg-world.com/en/products/antenna-measurement/hybrid-systems/t-dualscan (accessed August 2023)

[7] Kerns, D. M., "Plane-wave scattering-matrix theory of antennas and antenna-antenna interactions:Formulation and applications," Journal of Research of the National Bureau of Standards, vol. 80B, no. 1, pp. 5–51, 1976.

[8] A. G. Repjar, A. C. Newell, M. H. Francis "Accurate Determination of Planar Near-Field Correction Parameters for Linearly Polarized Probes", IEEE Transactions on Antennas and Propagation, vol. 36, no. 6, June 1988

[9] Newell, A. C., "Error analysis techniques for planar near-field measurements," IEEE Transactions on Antennas and Propagation, vol. 36, no.6, pp. 754–768, June 1988.

[10] A. D. Yaghjian, "Approximate Formulas for the Far Field and Gain of Open-Ended Rectangular Waveguide", IEEE Trans. Antennas Propagat., vol. 32, N4, 1984, pp. 378-384