OTA Testing of Antennas & Devices using Plane Wave Generator or Synthesizer

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Abstract— **Over-The-Air (OTA) testing aims to determine performance parameters of a device in the Far-Field (FF). The FF condition is achieved at sufficient distance between the device and the probe/range-antenna where the wave-front radiated by the device and probe/range-antenna approximates a plane-wave. For electrically large devices this condition may require a large separation and a corresponding high free-space attenuation. Alternative testing methods is to use a Plane Wave Generator or Synthesizer (PWG/PWS) as probe or range-antenna. The PWS approximates the desired plane-wave condition and thus FF condition over a finite volume at a reduced distance called the Quiet Zone (QZ). Examples of such generators are the Compact Antenna Test Range (CATR) and array based PWS. The latter consists of an array of elements with suitably optimized complex coefficients. In [1,2], the concept of a high performance, dual polarized PWS supporting up to 1:10 bandwidth was presented. A demonstrator of a dual polarized PWS has been designed, manufactured and tested in the 600MHz to 6GHz frequency range.**

In this paper, we report on the measured QZ performance of different implementations of the PWS demonstrator. QZ fields are determined within a volume by spherical NF measurements and back-propagation. It is shown experimentally that the QZ field uniformity can be trade-off with size. Results of the verification testing and comparison to spherical near field measurements are reported using electrically small devices.

I. INTRODUCTION

The testing of Antenna/Device Under Test (AUT/DUT) in Far-Field (FF) condition is described in the IEEE standards 149-1979 on antenna measurements. A revision of this standard is currently under preparation [3]. This standard also includes techniques to approximate a plane wave in the test volume occupied by the AUT/DUT. Such techniques comprise: Compact Range Reflectors, Dielectric Lenses, Metallic Lenses, Transmit Array, Reflect Arrays and Arrays. A separate IEEE standard 1720-2012 covers Near-Field (NF) techniques suitable for AUT/DUT testing [4]. A good reference for NF testing can also be found in [5].

In 3GPP documentation on testing of 5G enabled devices measurement techniques are reported using a slightly different terminology [6-8]. This is due to the lack of coordination and collaboration between 3GPP and the IEEE Standardization Association. In 3GPP terminology, "direct far-field testing" is when a plane wave condition in the test volume is approximated by separation distance. "Indirect far-field testing" is a category of techniques were the plane wave condition in the test volume is achieved by other means. Examples of such techniques are the Compact Antenna Test Range (CATR) and Plane Wave Generator or Synthesizer (PWG/PWS). 3GPP is also continuing the investigation of NF techniques although at a slower pace.

Although not widely accepted in standardization communities, the CATR and PWG/PWS are NF techniques as the testing is performed in the NF of the AUT/DUT. In CATR testing, the Near-Field to Far-Field (NFFF) transformation is performed over a continuous surface by the reflector. In PWG/PWS testing, the NF sampling is on a grid determined by the positions of the array elements.

Due to the similarities between the CATR and the PWG/PWS as testing technique it is interesting to compare their performances. Both techniques aim to achieve far-field testing conditions in the test volume and thus the possibility to perform direct measurement of far-field performance in a controlled indoor environment. However, the PWG/PWS has the advantage of reduced physical size compared to the a CATR with equivalent testing capabilities. The physical size advantage is particularly evident at lower frequencies as it affects system dimensions and thus associated cost of the anechoic chamber. This advantage is of particular importance for testing at sub-6GHz frequencies for Over-The-Air (OTA) testing of 4G and the upcoming 5G devices.

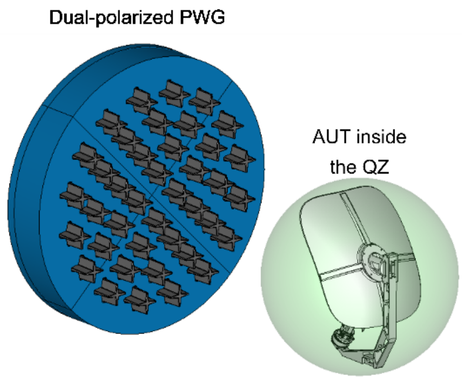

Fig. 1. Sketch of the PWG/PWS: a plane wave is approximated at close distance in a spherical QZ (in green).

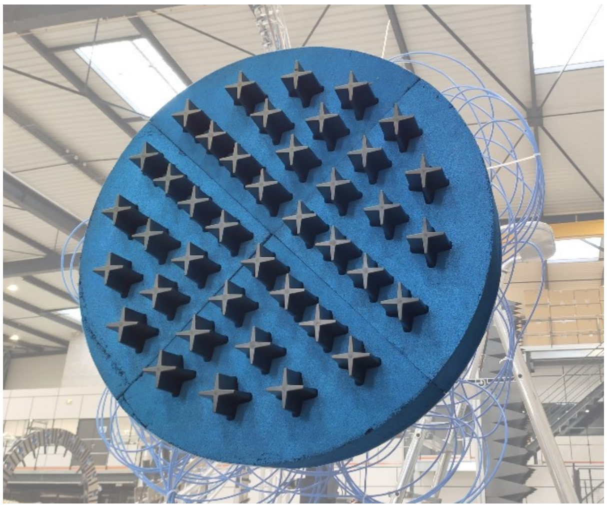

Fig. 2. PWG/PWS demonstrator: An approximate plane wave is generated by suitably excited array elements

II. PWG/PWS DESCRIPTION

The PWG/PWS is meant to be a flexible system, to measure full spherical radiation patterns of any AUT/DUT.

The spherical measurement can be traditionally performed by a simple mechanical rotation of the PWG/PWS or the AUT/DUT in the 3D space. Alternatively, different excitation patterns can be implemented to steer the beam of the array without mechanical movement. This steering is, however, limited to small angles of incidence [5-6]. In the implementation presented here, we rely on the former approach. In particular, the array is disposed in a circular lattice, which is the most natural way to produce the spherical QZ [9-14]. This approach reduces the complexity of the system, allowing to divide the PWS in sub-arrays in the form of rings with the equal amplitude and phase excitation and, thus, reducing the number of active controls.

The number of rings and the elements density and type are design parameters linked to the QZ requirements: the size of the spherical QZ and its distance from the PWS are used to define the spatial discretization of the array.

A key parameter to consider the PWS a valid alternative to CATR is the achievable bandwidth. The PWS design goal is a wide band system, able to generate a uniform QZ for several octaves. A dual polarized PWS, design for a 10:1 frequency range has been presented in [3,4] including design guidelines and justification. The synthesized QZ using ideal array coefficients of the measured PWS subarrays shows promising results. Conclusions were supported by emulation of different measurement scenarios by post-processing.

For the purpose of the investigation reported in this paper a narrow band Beam Forming Network (BFN) has been implemented at 3.5GHz. The BFN implementation allow to investigate experimentally, the tradeoff between performance and size of the QZ for different configurations. It also allows to investigate actual measurement accuracy for electrically small and medium size antennas.

III. MEASUREMENT OF QZ / TEST VOLUME PERFORMANCE

The QZ performance of a CATR or PWG/PWS system is an indication of the quality of the plane wave approximation in the test volume. Common quality factors are amplitude taper, amplitude ripple and phase variation on a planar test surface in the test volume. The measurement is traditionally performed by moving a probe in the QZ so that the incident field is sampled as a function of position over the test aperture [3]. The probe antenna should be low to moderately directive. A high directivity probe would discriminate against wide-angle reflections from the chamber and surroundings and also reflections from the probe-mounting structure. However, if the probe is too directive it will average the fields over the aperture and thus alter the real performance of the QZ acting as a low pass filter on the variations that are being measured.

Due to the availability of Spherical NF measurement of the PWG/PWS demonstrator discussed in this paper we investigate the field variation over the entire test volume. The spherical wave expansion of the measurement allows to determine the fields in arbitrary grid test points within the entire test volume with high accuracy. In contrast to the traditional plane QZ sampling, the volume measurement allows to appreciate also the down-range taper of the system that is of importance when evaluating the plane wave approximation of the system. The spatial filtering properties of the spherical wave expansion attenuates the influence of chamber interactions and stray fields. This procedure is thus very suited to evaluate the achievable performance of the PWG/PWS by itself.

The measurements of the PWG/PWS with different performance settings of the QZ size and performance was performed in the Spherical NF, multiprobe system SG-64 in Paris as shown in Fig. 3. As discussed in [3,4] the plane wave approximation in the QZ is a trade-off including measurement distance, array size and number of elements. To further investigate the trade-off between size and quality of the QZ plane wave approximation, two set of excitation coefficients have been optimized. Both sets generate a spherical QZ centered in *950* mm from the PWG/PWS aperture, but they differ in QZ diameter, which is $d_{QZ1} = 480$ mm in the first case and $d_{QZ2} = 360$ mm in the second. The down-range QZ

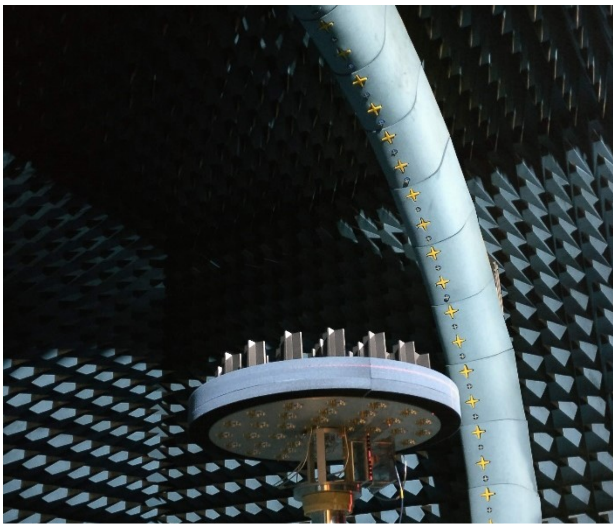

Fig. 3. PWG/PWS during validation measurement in the spherical NF multi-probe system SG-64 in Paris.

amplitude field distribution generated by the PWG/PWS @ 3.5GHz in the two configurations is shown in Fig. 4 (a) and (d). The radiated field cut parallel to the PWG/PWS aperture is shown in Fig. 4 (b) and (c) in amplitude and phase for the d_{QZ1} case. Similarly, the same maps are presented for the d_{QZ2} case in Fig. 4 (e) and (f).

The measured QZ amplitude variation within the entire spherical region is lower than ± *0.9* dB for the for the d_{QZ1} case and lower than ± *0.4* dB for the for the d_{QZ2} case. The Root Mean Square (RMS) of the amplitude variation is always lower than *0.4* dB and 0.3 dB for the first and second configurations, respectively. The worst-case phase variation has similar behavior, being lower than ± *7* deg for the for the d_{QZ1} case and lower than ± *4* deg for the d_{QZ2} case, within the QZ. Also in this case, the RMS is fairly low, with a maximum value of *3°* and *1.5°* for the two configurations, respectively. These values confirm the expected QZ deviations predicted from ideal excitation coefficients as reported in [3,4].

IV. VALIDATION OF PWG/PWS BY MEASUREMENT OF GAIN OF LOW DIRECTIVITY ANTENNA

In [3] the expected measurement accuracy was evaluated by simulation using the measured QZ performance of the PWG/PWS and a known antenna. In [4] we measured the on-axis gain of a low directivity antenna and compared it with results from measurement in a standard spherical near field system. In both papers, it was shown that the deviation from perfect plane wave condition in the QZ is sufficiently low to expect a good measurement accuracy.

Here, we test the measurement accuracy considering bandwidth and the position of the AUT in the QZ that was not investigated in previous campaigns. The investigation has been performed in a bandwidth centered @ 3.5GHz. The AUTs are two dual-ridge horns: SH800 covering the 0.8-12 GHz frequency range and the SH2000 covering the band 2-32 GHz. The SH800 can be considered a low-medium gain AUT at these frequencies whereas the SH2000 is a low gain antenna due to its small physical size. The measurement setup is shown in Fig. 5. The cables of the analog BFN can been seen on the back of the PWG/PWS. Also, the surrounding environment is not completely anechoic.

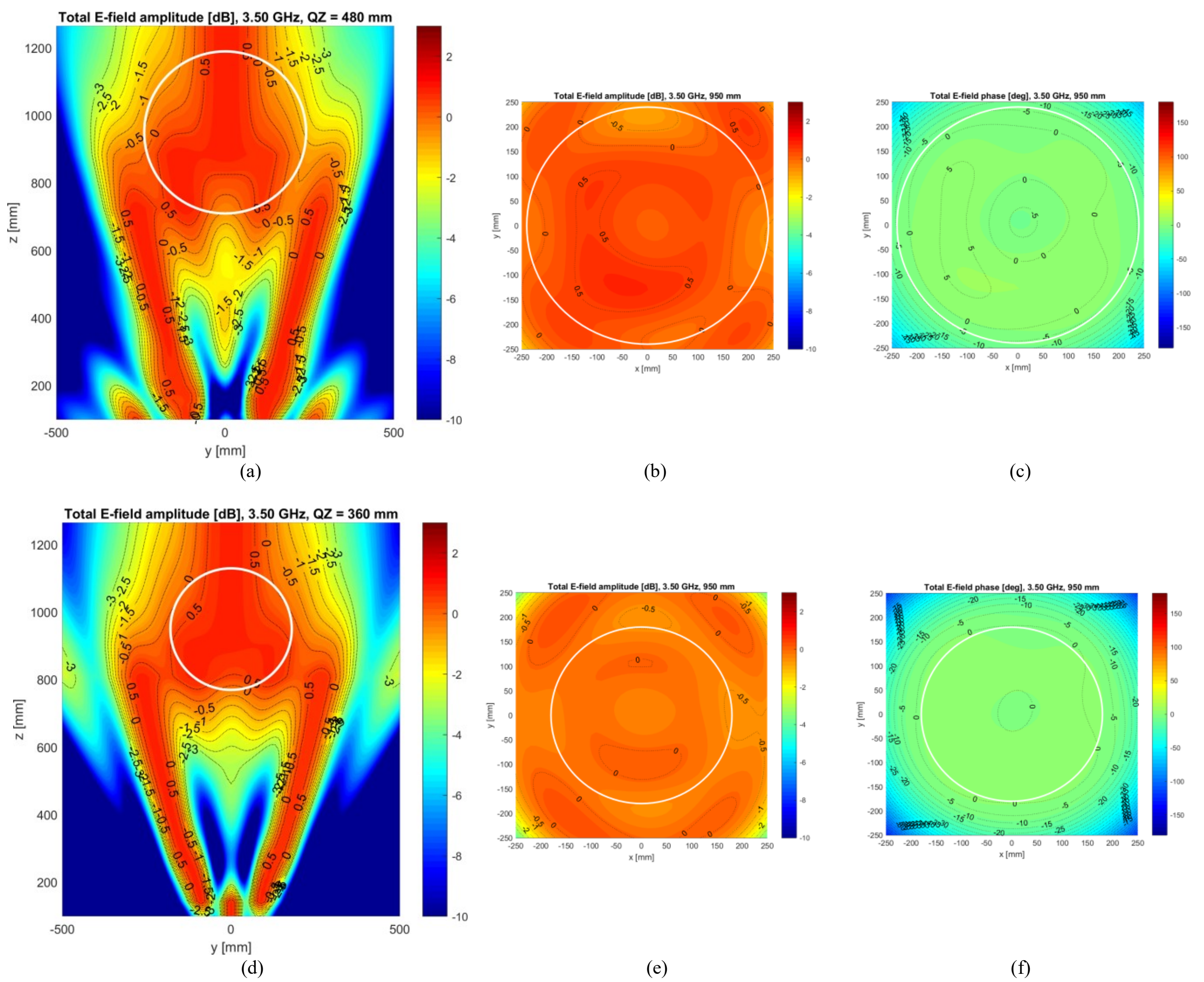

Fig. 4. Measured E-field amplitude map @ 3.5 GHz: d_{QZ1} down-range amplitude (a), d_{QZ1} parallel plane amplitude (b) and phase (c), d_{QZ2} down-range amplitude (d), d_{QZ2} parallel plane amplitude (e) and phase (f). The white ring indicates the QZ position centered in *950* mm.

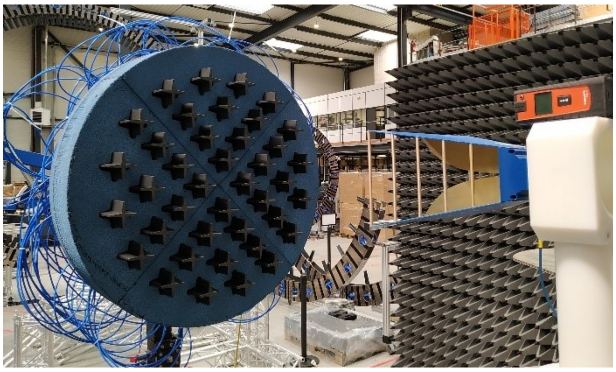

Fig. 5. Illustration of the on-axis gain measurements using the PWG/PWS demonstrator.

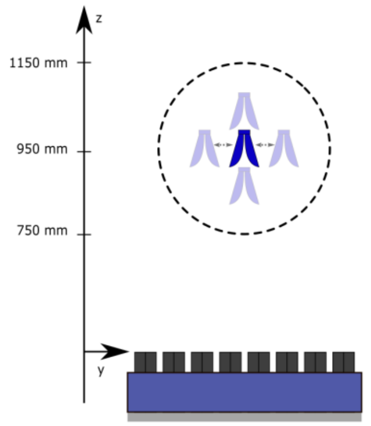

Fig. 6. Sketch of the measurement. The antenna is placed in different positions within the QZ.

In this investigation we use the gain substitution technique to determine gain of one antenna, with the other as reference. The PWG/PWS configuration has been set to QZ diameter $d_{QZ1}= 480$ mm, centered at *950* mm from the aperture. The measured QZ uniformity for this configuration at center frequency 3.5GHz is ±*0.9* dB/ ±*7°* as shown in Fig 4a. Fig 4b and Fig 4c. In order to investigate variability with QZ uniformity the AUT gain is measured at five different positions within the QZ with 100mm separations in the *yz*-plane as shown in Fig. 6. Measurements consist in measuring the coupling S21 of the PWG/PWS and antenna in the QZ using a Network Analyzer (NA).

The variation in measured gain, with frequency, of the larger sized SH800 antenna with different QZ position is shown in Fig. 7a. The SH2000 in the center position has been used a reference. The variation in measured peak gain for the different positions within the QZ are less than 1dB. As can be expected, when amplitude averaging the five measurements, the mean value is close to the reference curve within a few tenths of a dB. Similar conclusion can be made for the measurements of the physically smaller SH2000 using the SH800 as reference. The measured peak gain with frequency, for five different positions of the SH2000 are shown in Fig. 7b. In this case, gain variations with position and frequency are larger. Due to the smaller physical size, the SH2000 is, more sensitive to the local variations of the QZ. As expected, when amplitude averaging the five measurements, the mean value is close to the reference curve within a few tenths of a dB. In both cases, it is interesting to note that the measured gain variability with QZ position is less than the maximum point-to-point variability of the QZ owing to the aperture averaging of the AUT's.

It is worth noting that the measurements are performed with a narrow band BFN, optimized for a single frequency point. The gain variations with QZ position is expected to decrease significantly if measured in the PWG/PWS configuration with smaller QZ size and thus better QZ uniformity. Despite the short measurement distance, the measurements show no sign of standing waves that could exist between the large surface of the PWG/PWS and the AUT. This effect is indeed very small. This is likely due to the absorbing material embedded within the PWG/PWS.

V. Conclusion

Measurement of QZ amplitude/phase uniformity, and assessment of achievable gain accuracy of small/medium size antennas using a Plane Wave Generator/Synthesizer (PWG/ PWS) has been presented. The measurements are performed with a dual polarized, wideband demonstrator but equipped with an analog narrow band beam forming network @3.5GHz.

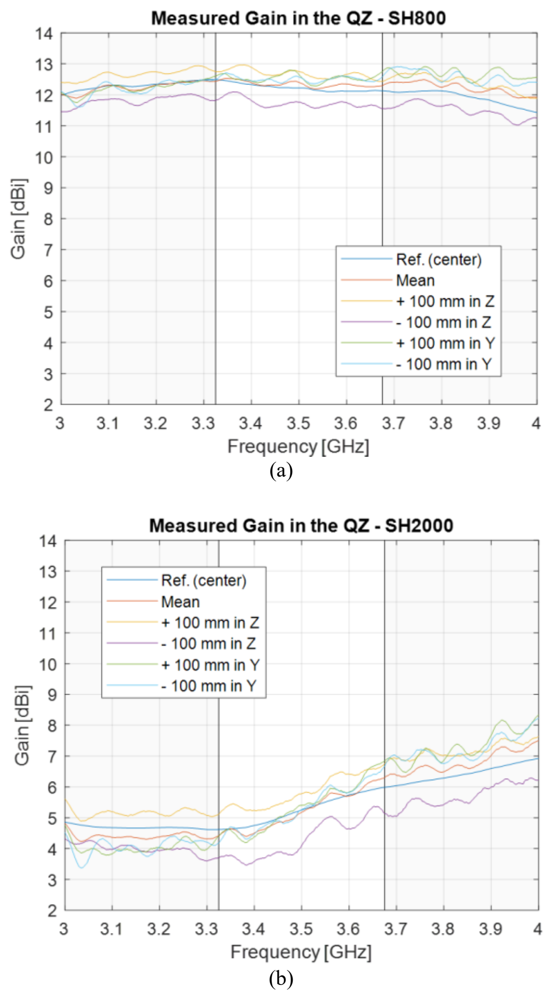

Fig. 7. Measured AUT gain inside the QZ: moving the dual-ridge horns SH800 (a) and SH2000 (b) inside the QZ.

The QZ fields have been determined point-by-point within a volume by spherical Near-Field (NF) measurements and back-propagation. It has been experimentally verified, how QZ amplitude and phase uniformity can be notably improved by reducing the target QZ size. A measured uniformity of ±*0.4* dB/ ±*4*° has been shown for a QZ, roughly half the size of the PWG/PWS. Larger QZ can be synthesized with some loss of QZ field uniformity.

Peak gain measurements have been performed with small/medium antennas. As expected, the smaller antennas are sensitive to QZ variation but some degree of averaging effect of the aperture has been detected. It has been further shown, that mediating a few measurements at different positions within the QZ is able to dramatically improve the measurement uncertainty due to QZ variation.

Despite the short measurement distance, the measurements show no sign of standing waves phenomenon's that could exist between the large surface of the PWG/PWS and the AUT for this demonstrator.

Further activities are on-going to fully characterize the radiation patterns with this PWG prototype.

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