Spherical Near-field Probe Fed Antenna Techniques for Accurate Millimeter Wave Measurements

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Abstract— **This paper present a specific set-up developed for antenna pattern measurements of probe-fed antenna with a 500mm AUT-probe distance. An example of Near-Field measurement is proposed and shows important errors on phase acquisition at 90GHz. Raw measurements are improved using a spherical correction based on laser-tracker structural data. Phase error and Near-field to Far Field transformation are strongly improved with this technique.**

Index Terms*—Millimeter Waves, Probe-fed antenna, *Spherical Scanner

I. INTRODUCTION

Spherical near-field measurement suits perfectly for measurement of low directivity antenna. Measurements in the millimeter wave (MMW) frequency range are very challenging because of the very small wavelength and large space attenuation. From the last decades, millimeter wave have been mainly dedicated for radar and point to point communication, thus requiring very highly directive antenna. Recently, several applications for very high data rate transmission over short range have been proposed. As an exemple, WiGIG standard propose up to 7Gb/s data rate transmission for WLAN application [1]. These emerging applications integrate lower gain antenna and antenna array.

Considering the large space attenuation at millimeter wave, link budget is very constrained at millimeter wave (MMW). In order to design efficiently radiating system, MMW transceiver has to be placed as close as possible to the antenna. In order to measure integrated MMW antenna, waveguide flange or coaxial connectors are not an option because an additional transition would be needed and it will strongly impact the radiation of the Antenna Under Test (AUT). Thus, this type of antenna must be connected using microelectronic RF probe technology on the ground-signal-ground (GSG) pad of the antenna with the AUT being fixed during measurement so as to provide a stable electrical connection.

Several systems have been proposed to measure antenna fed with RF probe. Most of the set-ups are based on far-field spherical scanners [2-3]. The technique limits the size of AUT and suffers from scattering from the probing part. Advanced processing techniques implying the determination of phase are not available. To offer additional features, 2D-scanner with near-field acquisition have been proposed [4-5]. Recently, a hybrid solution using a robotic arm has been proposed [6]. Recently, MMW spherical near-field set-up have been proposed to improve AUT measurements [7-8]. This type of system solution need very accurate mechanical scanner combined with a very stable guided wave-path.

II. SET-UP DESCRIPTION

A. Mechanical part

The set-up has been fully described in [9]. Considering all the different constraints related to probe fed measurements, a 3-axis scanner with a fixed AUT has been designed by NSI and can be seen presented in Figure 1.

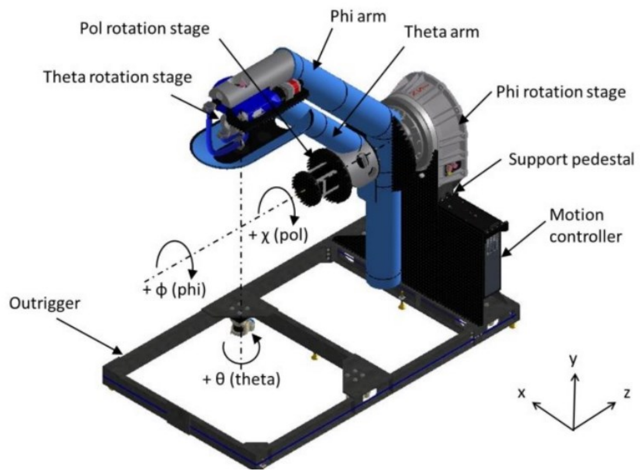


Fig. 1. NSI-700S-360 Articulating 3-axis spherical near-field scanner

This robotic positioning system consists of 500 mm rotational positioner mounted on a large floor stand. This positioner defines the horizontal ϕ-axis of rotation. A second rotation stage is attached to this stage at an angle of 90° to the ϕ-axis and this forms the θ-axis of a conventional right handed polar spherical coordinate system. A third rotary stage is attached to the θ-stage again at an angle of 90° to the θ-axis and this forms the χ-axis. A first MMW extension module is directly attached to the end of the rotating arms, and a second module is placed close to the AUT. Laser system is used to accurately position the antenna in the center of the conceptual sphere centered about the intersection of those orthogonal phi and theta axes (Figure 2).

A wave guide connection is used to connect a MMW module [10] to the GSG RF probe. A micro-positioner system is used to accurately contact the RF probe to the AUT pads as shown in Figure 3.

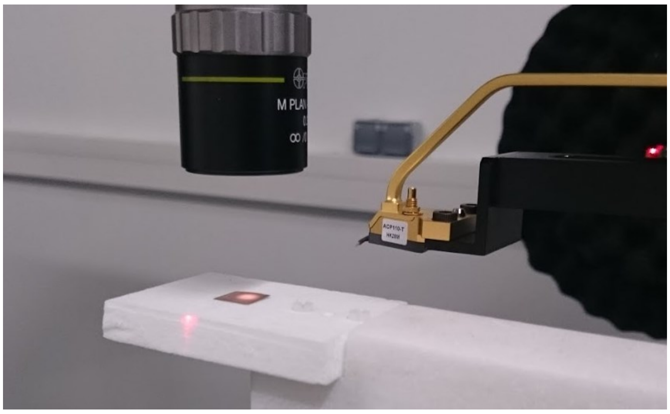


Fig. 2. Waveguide GSG probe and laser alignement of the AUT

Fig. 3. Microscope view of the probing operation with a 250um GSG probe

III. FAR-FIELD AND NEAR FIELD MEASUREMENTS

A. Reference antenna

A reference antenna was used for measurement. A single layer simple structure was chosen for accurate simulation. The structure is composed by a coplanar transmission coupled with a patch on the opposite side of the substrate, as shown in Fig.4. This case is typical of Antenna in Package structure where the chip is placed on the opposite side of the substrate to limit chip-antenna interaction.

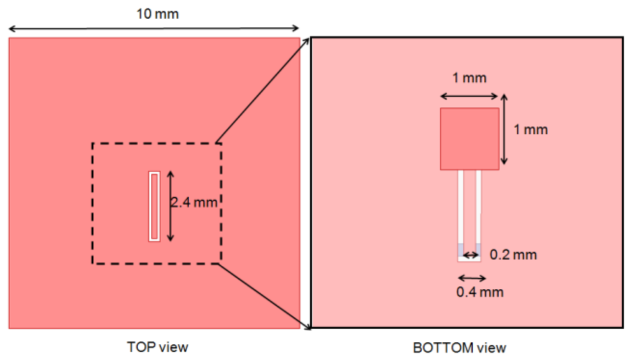


Fig. 4. Antenna dimensions

B. Near-field measurement

A measurement was realized using the robotic articulated spherical arm system. The AUT was scanned for a phi variation from -90° to 90° and theta variation from -140° to 140°. This corresponds to a coverage of 88% of the total surface of the sphere. The distance between the AUT and the probe is 587 mm. A comparison between far-field normalized theta gain simulation and measurement is presented on Figure 5 with a 30dB of dynamic. A first order agreement is observed between simulation and measurement. However, an important back radiation in the probe direction is observed.

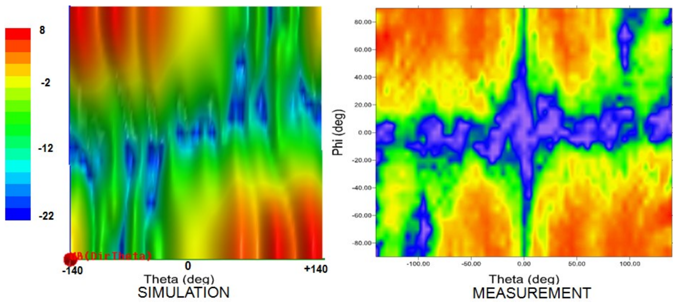


Fig. 5. Comparison between simulated and measured theta gain (dBi) 3D radiation pattern

C. Phase acquisition and radial correction

As its core, the standard spherical near-field theory includes the requirement to accurately and precisely know the phase of the electric near-fields. Due to the very short wavelengths associated with mm-wave, a very significant demand upon the positional accuracies of the robotic-positioners is needed. The accuracy of the mechanical positioning system is achieved through the careful design utilizing structural analysis [8] and through the use of on the fly structure, *i.e.* droop, correction techniques. However, at the upper end of in the 90 – 110 GHz band the radial uncertainty reported above of ±1.2 mm still translates to ± 158° of electrical phase and this does not include any additional impact resulting from changes in phase of the RF guided wave path. Thus, as it has been established through computational electromagnetic simulation that the radial error is the most critical for SNF testing a novel radial phase correction technique, that utilizes the aforementioned laser tracker co-ordinate measurement data, is utilized to further improve the phase stability of the test system thereby increasing the upper frequency limit of the SNF test system [8].

The spherical scanner structural and positioning performance data can be obtained from laser tracker dimensional measurements. These results allow one to establish a perturbed (θ', ϕ', r') grid, based on a regular (θ, ϕ, r) SNF grid. For the scanner shown in Figure.1, the total region of motion is practically limited to $-150° \leq \theta \leq 150°$ and $-180 \leq \phi \leq 180°$ by the AUT support stand, described below. It should be noted that these limitations are determined by the requirement to locate an AUT support in the keep-out region as the each of the individual positioners is capable of 360° motion. Results obtained for r' as a function of (θ, ϕ) are depicted below in Figure 2 in the form of a false color virtual 3D surface. Radial distance variation measured was less than ±1.2 mm over the spherical surface. Based on the result of the measurement radius r' a corresponding electrical phase correction pattern can be generated at each frequency of interest. This phase correction can then be applied to the measured SNF data as a first order correction term in an attempt to remove the phase impact of the structural variation. This correction is referred to as R-correction below.

In order to highlight the mechanical deviation during a spherical scanning, the phase on yOz plane is presented in Figure 6. for phi=-90° and phi = 90°. Without any correction, a maximum error of 92° of obtained for theta=90° and -90°.

After applying the radial correction, the maximal phase error between the theta=90° and -90° cases is reduced to 30°.

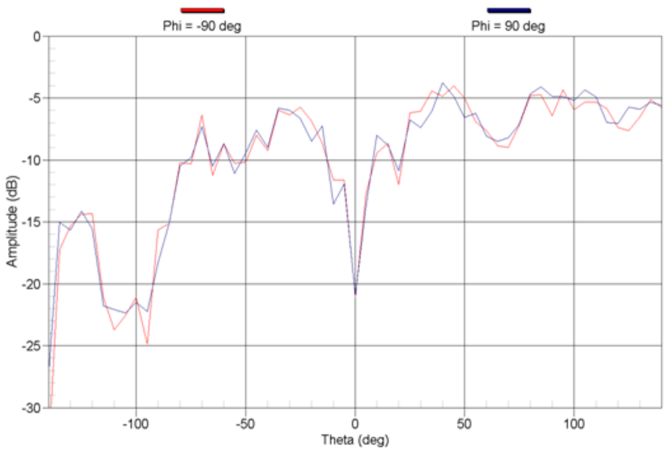


Fig. 6. Near field amplitude on yOz plane for phi=-90° (red) and phi=90° (blue) without correction for Copol

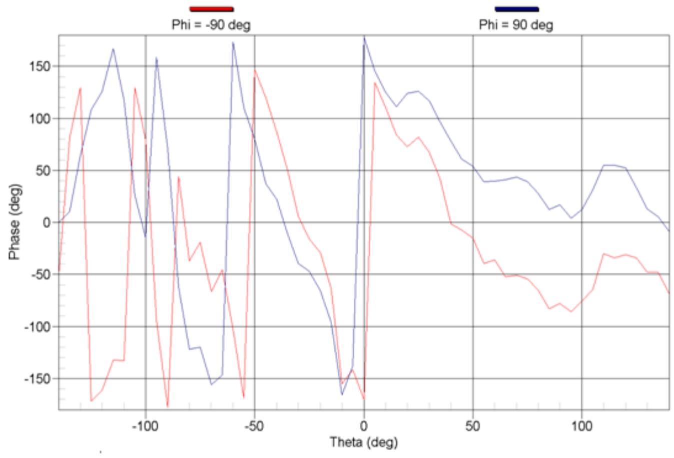
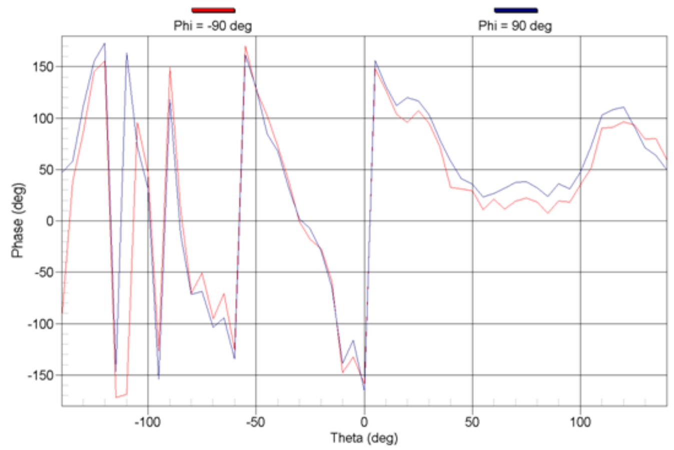


Fig. 7. Near field phase on yOz plane for phi=-90° (red) and phi=90° (blue) without correction for Copol



Near field phase on yOz plane for phi=-90° (red) and phi=90° (blue) with correction for Copol

D. Near-field to far field transformation

In order to highlight the improvement of phase measurement thanks to the radial correction, two different Near-field to Far-field (NF-FF) transformations are presented in Figs 9&10. In Fig. 9, we use raw data without any radial correction. An incorrect discontinuity is observed for phi=90°. As shown in Fig 7, the phase error in this scanning part is large and induces an important error in the far-field result. Considering the NF-FF transformation with radial correction on Fig. 10, discontinuity for phi=90° is considerably reduced and a better agreement with simulation is observed.

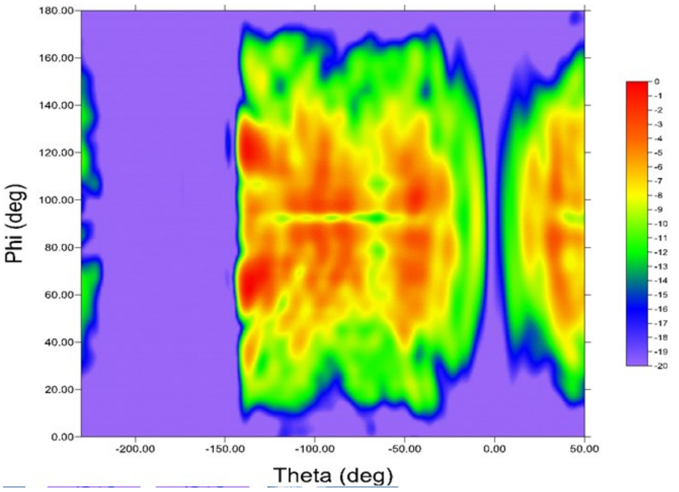


Fig. 8. Far-field transformation from Near-Field measurement without radial correction

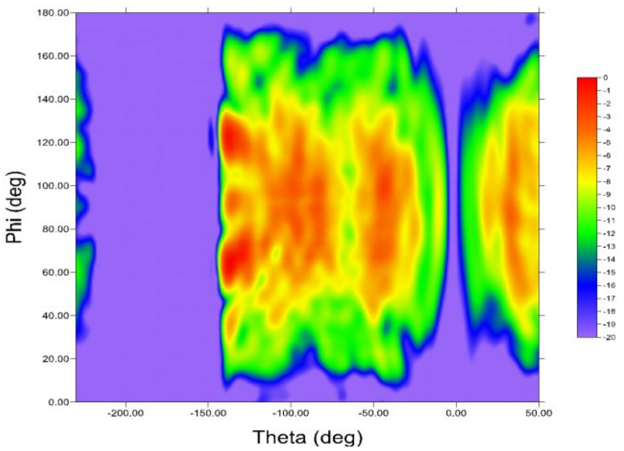


Fig. 9. Far-field transformation from Near-Field measurement with radial correction

IV. CONCLUSION

This paper presents initial results obtained from a new spherical measurement system using a high accuracy spherical articulated arm. First results illustrate how a laser tracker structural measurement can be used to improve measurement accuracy at higher frequencies.

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