

Challenges of 60 GHz On-Chip Antenna Measurements

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Abstract—Performing on-chip antenna measurements at 60 GHz presents new challenges and magnifies legacy challenges. Testing on-chip antennas uses a micro-probe to interface the RF measurement system to the antenna under test (AUT). The small features of the antenna, the micro-probe, and the wavelength are among these challenges. In this paper, we assess these challenges and present techniques to ensure quality measurements.

I. INTRODUCTION

The goal is to develop a commercial millimeter wave electro-magnetic measurement platform to perform quality antenna measurements from 50 GHz to 110 GHz. We focus on the challenges of on-chip antenna pattern and gain measurements near 60 GHz. Identifying and mitigating these challenges is key to a successful design. We discuss these challenges and present techniques to mitigate their effects.

II. DISCUSSION

A. RF System Considerations

Cable losses above 50 GHz are significant. Depending on measurement geometry, cable lengths may exceed 6 meters to attain the desired measured pattern coverage. To achieve good system sensitivity and dynamic range, the use of frequency up/down conversion, such as Port Extension Modules (PEMs), located close to the transmitting and receiving antennas is critical. Standard PEMs are readily available from various test equipment manufacturers.

Using PEMs, the coax cables between the Vector Network Analyzers (VNA) and the PEMs carry frequencies less than 26 GHz. Calibrated noise floors in excess of 40 dBi and dynamic ranges in excess of 70 dB from 50 to 110 GHz are achievable (Fig. 1).

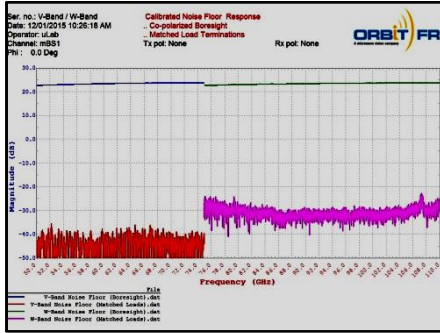


Fig. 1: V-band and W-band calibrated noise floor

B. Measurement Geometry

The variety of low gain (<-10 dBi) to high gain (> +15dBi) [1][2] antennas suggests using a spherical geometry. With the additional requirement for quick far field (FF) measurements the selection of a spherical geometry selection is clear.

We envision testing end-fire antennas, radiating away from the coplanar Radio Frequency (RF) microprobe, and antennas designed to radiate towards the upper as well as the lower hemisphere. With this variety of antenna designs, our goal was to achieve greater than 90% physical coverage of the measurement sphere.

C. Far-Field vs. Near-Field

We chose a spherical geometry with a measurement radius of 30 cm to accommodate a maximum device size comparable to a typical notebook computer. At this radius, in most cases, an individual radiating element is in the FF. If the maximum radiating structure of the antenna under test (AUT) is 1.8 cm, using the FF criteria, $R \gg 2D^2/\lambda$, the table shows the expected FF distance is within the chosen measurement radius. Antenna arrays with multiple beams and reasonably high gain will require near-field (NF) measurements.

Frequency(GHz)	Wavelength (cm)	Far-Field(cm)
60	0.50	12.96
75	0.40	16.20
110	0.27	23.77

D. Positioning System

Mechanical positioning errors in Spherical NF (SNF) have been studied at RF and microwave frequencies [3]. Large amplitude errors are not probable with small mechanical positioning errors. These errors (even if small) have a large effect on phase. Phase errors in the NF data correspond to amplitude and phase errors in the transformed FF patterns. With wavelengths less than 6 mm - positioning system accuracy, repeatability, and alignment of the axes cannot be ignored. A complete error budget is recommended and should include terms such as:

- Theta/Phi axis intersection and orthogonality
- Accuracy of NF probe position and polarization alignment on the measurement sphere
- Dynamic gravitational sag and NF probe pointing

Positioning systems with accurate encoder feedback are a sufficient solution to at least 110 GHz, and are readily available. Laser tracker systems have sufficient accuracy to

support the system alignment process and validation of the positioning system accuracy and repeatability.

E. Phase Stability

Phase stability and accuracy is important in the NF to FF transform process, and is important in FF data collection when precise Circular Polarization (CP) measurements are required. A 7° phase error translates to a 1 dB axial ratio error. WiGig and WirelessHD applications are likely to use CP as hand-held devices have unpredictable physical alignment. [2]

Besides positioning errors, another primary source of phase error is cable flexure. Assuming a system architecture using PEMs, phase variations in the RF or LO cables due to flexure are multiplied by the PEM. Depending on the PEM and the desired test frequency, the multiplication factors on the RF and LO ports are typically between 4 and 8.

Using PEMs, multiple coax cables are required for RF, LO and IF signals. Full 360° rotation with cable wraps, at frequencies below 26 GHz, maximum phase variation less than 4-5 degrees may be acceptable in many antenna measurement systems. However, after PEM multiplication the resulting phase variation could be in excess of 40 degrees.

Selection of superior RF cables and good mechanical design of cable wraps is critical to reduce phase variation due to cable flexure from theta and phi axis rotation and can produce repeatable phase with rotation. A phase correction algorithm was developed to correct repeatable phase variation in the RF and LO cable runs. Combining good mechanical design, high quality cables, and correction, the residual phase variations can be managed to acceptable levels.

F. Micro-probing of Chip Antennas

The small features of antennas (e.g. patch, and dipole elements) at 60 GHz suggest a coplanar micro-probe be used to interface the RF system to the AUT. The 2.4 mm and 1.0 mm coaxial connectors have significant interactions with the antenna on-chip and a greater impact on the measurement than a coplanar micro-probe. [4]

Micro-probing of chip antennas brings new challenges to antenna measurements. Micro-probe stations are physically large and heavy due to anti-shock and anti-vibration techniques implemented to protect the probe and improve measurement integrity. An approach providing similar protection and integrity is isolating the positioning system and moving the NF probe around the AUT (keep AUT stationary).

Micro-probe stations utilize a large steel chuck on which the device under test is placed. The chuck, and other metal parts, makes the probe station a less than ideal choice for radiated measurements. Absorber combined with complicated measurements and processing techniques have been used to mitigate these effects.[5] We prefer a simpler approach using a low loss, low dielectric material chuck to hold the AUT [6].

The micro-probe and associated probe positioner not only provide physical blockage limiting spherical coverage, but are sources of radiation interference with the intended signal [5],[7]. Absorbing material is used to mitigate these effects. Critical considerations for the antenna designer are the

transmission lines and feed networks controlling the interaction with the micro-probe and surface waves on the chip. [8]

Antenna measurements at microwave frequencies require adaptors to interface the RF measurement system to the AUT. Using a micro-probe is similar, except the effects of the micro-probe on the measured gain are more significant. Insertion loss of a micro-probe is nominally <1.0dB. De-embedding the micro-probe is recommended [6]. Micro-probe S-Parameters vary over time, and regular measurement of them is recommended. A system with an automated process for de-embedding is helpful.

Accounting for the S11 of the AUT improves the accuracy of the measured gain, and it is necessary for efficiency. Measuring the AUT S11 in the chamber on a non-metallic chuck is the best environment for accurate S11 measurements. An RF system designed for S11 calibration and measurements of the AUT along with software to automate the process simplifies this exercise.

III. CONCLUSIONS

Development of IEEE 802.11AD and related technologies have led the requirement to performing on-chip antenna measurements at 60 GHz, and beyond. This presents new challenges for the system designer as well as those making the measurements. In this paper, we offered a brief evaluation of the more dominate consideration when making on-chip antenna measurements. We show that, with careful consideration of these potential pitfalls, opportunities exist to mitigate errors and make accurate measurements on-chip and at millimeter wave frequencies.

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