Räisänen, Antti V.; Zheng, Jianfang; Ala-Laurinaho, Juha; Viikari, Ville

Antenna measurements at millimeter wavelengths - Overview

Published in:
12th European Conference on Antennas and Propagation (EuCAP 2018)

DOI:
10.1049/cp.2018.0709

Published: 01/01/2018

Document Version
Peer-reviewed accepted author manuscript, also known as Final accepted manuscript or Post-print

Please cite the original version:
Räisänen, A. V., Zheng, J., Ala-Laurinaho, J., & Viikari, V. (2018). Antenna measurements at millimeter wavelengths - Overview. In *12th European Conference on Antennas and Propagation (EuCAP 2018)* EurAAP. https://doi.org/10.1049/cp.2018.0709

Antenna Measurements at Millimeter Wavelengths – Overview

Antti V. Räisänen[1], Jianfang Zheng[1], Juha Ala-Laurinaho[1], Ville Viikari[1]
[1] Department of Electronics and Nanoengineering, Aalto University, Espoo, Finland, firstname.lastname@aalto.fi

***Abstract*—Testing of electrically large antennas as well as that of electrically small integrated antennas at millimeter wavelengths is very challenging. In this overview we discuss the physical and technical challenges and limitations in testing of the various kinds of mm-wave antennas.**

***Index Terms*—antenna, measurement, millimeter wave**

I. Introduction

The 5G wireless communications systems and internet of things (IoT) bring a growing need for various antennas, electrically small and large, low-gain and large-gain, also at millimeter wavelengths. Frequencies of 28 GHz, 38 GHz, 58 GHz, 60 GHz, 71-86 GHz, 140-150 GHz, and some even higher "window" frequencies are of interest in the future communications networks. Different parts of the networks need many different kinds of antennas, each requiring the most suitable antenna test method.

Testing of electrically large antennas as well as that of electrically small antennas at millimeter wavelengths is challenging [1]. In principle, there are three methods for measuring radiation properties of an antenna: the far-field method (FF), the near-field method (NF), and the compact antenna test range (CATR). In case of large antennas, the classical far-field method has two major obstacles at millimeter wavelengths: impractically large measurement distance and high atmospheric loss. The near-field scanning methods are used indoors but often give useful information only on the main beam and its vicinity, because the field sampling is typically very sparse. Reflector, lens or hologram based CATR systems provide also an indoor environment and a relatively short measurement distance even for high-gain antennas. In case of small integrated antennas, various far-field techniques based on the use of an on-wafer probe have been developed: both 2-port measurements utilizing a robotic arm in one port and 1-port measurements utilizing antenna reflection coefficient measurements while the radiation field is disturbed.

II. Measurement Methods

A. *Far-field measurement*

The natural choice for antenna measurements is the far-field method. However, in case of electrically large antennas, the classical far-field method has some major obstacles. The separation between the antenna under test (AUT) and the source antenna must be so large that the spherical wave front radiated by the source antenna can be approximated as a plane wave. Typically, the required far-field distance is $d=2D^2/\lambda$, where D is the diameter of the AUT and λ is the wavelength. For example, the required separation is 125 m for a 0.5-m antenna at 75 GHz (gain about 50 dBi); a much larger separation may be needed when very low sidelobe levels are measured. The large attenuation and the distortions due to change of temperature and humidity of the atmosphere are the major problems. However, the far-field method is readily applicable for mm-wave antennas with gain of 10 - 20 dBi, because in this case the far-field measurement can be done in a controlled environment such as an anechoic chamber. On the other hand, for a microstrip patch antenna with only few dBi gain, any measurement method brings a lot of challenges, not because of the long distance – the far field distance may be only few millimeters – but because any connection to the antenna tends to disturb the measurement.

Figure 1 presents an overview of the minimum measurement distances as a function of frequency and the antenna gain as a parameter.

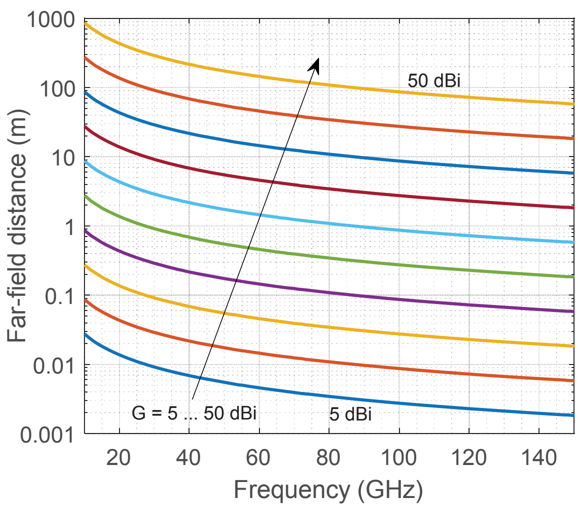

Fig. 1. Far-field distance as a function of frequency for antennas with varying gain from 5 dBi to 50 dBi. Curves are presented for every 5 dB gain levels. A circular antenna aperture with the total efficiency of 0.7 is assumed.

B. *Near-field measurement*

Near-field range measurements can be carried out indoors and in a relatively small space. The humidity and temperature of the measurement environment can be controlled and thus the distortions due to the atmosphere become small. The amplitude and phase of the AUT near field are sampled with a probe antenna and the far-field radiation characteristics are calculated using numerical methods. In case of a millimeter wave antenna, the sampling of the near field is normally accomplished over a plane. The sampling area has to be comprehensive so that all the significant energy transmitted by the AUT can be captured. The sampling has to be dense enough for satisfying the Nyquist sampling criterion, i.e., the distance between two sampling points has to be smaller than one half of the wavelength, i.e. $<\lambda/2$. For example, a 0.65 m x 0.65 m rectangular sampling grid, which covers a 0.5-m antenna, includes about 10^5 sampling points, if full sampling is carried out at 75 GHz. If the sampling rate is 10 samples/s, the measurement takes 10^4 seconds, i.e., about 3 hours. This brings a requirement for high stability of the measurement system and environment. Major error sources in the near-field scanning are the phase errors in bending and twisting cables, inaccurate positioning of the probe, and the reflections between the probe and the AUT.

C. *Compact antenna test range*

In a compact antenna test range the spherical wave front is transformed into a plane wave with a collimating element, which can be a reflector, e.g. [2], a lens, e.g. [3], or a hologram, e.g. [4]. CATRs enable the antenna measurements indoors in plane wave conditions, i.e., the radiation pattern can be directly measured by rotating the AUT. The AUT is placed into the quiet-zone (QZ), which is the extent of the volume where the wave front meets the requirements set on the plane wave. Typically, the maximum amplitude and phase deviations have to be less than ±0.5 dB and ±5°, respectively. Most of the CATRs are based on reflectors. The major problem is the very stringent surface accuracy requirement at high frequencies. The root-mean-square (rms) surface error should be less than 0.01λ, e.g., 40 µm at 75 GHz.

III. INSTRUMENTATION

As is clear from the descriptions above, the high test frequency introduces challenges for the RF-instrumentation in any antenna measurement. Minimum requirement is to have a frequency stable transmitter with sufficient output power and a sensitive receiver at the given mm-wave frequency. Amplitude (i.e. scalar) measurements may suffice in some applications, and the phase may also be retrieved by using holographic means. In holographic measurements a sensitive power meter or detector may be used as a receiver [5], [6], [7]. A spectrum analyser is an excellent incoherent receiver (when equipped with external down-conversion units). In most antenna measurements, however, a vector, i.e. both amplitude and phase, measurement is desired. Today, there are commercially available vector network analysers (VNA) with extension units up to terahertz frequencies based on frequency multiplication and harmonic mixing.

IV. ON-WAFER PROBE BASED FAR-FIELD MEASUREMENTS OF ELECTRICALLY SMALL INTEGRATED ANTENNAS

In case of electrically small integrated antennas the major problem in antenna testing is electric connection to the antenna. The GSG probe developed for on-wafer measurements of integrated circuits provides means also in measurement of small integrated antennas. In published 2-port measurements at 50–110 GHz the AUT connected with the GSG probe is one port, while the other port with a horn antenna is moved around utilizing, e.g., a robotic arm [8], [9], [10], [11]. More recently, we have at Aalto University developed a 1-port method (see Figure 2), where the radiation field of the AUT is disturbed with a movable flat piece of good conductor and the radiation pattern and also the antenna gain are retrieved from the reflection measurements [12], [13].

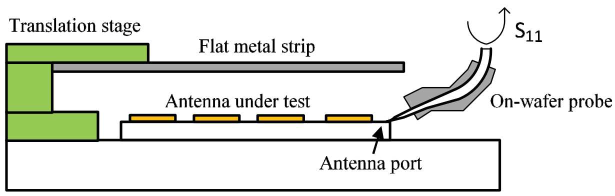

Fig. 2. Setup for characterizing a small integrated antenna on a probe station [1]. The xyz-translation stage is used to alter the position of the reflective flat metal strip.

V. CONCLUSION

We have given a brief overview of the challenges and limitations of various antenna measurement methods at millimeter wavelengths. Table I summarises the applicability of different antenna test methods at mm-wavelengths.

TABLE I. COMPARISON OF VARIOUS ANTENNA TEST METHODS AT MILLIMETER WAVELENGTHS

	Gain of AUT		
	<10 dBi	**10…30 dBi**	**>30 dBi**
FF	++	+	–
NF spherical	++	+	–
NF planar	~	+	+
CATR	–	~	++

ACKNOWLEDGMENT

This work was partially supported by Academy of Finland through the DYNAMITE project.

REFERENCES

[1] A.V. Räisänen, J. Ala-Laurinaho, T. Crowe, S. Pivnenko, M. Sierra Castañer, and V. Viikari, "Antenna measurements at millimeter and submillimeter wavelengths," Chapter 13, pp. 409–450, in A. Boriskin and R Sauleau (eds.), *Aperture Antennas for Millimeter and Sub-Millimeter Wave Applications*, Springer, 2017.

[2] J. Hartmann, J. Habersack, H.-J. Steiner, J. Lemanczyk, and P. de Maagt, "Calibration and verification measurements in compensated compact ranges up to 500 GHz," in *Proc. of 23rd AMTA*, Denver, USA, Oct. 2001, pp. 377–382.

[3] W. Menzel and B. Huder, "Compact range for millimeter-wave frequencies using a dielectric lens," *Electronics Letters*, vol. 20, no. 19, pp. 768–769, 1984.

[4] J. Ala-Laurinaho, T. Hirvonen, P. Piironen, A. Lehto, J. Tuovinen, A.V. Räisänen, and U. Frisk, "Measurement of the Odin telescope at 119 GHz with a hologram type CATR," *IEEE Trans. Antennas and Propagation*, vol. 49, no. 9, pp. 1264–1270, Sept. 2001.

[5] A.V. Räisänen and J. Ala-Laurinaho, "Holographic principles in antenna metrology at millimeter and submillimeter wavelengths," in 9th *European Conference on Antennas and Propagation, EuCAP2015*, Lisbon, Portugal, 12-17 April 2015, paper no. 1570049573.

[6] A. Arboleya, J. Laviada, J. Ala-Laurinaho, Y. Alvarez, F. Las-Heras, and A.V. Räisänen, "Phaseless characterization of broadband antennas," *IEEE Trans. Antennas and Propagation*, vol. 64, no. 2, pp. 484–495, Feb. 2016.

[7] A. Arboleya, J. Laviada, J. Ala-Laurinaho, Y. Álvarez, F. Las-Heras, and A.V. Räisänen, "Indirect off-axis holography for antenna metrology," Chapter 11 in I. Naydenova, D. Nazarova, and T. Babeva (eds.), *Holographic Materials and Optical Systems*, InTech, 2017, available from: http://www.intechopen.com/books/holographic-materials-and-optical-systems/indirect-off-axis-holography-for-antenna-metrology.

[8] T. Zwick, C. Baks, U.R. Pfeiffer, D. Liu, and B.P. Gaucher, "Probe based MMW antenna measurement setup," in *Proc. of the IEEE AP-S Symposium 2004*, Monterey, CA, USA, 20–25 June 2004, pp. 747–750.

[9] Ranvier, S., M. Kyrö, C. Icheln, C. Luxey, R. Staraj, and P. Vainikainen, "Compact 3-D on-wafer radiation pattern measurement system for 60 GHz antennas," *Microwave and Optical Technology Letters*, vol. 51, no. 2, pp. 319–324, Feb. 2009.

[10] S. Beer and T. Zwick, "Probe based radiation pattern measurements for highly integrated millimeter-wave antennas," in *Proc. of 4th European Conference on Antennas and Propagation*, 1–5 Apr. 2010.

[11] K. Mohammadpour-Aghdam, S. Brebel, A. Enayati, R. Faraji-Dana, G. A. E. Vandenbosch, and W. Deraedt, "RF probe influence study in millimeter-wave antenna pattern measurements," *International Journal of RF and Microwave Computer-Aided Engineering*, vol. 21, no. 4, pp. 413–420, July 2011.

[12] Z. Du, V. Viikari, J. Ala-Laurinaho, A. Tamminen, and A.V. Räisänen, "Antenna pattern retrieval from reflection coefficient measurements with reflective loads," *Progress In Electromagnetics Research,* vol. 148, pp. 15–22, 2014.

[13] J. Zheng, J. Ala-Laurinaho, and A. V. Räisänen, "A simple method for on-wafer antenna gain measurement," in *Progress In Electromagnetics Research Symposium (PIERS 2017 St Petersburg)*, Russia, 22–25 May 2017, paper #3 in Session 2A 14a.