Investigation of Planar Near-Field Measurement of Millimeter-Wave Antenna for 5G Application

Bo Xu[1,4], Jakob Helander[2], Andreas Ericsson[2], Zhinong Ying[3], Sailing He[1],
Mats Gustafsson[2] and Daniel Sjöberg[2]
[1]Department of Electromagnetic Engineering, KTH Royal Institute of Technology, Stockholm, Sweden
[2]Department of Electrical and Information Technology, Lund University, Lund, Sweden
[3]Network Technology, SONY Mobile Communications AB, Lund, Sweden
[4]Centre for Optical and Electromagnetic Research, Zhejiang University, Hangzhou, Zhejiang, China

Abstract **– The requirement of higher data rates and the emergence of new wireless device demands in future 5G communication put millimeter-wave frequencies in focus. To investigate electromagnetic-filed exposure at such frequencies for 5G cellular phone application, a planar near-field antenna measurement system is established. A tapered open-ended rectangular waveguide was used as the probe antenna, and a patch array antenna operating at 28 GHz was used as antenna under test. The distribution of power density above the antenna surface was calculated based on the measured data and the plane wave expansion method.**

Index Terms **— Antennas, 5G, near-field, measurement, power density.**

1. Introduction

As the fourth generation mobile communication system (4G) has now been deployed and is reaching maturity, researches focus on the next generation mobile communication system (5G) to meet the requirements of future traffic volume, data rates, and accommodation of new types of devices and services [1], [2] . A potential disruptive move is to extend the communication spectrum to include frequency bands above those used today for mobile and wireless communication systems (typically located below 6 GHz).

For wireless user devices, such as cellular phones, tablets, and smart watches, an important issue is the output power limitation in terms of electromagnetic field (EMF) exposure. To prevent from elevated tissue temperatures resulting from EMF exposure, safety guidelines have been published by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) [3], Federal Communication Commission (FCC) [4], and IEEE [5], [6]. In the frequency range used for mobile communication nowadays, the fundamental exposure metric is the specific absorption rate (SAR). At frequencies above 3 GHz (IEEE), 6 GHz (FCC) and 10 GHz (ICNIRP), the exposure limits change from SAR (measured in W/kg) to free-space power density (PD, measured in W/m^2). There have been some theoretical studies on EMF exposure above 6 GHz by Ericsson [7] and Sony Mobile [8]. However, measurements of EMF exposure above 6 GHz are still rare in the literature.

In this work, we establish a planar near-field (NF) antenna system to measure the electrical NF of a patch array antenna operating at 28 GHz, a potential candidate of 5G cellular phone antennas [8], and calculate the PD distribution in proximity of the antenna under test (AUT) at 28 GHz. The comparison of simulated and measured PD is also presented.

2. Measurement Theory

The theory of planar NF antenna measurement has been well developed in the last 50 years [9], [10]. The configuration of NF measurement is shown in Fig. 1. The probe antenna is used to measure the tangential component of the E-field of the stationary AUT in the *x-y* plane with a distance of z = d_0. The main concept is to use a plane wave (modal) expansion to represent the tangential E-field at the scanning plane z = d_0 as a superposition of plane waves [10]:

$$\mathbf{E}(x,y,d_0)=\frac{1}{4\pi^2}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\tilde{\mathbf{E}}(k_x,k_y)e^{-j(k_x x+k_y y)}dk_x dk_y. \quad (1)$$

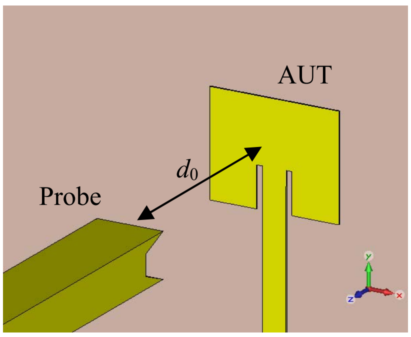


Fig. 1. Configuration of the planar NF antenna measurement.

Each plane wave can be derived by inverse Fourier transform:

$$\tilde{\mathbf{E}}(k_x,k_y)=\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\mathbf{E}(x,y,d_0)e^{j(k_x x+k_y y)}dxdy. \quad (2)$$

Thus, the back-propagated tangential field at z = d_1 ($0 < d_1 < d_0$) can be written as

$$\mathbf{E}(x,y,d_1)=\frac{1}{4\pi^2}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\tilde{\mathbf{E}}(k_x,k_y)e^{-j(k_x x+k_y y)}e^{jk_z(d_0-d_1)}dk_x dk_y, \quad (3)$$

in which

$$k_z = \begin{cases} \sqrt{k^2 - k_x^2 - k_y^2}, & \text{if } k_x^2 + k_y^2 \le k^2, \\ -j\sqrt{k_x^2 + k_y^2 - k^2}, & \text{otherwise.} \end{cases} \quad (4)$$

By using the orthogonality conditions of an EM wave $\mathbf{k}\cdot\tilde{\mathbf{E}} = 0$ and $\tilde{\mathbf{H}} = \mathbf{k}\times\tilde{\mathbf{E}}$, we can get both the tangential and normal components of the E- and H-field, respectively. The PD at position (x, y, d_1) can be written as

$$\mathbf{P}(x, y, d_1) = \frac{1}{2}\mathrm{Re}[\mathbf{E}(x, y, d_1)\times\mathbf{H}^*(x, y, d_1)]. \quad (5)$$

After calculating the field of AUT, time-gating technique was used to decrease the noise due to multipath components in the measured signal and to increase the precision. Zero-padding technique was used to increase the resolution of the fields. Probe correction method [11] was also used to compensate the coupling between the main component of the probe and the cross component of the AUT.

3. Measurement and Results

A planar NF antenna measurement system is established at the Department of Electrical and Information Technology (EIT), Lund University, as shown in Fig. 2. The AUT is a patch array antenna operating at 28 GHz, a potential candidate of 5G cellular phone antennas [8]. The probe is a tapered open-ended rectangular waveguide whose cut-off frequency is 22 GHz. The AUT is stationary and the probe is fixed on the platform of a planar scanning system. The probe and the AUT were connected to a vector network analyzer (VNA). For convenience and simplicity, only one port of the AUT was excited in the measurement. RF Microwave absorbers were used to suppress the reflection. The distance between the AUT and the probe is d_0 = 75 mm. The scanning area is 20 cm × 20 cm. The sampling spacing is 0.5 mm.

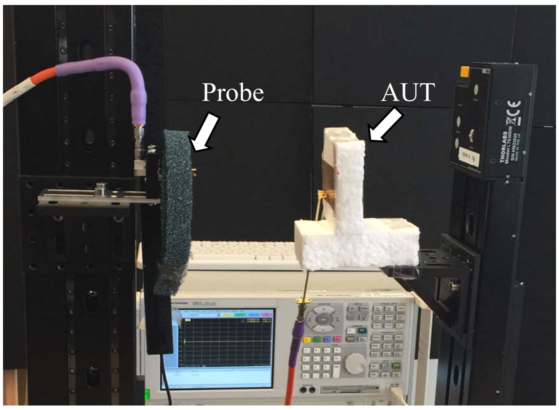


Fig. 2. Planar NF antenna measurement setup.

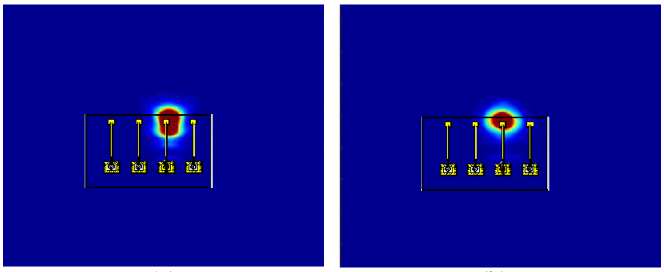
CST Microwave Studio was used to simulate the radiation from the patch array antenna. The simulated and measured PD distribution at d_1 = 10 mm above the antenna is shown in Fig. 3. The discrepancy between the simulated and measured results may attribute to the disturbance of the rigid feed line, instability of structure of the foam support, lack of information of the evanescent part, and the limited scanning area.

4. Conclusion

The main concept, measurement setup and results of NF antenna measurement have been presented in this paper. More details and results will be presented in ISAP 2016.

Acknowledgment

This work is sponsored by China Scholarship Council (CSC) under the Grant No. 201506320137. The authors would like to acknowledge L. Hedenstjerna, S. Shi, K. Liu and K. Zhao.



(a) (b)

Fig. 3. Configuration of the patch array antenna and distribution of (a) Simulated and (b) measured PD (both are linearly-scaled) with d_1 = 10 mm above the patch array antenna.

References

[1] J. G, Andrews, S. Buzzi, W. Chio, S. V. Hanly, A. Lozano, A. C. K. Soong, J. C. Zhang, "What will 5G be?" *IEEE J. Sel. Areas Commun.*, vol. 32, no. 6, pp. 1065-1082, Jun. 2014.

[2] T. S. Rappaport, S. Sun, R. Mayzus, H. Zhao, Y. Azar, K. Wang, etc., "Millimeter wave mobile communications for 5G cellular: it will work!" *IEEE Access*, vol. 1, pp. 335-349, May 2013.

[3] International Commission on Non-Ionizing Radiation Protection, Health Physics, "Guidelines for limiting exposure to time-varying electric, magnetic, and electromagnetic fields (up to 300 GHz)," *Health Phys.*, vol. 74, no. 4, pp. 494–522, Oct. 1998.

[4] FCC, "Code of Federal Regulations CFR title 47, part 1.1310," 2010.

[5] *Standard for safety levels with respect to human exposure to radio frequency electromagnetic fields, 3 kHz to 300 GHz*, IEEE C95.1, 2005.

[6] *Standard for safety levels with respect to human exposure to radio frequency electromagnetic fields, 3 kHz to 300 GHz. Amendment 1: specifies ceiling limits for induced and contact current, clarifies distinctions between localized exposure and spatial peak power density,* IEEE C95.1a, 2010.

[7] D. Colombi, B. Thors, and C. Törnevik, "Implications of EMF Exposure limits on output power levels for 5G devices above 6 GHz," *IEEE Antennas Wireless Propag. Lett.*, vol. 14, pp. 1247-1249, 2015.

[8] K. Zhao, Z. Ying, and S. He, "EMF exposure study concerning mmWave phased array in mobile devices for 5G communication," *IEEE Antennas Wireless Propag. Lett.*, vol. 15, pp. 1132-1135, 2016.

[9] C. A. Balanis, *Antenna theory, analysis and design*. Wiley: New Jersey, 2005, pp. 1014-1021.

[10] F. Ferrara, C. Gennarelli, R. Guerriero, "Near-Field Antenna Measurement Techniques," *Handbook of Antenna Technologies.* Springer: Singapore, 2015, pp. 1-49.

[11] A. G. Repjar, A. C. Newell, and M. H. Francis, "Accurate determination of planar near-field correction parameters for linearly polarized probes," *IEEE Trans. Antennas Propag.*, vol. 36, no. 6, pp. 855-868, Jun. 1988.