Advances and Challenges in Handset Antenna Efficiency for 5G and Beyond

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Abstract—**Increasing system requirements for 5G and beyond wireless systems translate into an increasing importance of antenna efficiency. In this paper we show that frequency-reconfigurable antennas are a very promising solution to increase the efficiency, exhibiting an upper bound on the radiation efficiency that is significantly increased compared to traditional designs. We then compare several efficiency measurement techniques, from which we can conclude that reverberation chamber measurements are an ideal solution for 5G and beyond.**

I. Introduction

As 5G and beyond wireless standards require ever larger bandwidths, the Chu-Harrington limit [1], [2] becomes more challinging to deal with for handsets, in particular in the sub-6 GHz bands of 5G [3]. Since size is constrained and directivity is already small in the sub-6 GHz bands, this results in a decreased efficiency. Add to this the ever increasing number of wireless standards that handsets need to support, and the efficiency becomes more crucial than ever.

An antenna has two types of efficiency: the total efficiency $\eta_{\text{tot}} = P_{\text{radiated}}/P_{\text{available}}$, with is the ratio of the available and radiated powers, and the radiation efficiency $\eta_{\text{rad}} = P_{\text{radiated}}/P_{\text{accepted}}$, which is the ratio of the accepted and radiated powers. In other words, the radiation efficiency is excluding mismatch losses, while the total efficiency includes mismatch losses. In this paper, we study some recent advances in handset antennas from an efficiency point of view, focussing on the sub-6 GHz bands, and provide an outlook for 5G and beyond applications. We start out by a new emperical study of the limitations on radiation efficiency of a highly flexible frequency-reconfigurable antenna in Section II. We then discuss measurement methods of antenna efficiencies in Section III, concluding the paper in Section IV.

II. Recent Advances in Handset Antennas

Traditionally, antennas in mobile handsets were completely un-reconfigurable devices. More recently, adaptive matching networks became common in commercial designs [4], [5], with research pushing towards aperture-tuned devices [6]–[8]. The adaptive matching network introduces the potential to adapt the matching in an optimal fashion, thereby offering the possibility to increase the total efficiency. However, the radiation efficiency cannot be affected using an adaptive matching network - this is the domain of aperture-tuned antennas.

Aperture-tuned, frequency-reconfigurable antennas are extremely promising to cope with the ever increasing requirements of 5G and beyond. In Fig. 1 several antennas are compared: five commercial smartphone antennas [5] (dashed lines) and several settings of an aperture-tuned frequency-reconfigurable antenna [9] (solid lines). Though similar in size, the frequency-reconfigurable antenna achieves a higher radiation efficiency. It uses three tuning components in the aperture, creating more freedom to find optimal settings for the efficiency. It also exhibits a reject-band, which may help to achieve a fully frequency-reconfigurable front-end as its filtering requirements are relieved. Also shown, with a broad curve in black, is the highest achieved radiation efficiency over all measured settings (not all shown). This curve is frequency-averaged over a 50 MHz band to reduce the influence of noise on individual settings on the upper-bound, resulting in some noise responces to peak above it.

It is very interesting to observe that there is a smoothly developing upper limit to the radiation efficiency for this antenna. While the Chu-Harrington limit would predict a much higher upper limit for the efficiency in this frequency range, its concept still holds for frequency-reconfigurable antennas, provided optimal bias settings are found. A deeper study of tunable antennas and these effects is extremely interesting for future research.

III. Efficiency Measurements for 5G and Beyond

In general, antenna efficiency can be measured using the Wheeler cap method, anechoic chamber (AC) techniques, or reverberation chamber (RC) techniques. The Wheeler cap method makes use of a change in the input resistance when covering the antenna with a conducting cap placed at $\frac{\lambda}{2\pi}$ (R_{cap}) compared to it radiating into free space (R_{free}). The radiation efficiency can then be estimated as $\eta_{\text{rad}} = \frac{R_{\text{free}}-R_{\text{cap}}}{R_{\text{free}}}$ [10]. This means assuming the antenna is small, and working in an extremely small bandwidth. It is therefore rather unpractical for 5G's wideband designs.

The anechoic chamber is the tradiational environment of choice for antenna measurements, since it can provide a good approximation of free-space, making it ideal for radiation pattern measurements. However, measuring the radiation efficiency is usually performed by measuring the gain G and directivity D, resulting in a radiation efficiency $\eta_{\text{rad}} = \frac{G}{D}$ [10]. The directivity measurement requires a full 3D pattern

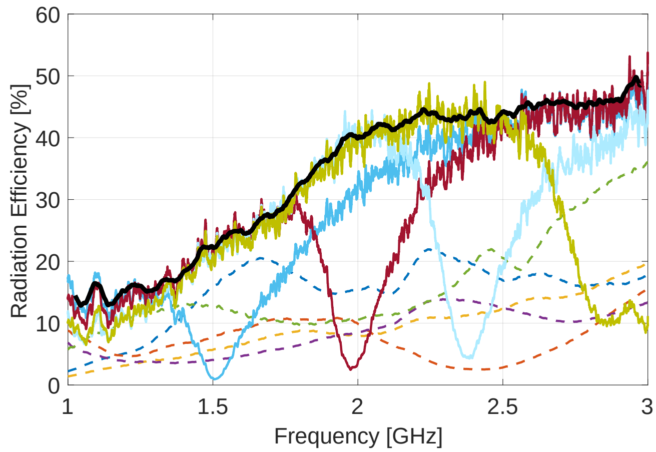

Fig. 1. Comparison of the radiation efficiencies of a commercial smartphone's antennas (dashed) [5] and a recent frequency-reconfigurable antenna (solid) [9]. Using the frequency-reconfigurability, a setting can be chosen to maximize the antenna's efficiency. All settings are bounded by a maximum-efficiency curve, shown using a thick solid line in black. As can be seen, this particular frequency-reconfigurable antenna has a reconfigurable reject band.

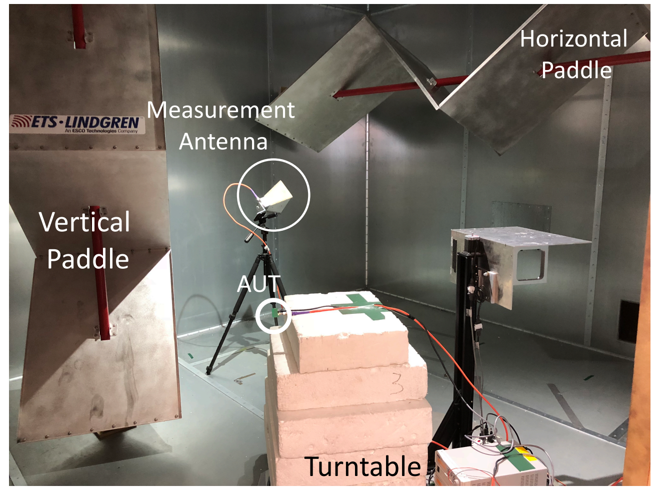

Fig. 2. Typical example of a two-antenna efficiency measurement method configuration in a reverberation chamber. Shown are two paddles (vertical and horizontal) for stirring, a rotating platform, a reference antenna (measurement antenna) and a frequency-reconfigurable antenna under test (AUT).

measurement with a sufficiently fine angular grain for the antenna under test (AUT), making it time-consuming. It is also difficult for low-gain antennas since the antenna holder may influence the results. In addition, the gain requires a reference antenna or usage of the three-antenna method.

For these reasons, efficiency measurements in RCs [11]–[13] are gaining popularity. These chambers, with a typical example and configuration shown in Fig. 2, are the opposite of ACs: they maximize reflections from all walls. The electromagnetic modes in the chamber are then changed by moving one or more (two are shown) paddles. In addition, one or both of the antennas in the room can be placed on a turntable to provide another stirring mechanism. The average over a set of positions can then be used to obtain the antenna's total and radiation efficiencies using a reference antenna [11] or without one [13]. Usually, 100 paddle positions (in the chamber shown 10 positions for each of the paddles) are sufficient to obtain a satisfactory uncertainty, resulting in a significant time reduction compared to to AC approaches. The setup of the measurement is also simplified compared to the AC - low-gain antennas such as a frequency-reconfigurable antenna can easily be placed on a block of foam.

IV. Conclusion

In this paper we showed a new upper-bound on the radiation efficiency of a frequency-reconfigurable antenna. This bound, which can be reached due to its emperical nature, lies significantly higher than the radiation efficiencies of traditional commercial designs. This shows the importance of reconfigurability in handset antennas for the efficiency, which becomes ever more important due to increasing system requirements. We then compared several methods to measure antenna efficiencies. From this comparison we can conclude that reverberation chambers are a very promising measurement solution for 5G and beyond.

References

[1] L. J. Chu, "Physical limitations of omni-directional antennas," *Journal of Applied Physics*, vol. 19, no. 12, p. 1163, 1948.

[2] R. F. Harrington, "Effect of antenna size on gain, bandwidth, and efficiency," *Journal of Research of the National Bureau of Standards, Section D: Radio Propagation*, vol. 64D, no. 1, p. 1, 1960.

[3] 3rd Generation Partnership Project; Technical Specification Group Radio Access Network, "Nr; user equipment (ue) radio transmission and reception; part 1: Range 1 standalone (release 15)," 2018.

[4] J. L. Hilbert, *Tunable RF Components and Circuits: Applications in Mobile Handsets*. CRC Press, 2015.

[5] L. A. Bronckers, A. Roch, and A. B. Smolders, "Benchmarking a high-end smartphone's antenna efficiencies," *IEEE Access*, vol. 7, pp. 105 680–105 686, 2019.

[6] F. A. Ghaffar, M. Vaseem, L. Roy, and A. Shamim, "Design and fabrication of a frequency and polarization reconfigurable microwave antenna on a printed partially magnetized ferrite substrate," *IEEE Transactions on Antennas and Propagation*, vol. 66, no. 9, pp. 4866–4871, 2018.

[7] P. F. Hu, Y. M. Pan, X. Y. Zhang, and B. J. Hu, "A filtering patch antenna with reconfigurable frequency and bandwidth using f-shaped probe," *IEEE Transactions on Antennas and Propagation*, vol. 67, no. 1, pp. 121–130, 2019.

[8] W. Gao, S. J. Chen, W. Withayachumnankul, and C. Fumeaux, "Horizontally polarized 360-degree beam-steerable frequency-reconfigurable antenna," *IEEE Transactions on Antennas and Propagation*, vol. PP, no. c, pp. 1–1, 2019.

[9] L. A. Bronckers, A. Roc'h, and A. B. Smolders, "A new design method for frequency- reconfigurable antennas using multiple tuning components," *IEEE Transactions on Antennas and Propagation*, vol. 67, no. 12, pp. 7285–7295, Dec. 2019.

[10] C. A. Balanis, *Modern Antenna Handbook*, C. A. Balanis, Ed. Hoboken, NJ, USA: John Wiley & Sons, Inc., Aug. 2008.

[11] International Electrotechnical Commision, "Iec 61000-4-21:2011 electromagnetic compatibility (emc) - part 4-21: testing and measurement techniques - reverberation chamber test methods," 2011.

[12] P.-S. Kildal and K. Rosengren, "Correlation and capacity of mimo systems and mutual coupling, radiation efficiency, and diversity gain of their antennas: simulations and measurements in a reverberation chamber," *IEEE Communications Magazine*, vol. 42, no. 12, pp. 104–112, Dec. 2004.

[13] C. L. Holloway, H. A. Shah, R. J. Pirkl, W. F. Young, D. A. Hill, and J. Ladbury, "Reverberation chamber techniques for determining the radiation and total efficiency of antennas," *IEEE Transactions on Antennas and Propagation*, vol. 60, no. 4, pp. 1758–1770, Apr. 2012.