Thermal Loss in High-Q Antennas

Barrio, Samantha Caporal Del; Bahramzy, Pevand; Svendsen, Simon; Jagielski, Ole; Pedersen, Gert Frølund

Published in:
Electronics Letters

DOI (link to publication from Publisher):
10.1049/el.2014.1222

Publication date:
2014

Document Version
Early version, also known as pre-print

Thermal loss in high-Q antennas

S. Caporal Del Barrio, P. Bahramzy, S. Svendsen,
O. Jagielski and G.F. Pedersen

Tunable antennas are very promising for future generations of mobile communications, where antennas are required to cover a wide range of operating bands. This reported work was aimed at characterising the loss mechanism of tunable antennas. Tunable antennas typically exhibit a high quality factor (Q), which can lead to thermal loss due to the conductivity of the metal. The investigation shows that copper loss is non-negligible for high-Q values. In the proposed design, the copper loss is 2 dB, for a Q of 260 at 700 MHz.

Introduction: With the band proliferation that followed the standardisation of the fourth generation (4G) of mobile communications, active antennas have been investigated to enhance the operating bandwidth of mobile phone antennas while keeping a low profile. Active antennas can reconfigure their resonance frequency using microelectromechanical systems [1], *pin* diodes [2] or varactors [3]. These active components will add a varying reactance to the impedance of the antenna, thus modifying its resonance frequency. A recent overview of the tuning techniques is given in [4]. Independently of the tuning technique, when the antenna is forced into resonance at a lower frequency than its natural frequency, its bandwidth decreases and its quality factor, Q, increases inversely proportionally [5]. As the Q of the antenna increases, its efficiency decreases due to higher currents in the equivalent series resistance of the tuner. For high-Q values, the loss due to the tuner alone cannot explain the measured total loss [6]. In the work reported in this Letter, the authors investigated the existence of a thermal loss in high-Q antennas, due to the conductivity of copper. For this investigation, the authors have designed a large patch antenna, naturally resonating at 700 MHz, as it is the lowest frequency to reach with 4G nowadays [7]. Different widths of the patch result in different antenna Q, while maintaining the resonance frequency. The measured radiation efficiencies are compared to determine the influence of Q on the thermal loss of antennas.

Geometry: The geometry of the design used to investigate thermal loss is shown in Fig. 1. It consists of a slot-fed patch, placed above a large ground plane. A design with a large ground plane has been chosen in order to mitigate the effect of the cable, while measuring the radiation efficiency. The ground plane (GP) has a rectangular slot in its centre. The feeding is positioned across the slot, in its centre along the $+z$-axis. The patch is placed 10 mm above the ground ($+x$-direction). The length of the patch controls the resonance frequency, the width of the patch W controls its Q and the height of the patch controls the matching to the 50 Ω feeding line. The strength of the presented design is that the width of the patch only affects Q, without modifying its other parameters, i.e. resonance frequency and match. Therefore comparisons can be made between antennas, where the only variable is their Q. The mock-ups are made out of pure copper only, in order to investigate the existence of loss due to the conductivity of lossy metals. No lumped element is necessary to the design, thus isolating the copper loss. W varies from 2 to 25 mm and all the other dimensions of the design are fixed and summarised in Table 1. The length of the patch is $\lambda/2$ at 700 MHz, and the side of the GP is equivalent to $5\lambda/7$ at 700 MHz.

Q: Antenna Q is calculated according to [8]

$$Q_{\mathrm{A}}(\omega) = \frac{2\sqrt{\beta}}{\mathrm{FBW_V}(\omega)}, \qquad \sqrt{\beta} = \frac{s-1}{2\sqrt{s}}$$

where $\mathrm{FBW_V}$ is the fractional bandwidth at a matched voltage-standing-wave ratio (VSWR) and s is the specific value of the VSWR.

In practical antenna design, one can distinguish the unloaded Q ($Q_{\mathrm{unload.}}$) from the loaded Q ($Q_{\mathrm{load.}}$). The $Q_{\mathrm{unload.}}$ values are found through simulation of a lossless structure with a perfect electric conductor and describe the relationship between reactance and resistance in the element itself. They give a worst-case scenario; however, these values are useful for directly comparing one antenna with another. The $Q_{\mathrm{load.}}$ values are found through measurements and include the loss in the structure. Evidently, $Q_{\mathrm{load.}}$ values will always be lower than $Q_{\mathrm{unload.}}$ values. The difference between $Q_{\mathrm{unload.}}$ and $Q_{\mathrm{load.}}$ gives an insight into the amount of loss in the antenna structure. For this purpose, the authors introduce the ratio of loaded to unloaded Q values: R_Q. This ratio will be used to characterise the antennas in the following Sections.

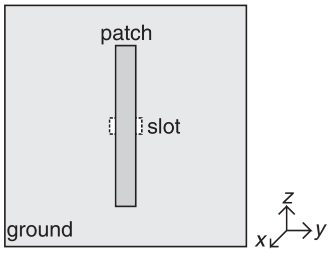

Fig. 1 *Design of high-Q antenna on large GP*

Table 1: Design dimensions

	Ground	Slot	Patch
Area (mm^2)	300 × 300	2 × 38	196 × W

Fig. 2 *Front (left) and back (right) views of mock-up*

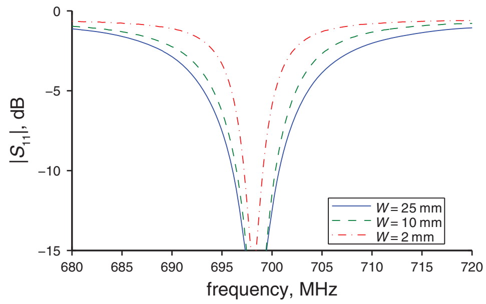

Fig. 3 *Measured frequency response for different widths of patch*

Measurements: The above-described antenna design is simulated using the finite element method solver in the Computer Simulation Technology [9] and built with pure copper. The mock-up is shown in Fig. 2 for $W = 25$ mm. Polystyrene spacers are used to stabilise the mock-up. Alignment of the plates is ensured, as it affects the resonance of the mock-up. The large ground plane limits the interaction between the radiator and the coaxial measuring cable. Measurements of the three patches reveal varying bandwidths depending on the width of the patch. Absolute and complex frequency responses of the mock-ups can be seen in Figs. 3 and 4, respectively. The centre frequency for the three mock-ups is 698 MHz. The absolute response shows a bandwidth enhancement as the patch width increases and the complex response shows Q comparability between the mock-ups as the curves cross very similar points in the Smith chart. This Figure also shows the entering and exiting frequencies (rounded to 1 MHz) of the VSWR circle. Simulated and measured Q values, as well as measured total efficiency (η_T), are summarised in Table 2.

The measurements show that the measured $Q_{\mathrm{load.}}$ values are close to the simulated $Q_{\mathrm{unload.}}$ values, and that the ratios R_Q are about 0.9. Nonetheless, it is observed that the total loss increases with the $Q_{\mathrm{unload.}}$. The only source of loss in the mock-up is copper, thus thermal loss is non-negligible for high-Q structures. In the presented design, the thermal loss is as high as 2 dB for the $Q_{\mathrm{unload.}}$ of 260 at 700 MHz. It is expected that for further increasing values of $Q_{\mathrm{unload.}}$, dropping values of R_Q and of η_T will be observed.

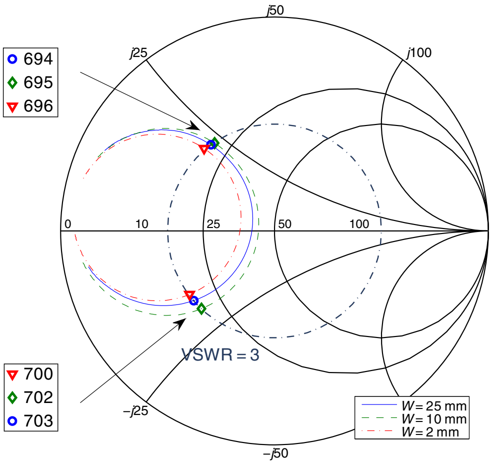

Fig. 4 *Measured frequency response for different widths of patch*
Entering and exiting frequencies of VSWR circle are given in MHz

Table 2: Design dimensions

	$Q_{unload.}$	$Q_{load.}$	R_Q	η_T (dB)
$W = 25$ mm	90	81	0.90	−1.1
$W = 10$ mm	175	160	0.91	−1.3
$W = 2$ mm	260	225	0.87	−2.0

Application: Thermal loss becomes more significant as $Q_{unload.}$ increases. In the presented design, in the case of $W = 2$ mm, the $Q_{unload.}$ of 260 led to a $Q_{load.}$ of 225, due to thermal loss. The $Q_{load.}$ of 225 is equivalent to a bandwidth of 4 MHz at 700 MHz, as can be seen from Fig. 4. In the 4G standard, channel bandwidths vary from 1.4 to 20 MHz [7], hence 4G can be addressed with narrow-band tunable antennas, which cover the bandwidth of a channel only, instead of a full band. This architecture was proposed in [10]. Such antennas will exhibit a very high $Q_{unload.}$, thus high thermal loss, in addition to the tuner loss. The existence of thermal loss for high-Q antennas limits the achievable efficiency of tunable antennas.

Conclusion: This Letter describes a patch antenna with varying Q. As the Q increases, the loss due to the copper conductivity increases as well and becomes non-negligible for high-Q values. The thermal loss is intrinsic to antenna manufacturing and can become a limiting factor to the miniaturisation of tunable antennas.

Acknowledgment: This work was supported by the Smart Antenna Front-End (SAFE) project within the Danish National Advanced Technology Foundation – High Technology Platform.

4 April 2014
doi: 10.1049/el.2014.1222
One or more of the Figures in this Letter are available in colour online.

S. Caporal Del Barrio, P. Bahramzy and G.F. Pedersen (*Antennas, Propagation and Radio Networking (APNet) Section, Department of Electronic Systems, Faculty of Engineering and Science, Aalborg University, DK-9220 Aalborg, Denmark*)

E-mail: scdb@es.aau.dk

S. Svendsen and O. Jagielski (*Intel Mobile Communication Denmark Aps, 35 Lindholm Brygge, Noerresundby 9400, Denmark*)

P. Bahramzy: Also with Intel Mobile Communication Denmark Aps, Noerresundby, Denmark

References

1 Boyle, K.R., and Steeneken, P.G.: 'A five-band reconfigurable PIFA for mobile phones', *IEEE Trans. Antennas Propag.*, 2007, **55**, pp. 3300–3309
2 Park, Y.K., and Sung, Y.: 'A reconfigurable antenna for quad-band mobile handset', *IEEE Trans. Antennas Propag.*, 2012, **60**, (6), pp. 3003–3006
3 Nguyen, V.-A., Bhatti, R.-A., and Park, S.-O.: 'A simple PIFA-based tunable internal antenna for personal communication handsets', *IEEE Antennas Wirel. Propag. Lett.*, 2008, **7**, pp. 130–133
4 Haider, N., Caratelli, D., and Yarovoy, A.G.: 'Recent developments in reconfigurable and multiband antenna technology', *Int. J. Antennas Propag.*, 2013, **2013**, pp. 1–14
5 Kivekäs, O., Ollikainen, J., and Vainikainen, P.: 'Frequency-tunable internal antenna for mobile phones'. 12th Int. Symp. Antennas (JINA), Melbourne, Australia, December 2002, pp. 53–56
6 Caporal, S., Barrio, D., Pelosi, M., Pedersen, G.F., and Morris, A.: 'Challenges for frequency-reconfigurable antennas in small terminals'. IEEE Vehicular Technology Conf. (VTC Fall), Quebec City, Canada, September 2012, pp. 1–5
7 3GPP TS 36.101: 'LTE; Evolved Universal Terrestrial Radio Access (EUTRA); User Equipment (UE) radio transmission and reception', 2013
8 Yaghjian, A.D., and Best, S.R.: 'Impedance, bandwidth, and Q of antennas', *IEEE Trans. Antennas Propag.*, 2005, **53**, (4), pp. 1298–1324
9 Computer Simulation Technology (CST). Available at http://www.cst.com, 'CST Microwave Studio', 2012
10 James, A.: 'Reconfigurable antennas for portable wireless devices', *IEEE Antennas Propag. Mag.*, 2003, **45**, (6), pp. 148–154