Thermal Loss in High-Q Antennas
Barrio, Samantha Caporal Del; Bahramzy, Pevand; Svendsen, Simon; Jagielski, Ole; Pedersen, Gert F.

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

Link to publication from Aalborg University

Citation for published version (APA):
Thermal loss in high-Q antennas

S. Caporal Del Barrio, P. Bahramzy, S. Svendsen, O. Jaglielski 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 report was aimed at characterizing 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 natural frequency for the three mock-ups is 698 MHz. The absolute response curves cross very similar points in the Smith chart. This Figure introduces the ratio of loaded to unloaded efficiency ($\eta$), 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.

Table 1: Design dimensions

<table>
<thead>
<tr>
<th>Area (mm²)</th>
<th>Ground</th>
<th>Slot</th>
<th>Patch</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design</td>
<td>300 × 300</td>
<td>2 × 38</td>
<td>196 × 11</td>
</tr>
</tbody>
</table>

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

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

Fig. 3 Measured frequency response for different widths of patch
antennas limits the achievable efficiency of tunable antennas. This is intrinsic to antenna manufacturing and can become a limiting factor. The existence of thermal loss for high-Q antennas will exhibit a very high unloaded Q, 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 unloaded Q. As the unloaded 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.

**Application**: Thermal loss becomes more significant as the unloaded Q increases. In the presented design, in the case of W=2 mm, the unloaded Q of 260 led to a loaded Q of 225, due to thermal loss. The loaded Q 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 unloaded Q, 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.

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

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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

**Table 2**: Design dimensions

<table>
<thead>
<tr>
<th>W (mm)</th>
<th>Q_{unloaded}</th>
<th>Q_{loaded}</th>
<th>unloaded Q</th>
<th>unloaded loss (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>90</td>
<td>81</td>
<td>0.90</td>
<td>-1.1</td>
</tr>
<tr>
<td>10</td>
<td>175</td>
<td>160</td>
<td>0.91</td>
<td>-1.3</td>
</tr>
<tr>
<td>2</td>
<td>260</td>
<td>225</td>
<td>0.87</td>
<td>-2.0</td>
</tr>
</tbody>
</table>

**Table 2**: Design dimensions

Entering and exiting frequencies of VSWR circle are given in MHz

**Fig. 4**: Measured frequency response for different widths of patch

**References**