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Barrio, Samantha Caporal Del; Pelosi, Mauro; Pedersen, Gert Frølund

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On the efficiency of frequency reconfigurable high-Q-antennas for 4G standards

S. Caporal Del Barrio, M. Pelosi and G. F. Pedersen

In the actual context of reducing the antenna size and operating in multiple bands tunable antennas are investigated. Moreover high-Q and low-Q tunable antennas are compared with respect to their efficiency. The paper addresses the loss issue that tunable high-Q antennas present. Using a variable capacitor as a tuning mechanism, simulations and measurements of a self-resonating antenna show the mismatch and the radiation efficiencies of the high-Q and the low-Q antennas. The investigated frequencies are in the low band of the 4G standard. Measurements are conducted for different tuning stages and the study shows that the high-Q design performs worse than low-Q one. A 1.4 dB degradation in total efficiency is observed for a high-Q antenna in a tunable system.

Introduction: Today the access to a large number of bands with a platform as small as a mobile phone is becoming a requirement for the majority of the consumers. As the fundamental antenna limits relate bandwidth, size and efficiency [1] it is a real challenge to design very compact and broad-band antennas. To overcome this constraint tunable (also named frequency reconfigurable) antennas are investigated. Tunable antennas offer the possibility to have an antenna size that is constant and a reconfigurable resonance frequency with the use of additional lumped components. Nevertheless the overall system complexity remains a challenge for the upcoming 4G-LTE standard as it requires to cover 25 bands from 700 MHz to 2.7 GHz. Unlike low-Q antennas, high-Q antennas are narrow-band. Therefore they have the potential to avoid the use of duplex filters and further to dramatically decrease the complexity of the Front-End architecture [2]. However the loss mechanism of high-Q antennas is not well understood yet. This letter will highlight the efficiency issue of a tunable self-resonating high-Q antenna by comparing it with a low-Q antenna. The investigated frequencies are in the low bands, below 1 GHz.

Antenna design: The self-resonating antenna is a Planar Inverted F-Antenna (PIFA) designed for 960 MHz, as it is the upper bound of the low frequencies for the 4G spectrum [3]. The PIFA has the dimensions of 55 x 10 mm^2 over a 55 x 120 mm^2 Ground Plane (GP), as shown in Fig. 1. The source and the short pins are placed 4 mm apart from each other and the tuning point is placed 45 mm away from the source. The height (H) of the PIFA over the GP will determine its Quality factor (Q).

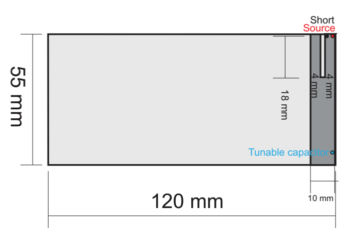

Fig. 1 *Antenna design*

Low-Q antenna A1 with H=8mm, High-Q antenna A2 with H=2mm.

Antenna Q: The Q of a single band self-resonating antenna is defined in [5] using the matched VSWR at the resonating frequency. Two cases are investigated with the above-design, on the one hand the PIFA is placed 8 mm above the GP and exhibits a Q of 6 at 960 MHz and on the other hand the PIFA is placed at 2 mm above the GP and exhibits a Q of 30 at 960 MHz. These designs will be denoted A1 and A2 respectively. In both cases when the antenna is tuned further away from the resonance frequency defined by its design, its Q is increased considerably.

Tuning capacitor: The tuning mechanism that is implemented is representing a variable capacitor of 1/8pF steps as it is the state of the art in Micro Electro-Mechanical Systems (MEMS) [4]. The simulation and the measurements are done with fixed capacitors placed between the PIFA and the GP, therefore they are not in a 50 Ω environment and insertion losses can arise. The resonance frequency of the overall system is fine-tuned to provide continuous coverage over different bands and channels, and comply with 4G requirements. The tuning system aims at reaching the frequency 800 MHz as it is one of the lowest LTE band to host 4G.

Simulation results: The simulation were realized with a Finite-Difference Time-Domain (FDTD) method. First the tunability of the high-Q and the low-Q designs is investigated and shown in Fig. 2 and Fig. 3. Fine-tuning is achieved for both designs showing their ability to cover all frequencies in a chosen range. The increase of the Q value for both A1 and A2 is shown in Fig. 4 with the associated bandwidths (BW) at -6 dB. A1 reaches the resonance frequency 800 MHz in three tuning steps only and its Q increases from 6 at 960 MHz to 14 at 800 MHz, accordingly its BW decreases from 125 MHz to 55 MHz. The high-Q antenna A2 can be tuned to 800 MHz with a total added capacitance of 1 pF. Moreover its Q increases from 30 at 960 MHz to 67 at 800 MHz, accordingly its bandwidth decreases from 30 MHz to 12 MHz. However the reduction of bandwidth is not a issue in tunable systems as it is only needed to cover one channel and not a full band. At 800 MHz A2 exhibits a Q close to 5 times the Q of A1.

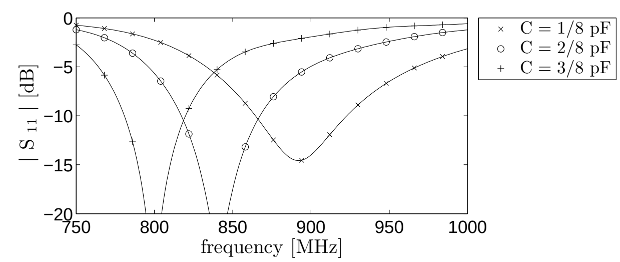

Fig. 2 *Tuning range of the low-Q antenna (A1)*

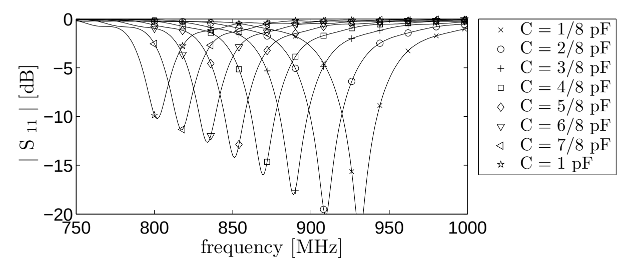

Fig. 3 *Tuning range of the high-Q antenna (A2)*

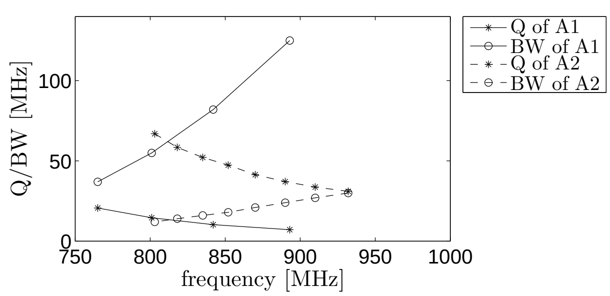

Fig. 4 *Q and BW increment over the tuning stages for A1 and A2*

Measurement results: Mock-ups of the simulated antennas are built and measured in order to calculate their efficiency and estimate its degradation with respect to the increasing Q. In the measurement fixed capacitors (C1 and C2) with low Equivalent Series Resistance (ESR) are used, their ESR is shown in Table 1. The return loss of A1 and A2 is depicted in Fig. 5 and the efficiencies are computed from anechoic chamber measurements with a 3D integration method. At 960 MHz A1 and A2 exhibit similar efficiencies whereas at 808 MHz A2 performs worse than A1, as shown in Table 2.

Loss mechanism: At the lowest frequency reached by A1 and A2, the high-Q antenna (A2) performs 1.4 dB worse than the low-Q antenna (A1) even though A2 uses a better (lower ESR) capacitor. In order to understand the loss mechanism of the high-Q antenna a closer look into the currents delivered to the tuning capacitor is taken and the results are shown in Table 3. It shows that at the last tuning stage the current running through C1 (0.3 pF) for A1 is 0.13 A whereas through C2 (1 pF) for A2 it is 0.45 A, both currents are normalized to 1 W input power. As the losses due to the ESR are proportional to the square of the currents, a lower ESR does not lead to an efficiency improvement if the currents delivered to it are more than tripled, as in the presented case.

Table 1: Fixed capacitors used for measurements

	C [pF]	f_r [MHz]	ESR [Ω]	Q
C1	0.3	808	0.9	685
C2	1	808	0.2	925

Table 2: Measured efficiencies

	C [pF]	f_r[MHz]	η_r[dB]	η_m [dB]	η_T[dB]
A1	x	960	-1.6	-0.4	-2.0
A1	0.3 (C1)	808	-2.2	0.0	-2.2
A2	x	960	-2.2	0.0	-2.2
A2	1 (C2)	808	-3.2	-0.4	-3.6

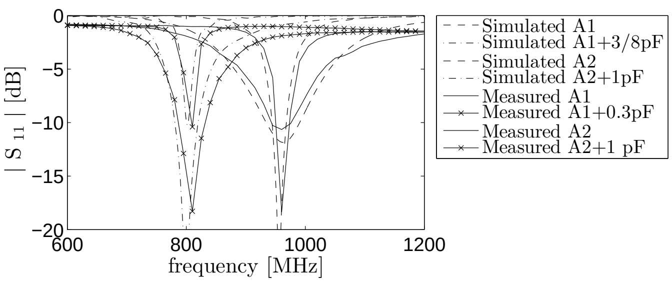

Fig. 5 *Simulated and measured reflection coefficient*

Table 3: Simulated currents delivered to the tunable capacitor for 1 W input power

C [pF]	1/8	2/8	3/8	4/8	5/8	6/8	7/8	1
Ic_{A1} [A]	0.04	0.08	0.13	x	x	x	x	x
Ic_{A2} [A]	0.05	0.10	0.15	0.21	0.26	0.32	0.38	0.45

Conclusion: For frequency reconfigurable antenna designs high-Q antennas open the possibilities for finer tuning and higher size reduction of the antenna. However their efficiencies is still lower than low-Q antennas. Measurements showed that the high-Q antenna performs similarly to the a low-Q antenna at the designed frequency (0.2 dB difference in total efficiency) but worse when tuned 150 MHz down in frequency (1.4 dB). This is explained by the antenna Q that is considerably higher (close to quintuple) for the high-Q design and therefore the currents delivered to the capacitor are an issue.

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

E-mail: scdb,mp,gfp@es.aau.dk

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