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Barrio, Samantha Caporal Del; Pedersen, Gert Frølund

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Antenna Design Exploiting Duplex Isolation for 4G Application on Handsets

S. Caporal Del Barrio and G. F. Pedersen

This letter presents a novel design addressing the antenna bandwidth issue for the future communication standards on handsets. It consists of a tunable-antenna-pair for operation with a tunable front-end. The antennas are narrow-band and frequency-reconfigurable. The study focuses in the low communication bands. Measurements of the design are shown in band 12, and exhibit a receiver-transmitter isolation above 25 dB at 700 MHz.

Introduction: Covering the frequency spectrum required for the 4^{th} Generation (4G) of mobile communication is a major challenge for antenna designers. Passive wide-band antennas often become too bulky, as their volume increases proportionally with the number of bands to support, for example [1]. A promising solution is the use of active Frequency-Reconfigurable Antennas (FRA), allowing a unique, small and efficient element to cover an overall wide bandwidth. The FRA can be instantaneously tuned to the targeted band with Radio Frequency (RF) Switches, as in [2], or with tunable capacitors, as in [3]. Besides the antenna bandwidth challenge, 4G also increased the complexity of the RF Front-End (FE) with the bands expansion. Component duplication in the RF-FE lead to higher power consumption, cost and volume on an already tight boards. In this study the authors consider the use of FRA with tunable capacitors, and demonstrate the support of all low-bands of the 4G spectrum, until 699 MHz [4]. Low communication bands are addressed as they are the toughest to cover on small platforms, due to intrinsic physical limitations of antennas [5]. Additionally the authors propose the use of two narrow-band and independent antennas, one transmitter (TX) and one receiver (RX), thus eliminating the need for duplex filters in the RF-FE. The antennas are not only used as radiators but also as filters, giving the opportunity to design simpler and smaller FE architectures.

Antenna Geometry: The proposed narrow-band antenna is designed for the integration of a Micro-Electro-Mechanical systems (MEMS) tunable capacitor, that will continuously tune its resonance frequency in the low-band of 4G (699 MHz to 960 MHz). The antennas are mounted on a ground plane of dimensions 120 $\times$ 55 mm, representing nowadays smart-phones. The design consists of a coupler, fed and placed on top of a slot. The antenna was designed to fit nowadays phone designs, where slimness and wide screens are essential. For this purpose only 1mm was allowed for the height of the antenna and 4 mm for its width. A fixed capacitor (C1=1pF) is placed at the end of the slot to force the initial resonance frequency to 960 MHz. The tunable capacitor is placed at a distance from the source determined by its minimum tuning step. Here 25 mm corresponds to steps of 0.06 pF, according to the commercial MEMS tunable capacitor in [6]. The detailed geometry of the antenna is shown in Fig. 1.

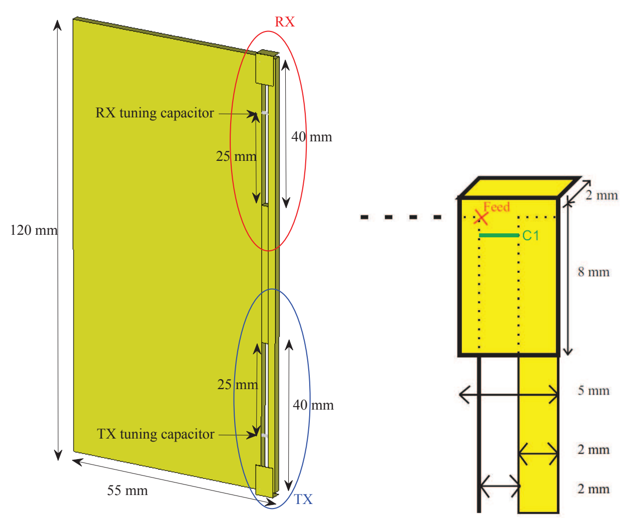

Fig. 1 *Antenna geometry, full board (left) and zoom on the dimensions of the CE and the slot (right).*

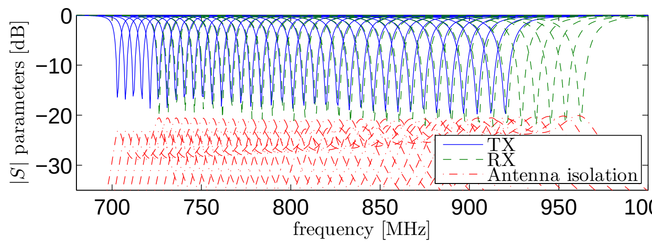

Fig. 2 *S parameters of the antenna-pair with tuning steps of 0.06 pF.*

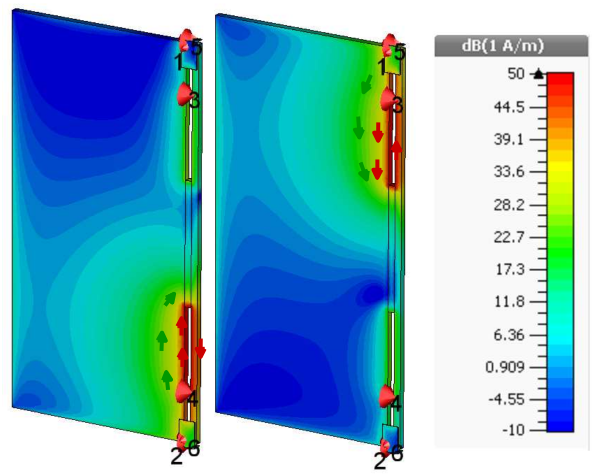

Fig. 3 *Surface currents at 699 MHz (left) and 729 MHz (right).*

Simulation results: Simulations show, in Fig. 2, the tunability of the TX and RX antennas, throughout all frequencies of the LTE low-band. It is observed that the impedance is very stable throughout tuning, and minimal mismatch loss is expected. The impedance bandwidth (at -6 dB) shrinks from 10 MHz at 960 MHz to 5 MHz at 700 MHz, as a result of tuning. Indeed as the antenna is tuned further away from its original resonance frequency, more energy is stored in the antenna structure. Consequently the Antenna Quality factor (Q_A) increases and the antenna bandwidth shrinks [7]. However narrow-band antennas are not an issue when an antenna pair is considered, the antennas only need to cover a channel, as opposed to a full band. The loss-less simulations show antenna isolation below 20 dB.

Isolation and efficiency in small platforms are most challenging for low frequencies, as the antennas share the same ground, and the ground itself is a significant part of the radiation [8]. Thus antennas at resonating at low-bands on a small platform are inherently coupled. The concept of antenna-pair appeared in [9]. Later studies have investigated TX/RX isolation, mostly with cancellation techniques as in [10] and [11], needing a separation of several wavelengths, or multiple antennas. The proposed design achieves duplex isolation in a small volume, with means of frequency separation (30 MHz in band 12), spatial separation (40 mm) and opposite direction of the surface currents, see Fig. 3. The results are shown for band 12, where transmitting frequencies are [699 MHZ - 716 MHz] and receiving frequencies are [729 MHz - 746 MHz]. It is inferred from the plot that high isolation will be achieved between TX and RX channels, as minimal current is leaking from one antenna to the other.

Measurement results: A mock-up of the presented design is built and shown in Fig. 4. It will be used to demonstrate high antenna isolation in band 12. For more practicality, the mock-up uses fixed capacitors instead of tuners. They are offset, 1.8 pF and 1.5 pF, in order to cover both TX and RX RF chains respectively. They exhibit a low Equivalent Series Resistance (ESR) in order to minimize insertion loss, 0.15 Ω and 0.12 Ω. Simulated and measured isolation curves between TX and RX antennas are shown in Fig. 5. The measured isolation is improved compared to the simulated curve, due to mock-up losses, showing a duplex isolation above 25 dB.

The Q_A of the mock-up is shown in Fig. 6 for three different stages. Firstly without any tuning capacitor, at its original resonance frequency, secondly with C1, setting the resonance to 960 MHz, and finally with the tuners, here fixed capacitors set to band 12. The Q_A is relevant for FRA because of its relation to stored energy and bandwidth. Bandwidth and Q_A

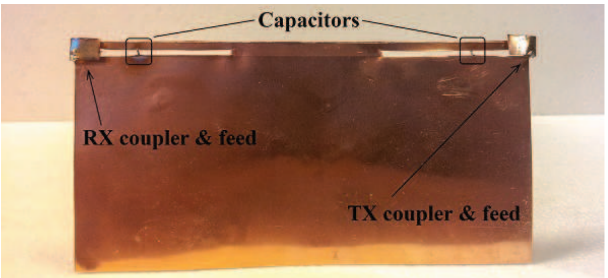

Fig. 4 *Mock-up of the proposed antenna design, using fixed capacitors.*

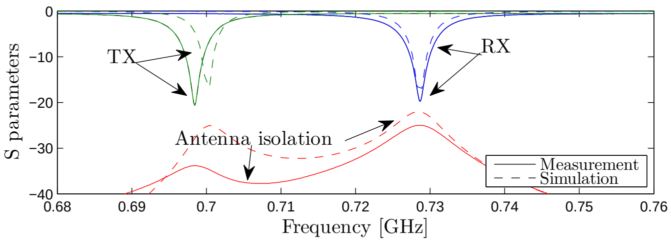

Fig. 5 *Measured and simulated frequency responses in band 12.*

relate to the Voltage-Standing-Wave Ratio (VSWR) [7]:

$$Q_A(\omega) = \frac{2\sqrt{\beta}}{FBW_V(\omega)},\ \sqrt{\beta} = \frac{s-1}{2\sqrt{s}},$$

where FBW_V is the matched VSWR fractional bandwidth and s is a specific value of the VSWR. The measured Q_A values of the RX antenna are plotted in Fig. 6. The loaded Q_A increases from 33 at its original resonance frequency, to 97 at 960 MHz, to 133 at 730 MHz; being multiplied by 4 throughout the tuning. Q_A values are similar for the TX.

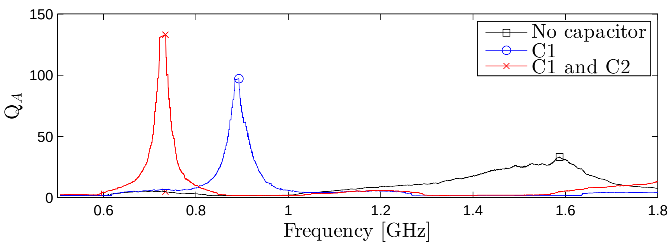

Fig. 6 *Measured Q_A of the RX antenna in different tuning stages.*

The radiation efficiency e_r was measured in anechoic chamber and computed with 3D integration pattern. The TX antenna exhibited e_r=-4.4 dB at 699 MHz, and the RX antenna exhibited e_r=-3.2 dB at 730 MHz. The insertion loss due to the capacitors can be computed and accounts for 2 dB of the measured loss. Thus it is inferred that a high thermal loss, due to high-Q_A and metal conductivity, is present in tunable antennas and may limit their efficiency. Nevertheless the measured values are still acceptable given the performances of nowadays handsets, at these frequencies [12].

Conclusion: FRA can operate in a large range of frequencies and easily cope with future addition of bands. Their potential is fully exploited when one considers their narrow-band characteristic and uses it to have a filtering antenna-pair, thus eliminating the need for duplex filters in the FE. A slim and simple design was presented to address this architecture, achieving 25 dB of duplex-isolation in band 12. The antenna efficiency relies mainly on the tunable components. In the future work a mock-up with MEMS tunable capacitors and MEMS tunable filters will be built, in order to appreciate the overall system performance. The proposed antenna-pair is a promising design for 4G communication implementation.

S. Caporal Del Barrio 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,gfp}@es.aau.dk

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