MEMS Tunable Antennas

Reaching for the 600 MHz-bands
Barrio, Samantha Caporal Del; Morris, Art; Pedersen, Gert Frølund

Published in:
Antennas and Propagation in Wireless Communications (APWC), 2014 IEEE-APS Topical Conference on

DOI (link to publication from Publisher):
10.1109/APWC.2014.6905571

Publication date:
2014

Document Version
Early version, also known as pre-print

Link to publication from Aalborg University

Citation for published version (APA):

General rights
Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal

Take down policy
If you believe that this document breaches copyright please contact us at vbn@aub.aau.dk providing details, and we will remove access to the work immediately and investigate your claim.
MEMS Tunable Antennas: Reaching for the 600 MHz-bands

Samantha Caporal Del Barrio ∗†
Art Morris †
Gert F. Pedersen ∗

Abstract — Addressing low frequency bands is challenging on small platforms. Tunability is a promising solution to cover the bandwidth required for 4G mobile communication. The work presents two designs and shows that for comparable efficiency and bandwidth, the tunable antenna occupies half the volume required by the wide-band antenna.

1 Introduction

Driven by the mobile users demand, the pressure on data rates is ever increasing. In order to improve connectivity, the 4th Generation (4G) of mobile communications was standardized. For antenna engineers, the two main challenges that 4G raises are the bandwidth extension and the need for multiple antennas [1]. They are contradictory in the sense that widening the antenna bandwidth requires to enlarge its volume in order to maintain a good efficiency [2]; whereas fitting more antennas into current phone form factors requires low-profile designs. Therefore, the real challenge is to extend the antenna bandwidth while reducing its volume. 4G has extended the radio frequency spectrum of mobile communications from 698 MHz to 2.69 GHz [1], and the auction on the 600 MHz-band is soon taking place [3]. It is well known that at low-bands the ground plane plays a major role in the radiation mechanism of the antenna. However, at 600 MHz, even the largest dimension of a typical phone is less than a quarter of the wavelength. Thus, reaching for lower frequencies while maintaining antenna volume has led to dramatic efficiency degradation, as reported in [4] for commercial phones.

Frequency-Reconfigurable Antennas (FRA) are antennas that can modify their resonance frequency, while keeping a fixed size. For example capacitively loaded antennas will see their resonance frequency decrease as the capacitance increases [5]. Combined with Micro-Electro-Mechanical Systems (MEMS) tunable capacitors – state-of-the-art in terms of insertion loss and voltage handling [6] –, FRA are the most promising way to address low frequency bands, while complying with today’s market requirements on efficiency and antenna volume.

∗Section of Antennas, Propagation and Radio Networking (APNet), Department of Electronic Systems, Faculty of Engineering and Science, Aalborg University, (scdb.gfp)@es.aau.dk
†Wispy Inc, Irvine, USA, art.morris@wispy.com

This paper aims at comparing the properties of a narrow-band FRA to a wide-band antenna, both addressing the 600 MHz-bands. Given the same overall bandwidth and efficiency, the comparison addresses antenna dimensions, surface currents and potential on antenna isolation.

2 Theoretical limits on small antennas

An antenna falls into the category of Electrically Small Antenna (ESA) when \( ka \leq 0.5 \), where \( k \) is the free space wavenumber, and \( a \) is the radius of an imaginary sphere circumscribing the maximum dimension of the antenna. For antennas placed on an electrically small ground plane, as is the case for mobile phones operating at frequencies below 1 GHz, the ground plane must be included in the circumscribing sphere. Indeed, in the low bands of 4G the ground plane is part of the radiating structure, i.e. part of the antenna.

For linear and passive antennas exhibiting single impedance resonance within their defined VSWR bandwidth, their Quality factor (Q) can be related to their size, bandwidth (BW) and efficiency (η) [7]. The low bound on the antenna Q (Qlb) for a given frequency (ω) relates to the antenna volume following Eq. (1). The η term in Eq. (1) shows that the lossier the antenna, the lower the Qlb. Additionally, Q is inversely related to the Fractional Bandwidth (FBW) of the antenna at a given Voltage standing wave ratio (V) of value s, as described by Eq. (2). Therefore, the low bound on Q is an upper bound on bandwidth. Hence, lossier antennas exhibit a higher upper bound on achievable bandwidth (FBWV,ub) following Eq. (3). Eq. (3) gives the maximum achievable bandwidth in a constraint volume. The upper bound on bandwidth at -6 dB return loss (BWV,ub,−6dB) is plotted in Fig. 1 for different efficiencies and different values of ka, at 600 MHz.

\[
Q_{lb}(\omega) = \eta \left( \frac{1}{(ka)^3} + \frac{1}{ka} \right) \quad (1)
\]

\[
Q(\omega) = \frac{2\sqrt{3}}{FBW_V(\omega)} \cdot \sqrt{\beta} = \frac{s - 1}{2\sqrt{s}} \quad (2)
\]

\[
FBW_{V, ub}(\omega) = \frac{2\sqrt{3}(ka)^3}{\eta(1 + (ka)^2)} \quad (3)
\]
3 Antenna designs

This section proposes two antenna designs: a narrow-band FRA and a wide-band antenna. The wide-band antenna covers simultaneously all the bands from 600 MHz to 960 MHz, while the FRA exhibits a narrow instantaneous bandwidth, that can be reconfigured to all frequencies between 600 MHz and 960 MHz. The proposed antennas are designed on a 120 mm × 55 mm FR-4 ground plane.

3.1 Wide-band antenna design

In nowadays mobile phones, the limited available volume to fit the antenna causes the antenna impedance to have a small real part and a large imaginary part, at low frequencies. In other words, the antenna is difficult to match to the 50 Ω feed line and the amount of power that can be radiated is low. Moreover, the wider the bandwidth is, the more difficult the matching becomes, if one considers all frequencies simultaneously. Typically, matching circuitry at the feed is necessary, at the cost of additional loss.

The proposed wide-band design is based on Capacitive Coupling Element (CCE) techniques, described in [11]. CCEs excite the board resonance to enhance bandwidth. In order to achieve the maximum bandwidth the CCE is located very close to the ground plane, on one of the short edges and fed in its center. A wide-band match is made with matching fixed components at the feeding line. The antenna design is detailed in Fig. 3, as well as the feed matching circuitry. The antenna is placed 1 mm above the ground plane and fed in its center. The width of the antenna is 10 mm, as slimness is essential for phone designs. However, a larger width would improve the matching of the antenna to the 50 Ω feed line and reduce mismatch loss. The dimensions of the proposed design lead to a mechanical volume of 1.65 cc.

3.2 Narrow-band FRA design

The FRA design is a monopole placed on top of the ground plane, and fed through coupling. The monopole is connected to a MEMS tunable capacitor [13], in order to modify the reactive part of its impedance, thus its resonance frequency. The tuning range is [0-4] pF with a resolution of 62 fF. The FRA design is shown in Fig. 4. Both the width (5 mm) and the height (6 mm) of the monopole control the bandwidth. Because of the tuning prop-
property of the design, the instantaneous bandwidth can be narrow, thus the antenna dimensions can be small. Additionally, the antenna is well match on its instantaneous bandwidth, thus limiting mismatch loss. However, the tuning component brings insertion loss to the total efficiency. The dimensions of the proposed design lead to a mechanical volume of 0.75 cc for the radiator.

4 Simulations and measurements

The excitation of the ground plane depends on the antenna element and its radiation mechanism. The wide-band antenna needs to fully exploits the ground plane in order to cover the required frequency range. Fig. 5 shows full excitation of the ground plane by the CCE, as opposed to confined fields around the FRA element.

A major consequence of the ground plane excitation type is the potential for electromagnetic isolation. 4G standards require Multiple-Input Multiple-Output (MIMO) operation, i.e. several antennas at the user terminal and the base station. To provide a MIMO gain the antennas need to be isolated, which is challenging on small terminals, where the maximum dimension is smaller than λ/2.

In the case of the wide-band antenna, a location for the secondary antenna that excites the same ground plane mode will result in very high antenna coupling. The theory of characteristic modes provides a tool to find a location that either excites a different mode of the ground plane, either does not excite the ground plane at all. In both cases, the secondary antenna will be less efficient. In the case of the FRA, the ground plane is not fully used by the antenna, therefore the location of the secondary antenna is more flexible. It can also benefit from part of the ground plane radiation, leading to similar efficiency for both main and secondary FRAs. Fields are intrinsically confined around the FRA, thus allowing for several feed locations on the board, where antenna coupling is low.

Both antenna designs have been built. They are shown in Fig. 6a and Fig. 6b. In Fig. 6a, one can see how the cable is led out in a low current location, in order to limit its interaction with the ground plane radiation. The antenna impedances are shown in Fig. 7 and Fig. 8 respectively. The bandwidth of the FRA shrinks from 20 MHz to 5 MHz, as it is tuned. The measured resonance of the wide-band antenna is slightly off compared to the simulated values, due to building imprecision. Additionally, in order to cover the required bandwidth and exhibit small dimensions, the wide-band antenna has a very poor match. A similar method was observed in the first commercial LTE-phone [14], in order to add the bands at 700 MHz. Increasing the antenna width improves the match, at the cost of the phone thickness. Poor match translates into poor efficiency ($\eta$), as total $\eta$ is the sum of radiation and mismatch $\eta$. Efficiency plots are shown in Fig. 9 and Fig. 10. The insertion loss of the tuner is part of the radiation $\eta$ of the FRA.
5 Conclusion

This paper has shown and compared two conceptually different antenna design: a narrow-band FRA and a wide-band antenna. They both address the low-bands of LTE, including the future 600 MHz bands. For comparable total bandwidth and efficiency, the narrow-band FRA occupies less than half the space needed for the wide-band antenna. Additionally, the FRA presents higher potential for antenna isolation. FRA are the most promising way of addressing the low frequency bands of LTE on small terminals.

References