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Published in:
Electronics Letters

DOI (link to publication from Publisher):
10.1049/el.2014.3237

Publication date:
2014

Document Version
Early version, also known as pre-print

Screen-printed silver-ink antennas for frequency-reconfigurable architectures in LTE phones

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Screen printing is a proven manufacturing technology enabling high volume production at low cost. This letter investigates the achievable efficiency of a screen-printed silver antenna structure for 4G mobile phone implementation, with a market-ready solution. The contribution of each element of the solution to the total efficiency is detailed.

Introduction: The main advantage of screen printing for antennas is its potential for low-cost and high-volume manufacturing. Practical implementation of printed antennas started in the 70s, when low-loss dielectrics arrived on the market. The screen printing technology offers the possibility for cost optimized inline reel-to-reel manufacturing. As a result, the antenna can be thinner, lighter, flexible and cheaper than with a conventional etching process.

While screen printing manufacturing technology won the Radio Frequency Identification (RFID) market, it did not enter the market of mobile phone antennas. Moreover, silver inks have proven to be competitive to copper [1] for RFID systems. This is a result of RFID antennas exhibiting a large bandwidth, e.g. about 150 MHz [2]. Indeed, the wide-band property of RFID antennas translates into a low Quality factor (Q), which mitigates the loss of the silver-ink material [3]. However, mobile phones antennas are folded in a confined volume, thus they exhibit a relatively high Q compared to RFID antennas, and they are more sensitive to thermal loss.

Next generations of mobile phone antennas are likely to comprise a narrow-band antenna and a tuner, such as Micro-Electro-Mechanical Systems (MEMS) tunable capacitors. That is to address the band proliferation challenge that mobile phone antennas are facing with the newest generations of mobile communication standards, i.e. Long Term Evolution (LTE) and LTE-Advanced (LTE-A). MEMS are very promising as they can efficiently enhance the antenna bandwidth without modifying its physical size. In an architecture that splits transmitting and receiving chains, e.g. [4], the tunable antenna takes advantage of the narrow channel bandwidth (20 MHz) to improve compactness. Consequently, the antenna exhibits a narrow-tunable-bandwidth, hence a high Q. With the ever-increasing popularity of mobile phones, there is a huge market for large scale manufacturing technology, like screen printing. Therefore, this letter investigates the feasibility of such tunable silver-ink antennas for LTE and LTE-A. The aim of the work is to understand the loss mechanism in such novel antenna structure, combining silver-ink, tuning component and mobile phone Printed Circuit Board (PCB).

Antenna design: The design used for this investigation is a subset of the design published in [4], which has been manufactured with MEMS tunable capacitors from [5]. [4] shows the tunability of the proposed antenna design throughout LTE bands and the potential of such tunable architecture in terms of compactness and efficiency. This letter investigates the achievable efficiency of the antenna design, in the case of manufacturing with screen printing technology instead of etched copper. For concision purposes, measurements are presented at one frequency only. The antenna design is detailed in Fig. 1 and it is mounted on a 120 × 55 mm PCB.

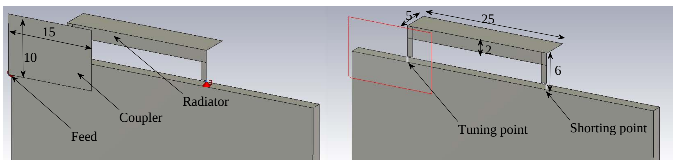

Fig. 1 *Antenna schematics.*

The antenna is designed according to the specifications of an implementation with a MEMS tuner from [5]. Therefore, the resonance frequency of the antenna is at 960 MHz when it is loaded with 1 pF, as it is the minimum capacitance of the MEMS tuner. The measurements were performed at 800 MHz, which corresponds to loading the antenna with and additional 0.8 pF. For demonstration purposes the investigation uses fixed components. The Equivalent Series Resistance (ESR) of the 1.8 pF fixed capacitor used in the demonstrators is 0.451 Ω at 800 MHz [6].

Five demonstrators of the antenna design are realized. Their description is summarized in Table . D1 is realized in pure copper and soldered to the PCB, while D5 is realized in silver ink and glued to the PCB. In order to characterize the source of loss and understand the role of each element in the total efficiency, intermediary combinations are also realized. D2 combines pure copper and glue, D3 investigates the contribution of the plastic foil and D4 isolates the contribution of the silver ink independently of the glue.

Table 1: Antenna demonstrators

	D1	D2	D3	D4	D5
Pure copper	x	x			
Copper tape			x		
Silver ink				x	x
PET foil			x	x	x
Soldering tin	x		x	x	
Conductive glue		x			x

The silver ink antenna is realized by screen printing onto a base foil. The silver ink layer exhibits a thickness between 7 and 9 μm and a conductivity of about 1.6×10^6 S/m, according to manufacturing specifications [7]. The silver ink rests on a PolyEthylene-Terephthalate (PET) substrate, which has a thickness of 125 μm, a dielectric constant of 3 at 1 GHz and a loss tangent of 0.14×10^{-4}. The connections to the board are made with conductive silver glue, which exhibits a conductivity of 2.5×10^5 S/m.

Measurement results: The five demonstrators were built and they are shown in Fig. 2. The frequency response of each design is shown in Fig. 3. The PET carrier resulted in a small shift in frequency. The demonstrators exhibit bandwidths of 10 MHz and 15 MHz, for D1 and D5 respectively. The wider bandwidth of D5 indicates larger loss.

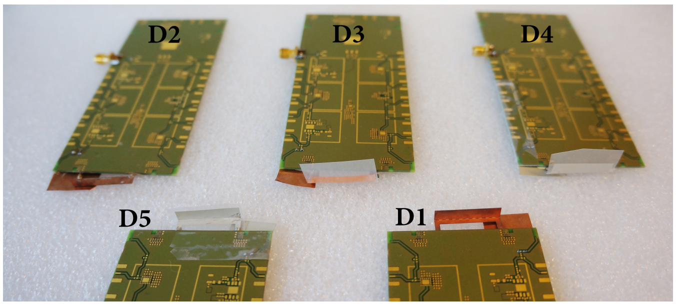

Fig. 2 *Antenna demonstrators.*

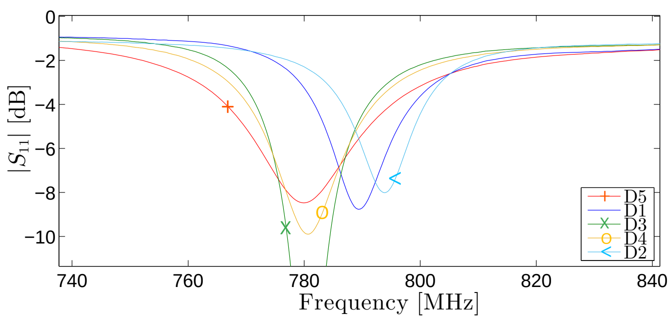

Fig. 3 *Measured frequency responses of the demonstrators.*

The loaded Q (Q_{loaded}) of the demonstrators has been measured and it is depicted in Fig. 4. The Q_{loaded} is the perfectly matched Q, calculated according to Eq. 1 from [8], where FBW_V is the fractional bandwidth at a matched Voltage-Standing-Wave Ratio (VSWR) and s is the specific value of the VSWR. The drop in Q from D5 to D1 is a factor 6, which indicates larger loss in D5.

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

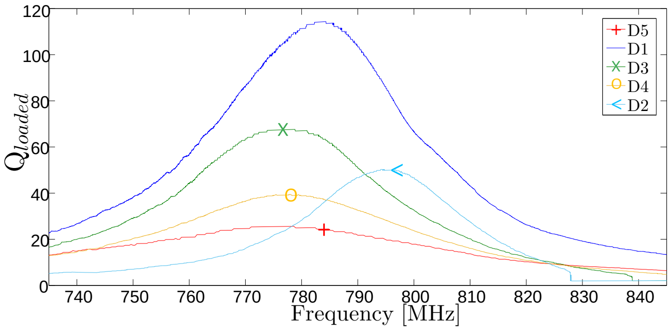

Fig. 4 *Measured loaded Q values for the demonstrators.*

Finally, the efficiency of the demonstrators was measured in anechoic chamber and processed with pattern-integration technique. The total efficiency η_T includes ESR loss, mismatch loss and trace loss. The contribution of the ESR of the fixed capacitor to η_T is about 1.5 dB at 800 MHz. The mismatch loss of the demonstrators is smaller or equal to 0.6 dB while the trace loss on the PCB is 0.41 dB at 800 MHz. Total efficiencies are shown in Fig. 5.

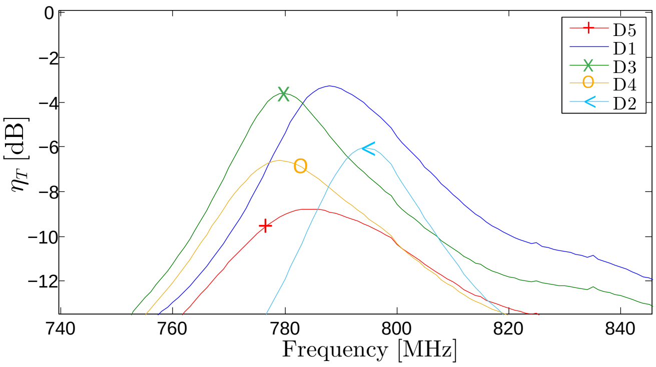

Fig. 5 *Measured efficiencies of the demonstrators.*

As expected, the ranking of the demonstrators according to their efficiency follows the ranking according to their Q_{loaded} values. It is observed that D1 and D3 exhibit very similar η_T: -3.3 dB and -3.6 dB, which suggests that the PET carrier is not a cause of loss. Moreover, D2 and D4 also exhibit similar efficiencies: -6.0 dB and -6.6 dB, inferring that the conductive glue or the silver paste contribute similarly to the total loss, about 3 dB extra. The combination of the silver ink and the conductive glue leads to the lowest efficiency, observed in D5: -8.8 dB.

It is expected that increasing the thickness of the printed silver-ink layer will directly lead to improving the total efficiency. Indeed, the conductivity of the silver ink corresponds to a skin depth of 14 μm, which is almost twice the thickness of the layer printed with the standard manufacturing technology. Alternatively, future improvements to the material, i.e. increasing the conductivity of the silver ink, include:

- increasing the particle density within the paste, by applying a compression process as described in [9],
- limit roughness issues with a gold layer, as suggested in [2].

Conclusion: This letter has shown the feasibility of printed frequency-reconfigurable antennas for LTE architectures, using silver-ink printing process. It has also investigated the performance of such antennas. The intrinsic high-Q property of tunable antennas leads to high fields in the antenna structure, which result in high radiation loss due to the low conductivity of the silver ink. The total efficiency is degraded by 5 dB when both silver-ink and conducting glue are used, compared to copper. However, the total efficiency is only degraded by 3 dB if the glue can be avoided, e.g. soldering. Additionally, the total efficiency can be further improved by increasing the thickness of the ink and by applying compression techniques. With an enhanced conductivity, screen-printed silver-ink antennas have a tremendous potential for LTE tunable antennas, thanks to their low cost and high volume manufacturing possibilities.

Acknowledgment: This work was supported by the Danish National Advanced Technology Foundation.

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