Compact Two-Element Reconfigurable Antenna System for the 470-702 MHz band

C. Lach[1], *L. Rudant*[1], *C. Delaveaud*[1], *A. Azoulay*[2]

[1]CEA-Leti, Minatec Campus, 17 rue des Martyrs, 38054 Grenoble Cedex 9, France, christophe.lach@cea.fr

[2]Département Recherche Electromagnétique, Supélec, 3 rue Joliot Curie, 91192 Gif-sur-Yvette cedex, France, alain.azoulay@supelec.fr

Abstract

This paper presents a miniature reconfigurable dual-antenna system addressing the UHF band. This system has been introduced for small mobile terminals, where form factor is very important. The whole structure respects some design rules in order to optimize antenna performances from diversity performances point of view. A specific active capacitive load has allowed the impedance reconfigurability and antennas miniaturization. Antenna miniaturization is used to combine radiating structures in an electrically small volume. The use of two antennas could bring good diversity gain to mitigate the fast fading effect introduced by multipath in mobility.

1. Introduction

The development of many types of smartphones, tablets, small PCs able to handle various wireless services in different frequency bands implies the design of new types of antennas (wide band, multi bands etc). The UHF TV broadcast band (470-860 MHz) has started to be switched to all digital services. In addition to DVB-T, there are some other technologies being potentially used in this frequency band. Among them, the DVB-H technology is implemented in some countries and depending on administrations, part of available spectrum in this band could be used by other wireless services (IMT-Advanced, LTE, WLANs etc). So, there is a real challenge to design new antennas for these applications, taking into account the lowest frequency used, and the size of mobile terminals.

In this paper, we present a compact frequency agile dual-antenna system for the 470-702 MHz band, consisting in two antennas integrated in a small size PCB, which dimensions are those of typical mobile terminals, suitable for applications described above.

2. Compact frequency agile dual-antenna system

This dual-antennas system consists of two antennas that are “notch antennas” designed in L-shape and symmetrically etched on printed circuit. These shapes allow a better decoupling between them. “Notch antennas” are good solutions for mobile terminals since they are easy to integrate and very low costs: the notches are etched at the top face of the printed circuit board (PCB). They can operate in the 470-702 MHz band through the reconfigurability technique. In order to miniaturize them and to control the resonance frequency of both structures, we use a capacitive active load, located at the open-end of both “notch” antennas to improve the tuning efficiency as it is mentioned in [1]. The space between antennas can be filled out with electronic components such as RF front end, diversity demodulator, chips etc. These antennas are fed by 50Ω microstrip lines. The optimum location for the feed and the addition of a capacitive-ended stub allow a good matching of both antennas over the dedicated frequency band. The multi-antennas design is depicted in figure 1.

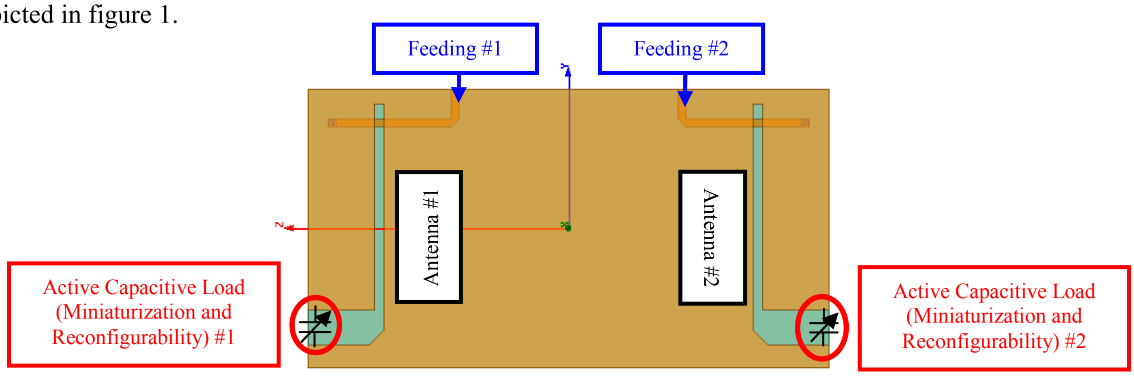

Figure 1: multi-antennas system design

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The board is constituted of a 0.8mm thick FR4 substrate (with dielectric constant ε_r=4.4 and loss-tangent Tanδ = 0.02) of 103x55mm² i.e. λ_0/6.2 x λ_0/11.6 at 470MHz and λ_0/4.2 x λ_0/7.8 at 700MHz. According to the definition given in [2], these antennas can be identified as electrically small. This PCB is compatible with the dimensions of wireless terminals such as a smartphone or a tablet.

The structure has been investigated and simulated using the electromagnetic simulator HFSS [3]. The active capacitive load is implemented using classical lumped elements such as resistors, capacitors, inductors and varicaps. These antennas are electronically tunable. In this paper, we synthesize the antenna performances using two different states of the antennas. The first one makes the antennas work at the higher part of the dedicated frequency band while the other one corresponds to an operating point at lower frequencies.

In figure 2a, we first present the return loss (left axis) of each antenna (the symmetry of the structure makes it identical for antenna #1 and antenna #2) and the coupling between antennas (right axis) for two different states of the active load. The total efficiency, which takes into account the impedance mismatch between the antennas and its feeding, is shown in figure 2b for the antenna 1. It is almost the same for both antennas. It is important for diversity performances, as it is explained in paragraph 3.

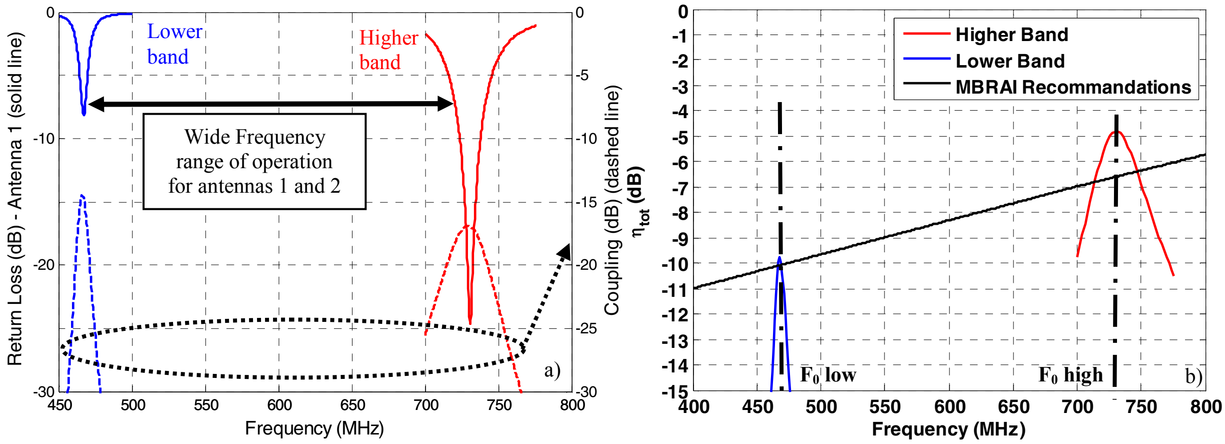

Figure 2: Antenna 1 Return loss and coupling between antennas (a) – Antenna 1 Total Efficiency (b)

We can clearly see the reconfigurability behavior of this double-antennas system. This system has a wide frequency range since it is tunable from around 470MHz to 730MHz with an instantaneous bandwidth of at least 9MHz considering a return loss lower than -3dB. The coupling between antennas is lower than -15dB over this band, that can makes this multi-antenna efficient to obtain good diversity performances.

The system has acceptable performances in terms of total efficiency over the frequency band according to EICTA/MBRAI [4]. The total efficiency has a maximum of -4.8dB around 730 MHz and is around -10dB at 470 MHz.

3. Diversity aspects: correlation and diversity gain

Multi-antennas systems have been investigated so as to mitigate fast fading effects of multipath, due to the environment and the mobility of the terminal [5]. To evaluate performances of antennas in diversity, the complex correlation coefficient (ρc) is a major criterion [6]. The envelop correlation coefficient (ρe) is widely used in diversity studies. Considering a Rayleigh canal, and with the hypothesis that the propagation canal and the arrival angular distribution density are uniform, this coefficient can be computed for two antennas 1 and 2 using radiation properties of the two antennas according to the formulas in [5].

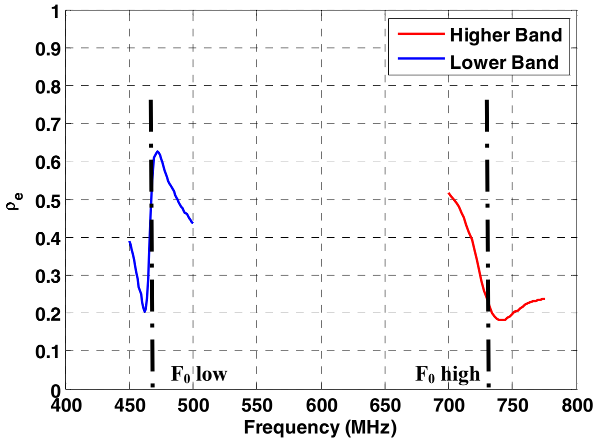

Figure 3: envelop correlation coefficient computed in simulation thanks to antennas radiation properties

The figure 3 shows the envelop correlation coefficient computed in simulation thanks to the complex far-field patterns. We can notice that the minimum of ρ_e is not exactly reached at the same frequency for which the total efficiency is the higher.

When combining signals received by the two antennas, several algorithms exist like Selection Combining (SC), Equal Gain Combining (EGC) or Maximum Ratio Combining (MRC). This last algorithm allows the better performances for multi-antennas system. The different signals are weighted in real-time with respect to their Signal to Noise Ratio (SNR), and then they are smartly summed-up to maximize the combined SNR to come up with one single improved signal.

The Mean Effective Gain (MEG) of an antenna is the ratio between power received by the antenna (P_r) and the power available in the air (P_a). Multi-antennas systems need balanced signals to improve diversity performances. The MEG can be used to measure this signals balance. Considering a uniform repartition of incident waves around the antennas, and balanced polarizations, the MEG of both antennas is MEG=$\eta_{tot}/2$, where η_{tot} is the total efficiency of each antenna.

Assuming a fast-fading Rayleigh distribution on both branches of this multi-antenna system, and an equal mean available power in the air (P_a=0dBm), it is possible to compute the cumulative distribution functions (cdf) of the recombined signal [7] in case of $\gamma_{0,MRC} << P_a$

$$P(\gamma_{MRC} \le \gamma_0) \approx \frac{2 \cdot \gamma_{0,MRC}^2}{\eta_{tot,diversity}^2 \cdot (1-\rho_e)}$$

For a Rayleigh channel, the cdf of a single reference antenna is given by:

$$P(\gamma_{\sin gle} \le \gamma_0) \approx \frac{2 \cdot \gamma_{0,\sin gle}}{\eta_{tot,ref}}$$

The procedure to compute the diversity gain in case of MRC is given in [7]:

$$DG(\alpha, \rho_e) = 10\log_{10}\left(\frac{\eta_{tot,diversity}}{\eta_{tot,ref}} \cdot \sqrt{\frac{2 \cdot (1-\rho_e)}{\alpha}}\right), \text{ where } \alpha = P(\gamma \le \gamma_0)$$

We represent in figure 4a the cdfs in different cases:

- Cases 1 and 2 (solid blue and red curves): cdfs for single antenna (SA) which total efficiency is the one given by figure 2b) at $F_{0,high}$ and $F_{0,low}$.
- Cases 3 and 4 (dashed blue and red curves): cdfs of our dual antennas system using MRC method in the same conditions (it takes into account ρ_e) as in cases 1 and 2.
- Cases 5 and 6 (dashed magenta and cyan curves): cdfs for two antennas whose total efficiency is given by MBRAI recommendations at $F_{0,high}$ and $F_{0,low}$. They are supposed to form a space diversity (the space between

antennas corresponds to the largest dimension of the PCB), and the envelope correlation coefficient is given by [8]. Signals coming from both antennas are combined using MRC method.

In figure 4b it is shown the diversity gain of our multi-antennas system in the higher and lower frequencies for 2 different $probability(\gamma \leq \gamma_0)$. Red curves are for the higher frequencies while blue curves are for lower frequencies.

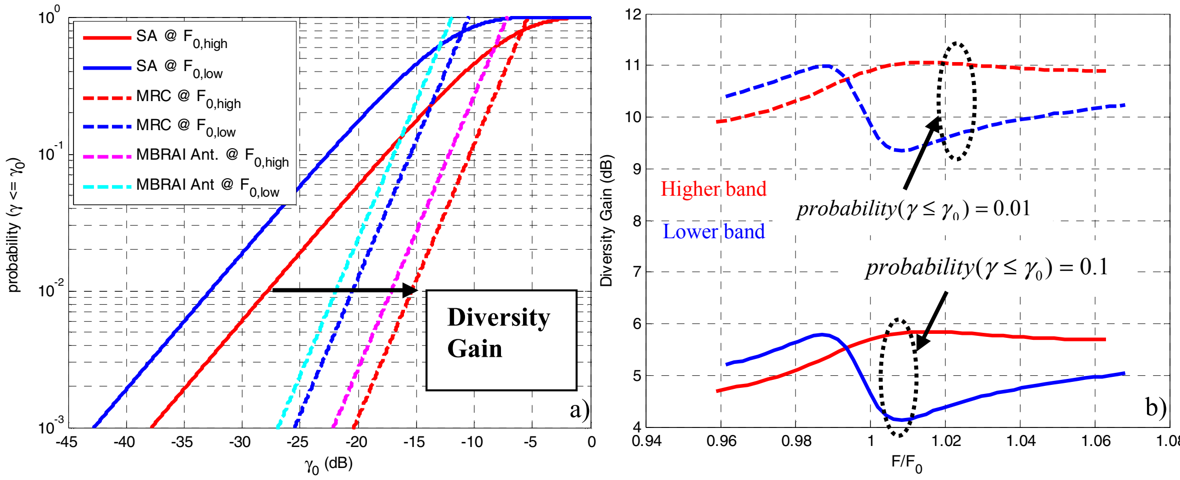

Figure 4: cdfs (a) and Diversity gain (b) of the dual-antenna system in different cases

The compact frequency agile dual-antenna system presented in this paper can bring benefits in terms of diversity gain whatever the antennas operate at the lower or the higher frequencies of dedicated frequency band.

4. Conclusion

We have presented in this paper a compact dual-antennas reconfigurable system for 470-730 MHz band. A wide frequency range is covered thanks to the use of an active capacitive load and good performances are achieved for both antennas. Simulations show that these antennas could be a good way to improve the RF system performances with diversity using MRC algorithm. Further work is still necessary to completely validate the antenna system, particularly the measurement of the diversity gain of the antenna system in presence of multipath scenario.

5. References

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