Flexible and cost effective reconfigurable UHF RFID antenna system

Flexible and Cost Effective Reconfigurable UHF RFID Antenna System

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Abstract—**In this paper a reconfigurable matching network for achieving frequency agility of an electrically small UHF RFID patch antenna is proposed. In order to allow switching under high power transmission a state-of-the-art SP3T CMOS switch is employed for selecting specific components and thus achieving a proper matching in the EU and US frequency bands. Moreover, in the proposed design, only one switch is used instead of four needed in standard aperture tuning approaches. An optimized design of a RFID microstrip antenna has been simulated, showing good performance and high degree of flexibility of this technique, which for its low cost and high integration rate, can become an alternative to aperture tuning for frequency agility purposes.**

***Index Terms*—RFID, frequency agility, matching network, switch, high power transmission.**

I. Introduction

Since its first applications in the 1940´s, Radio Frequency IDentification (RFID) has gained increasing importance in recent years. In fact, due to its versatile technology, RFID equipment can be used in a wide variety of applications such as tracking, security systems and distribution. In particular, asset tracking plays an important role in many industrial processes, as many companies have numerous identification tasks along their production lines that need to be handled.

Because the Ultra High Frequency RFID (UHF RFID) market features various technical approaches and different frequency ranges are required, there are many different standards needed all over the world. Therefore each country has a specific operating bandwidth, such as the 865 - 868 MHz band in Europe, the 902 - 928 MHz band in the United States and 950 - 956 MHz band in the Japanese market [1]. Due to this spread of standards and its universal use, it is somewhat critical to handle different antennas just to meet local frequency requirements.

In order to overcome this problem, some attempts to cover parts or even the entire RFID band with a wideband Circular Polarization patch (CP patch) antenna have been recently carried out, see e.g. [2] and [3].

In this work, we focused on RFID reader antennas that are integrated in automated production line, whose market covers both Europe and US. Due to demanding requirements that are set in order to have the highest reliability from the reader, this application usually requires a different design for the EU and US antennas. However, in recent years, frequency reconfigurability gained attention in such cases for combining different standards and features in a single design.

In this paper, we propose to apply the reconfigurability concept not at the antenna, but instead at the matching network. A similar approach was described through simulations in [4], where a quasi-wideband antenna was loaded with a tunable network in order to achieve high selectivity in the antenna frequency range. Moreover, in [5] a comparison between aperture tuning and tunable matching was carried out using a Planar Inverted-F Antenna (PIFA), revealing that at low frequency the reconfigurable matching provides better performance in terms of total radiated power.

In order to achieve reconfiguration capability, a high linearity SP3T switch developed in CMOS technology has been employed in the design. It is clear that the use of switching devices like PIN diodes is not suitable for the case of a UHF RFID reader antenna: in fact the power delivered from the RF front-end is up to 4 W, causing relatively high RF voltages in the antenna and in the feeding network and thus introduces non-linearity aspects that increase the design complexity. On the contrary, CMOS switches can handle high power and are easy to integrate and control at the expense, however, of a discretized number of possible tuning states that can be applied to the matching network.

II. RFID Antenna System Design

A. Antenna Design

Frequency agility of a microstrip antenna has been frequently achieved by using tuning techniques directly on the antenna structure [6] - [9], however in this study the aperture loading procedure has been applied to the antenna only for achieving a compact design, suitable for being integrated in the final product, without introducing a reconfigurable element on it. In fact, this antenna is intended to be integrated in an automation system, thus directives concerning fabrication, mounting and cost have to be considered in the design. Therefore, a linearly polarized microstrip antenna element of total size of 0.174λ x 0.174λ (with λ calculated at 868 MHz) and height of 20 mm has been designed. Moreover, the patch antenna is realized on a suspended substrate with thickness of 0.5 mm, while the ground plane is a square metal plate of dimensions 0.274λ x 0.274λ, printed on a FR4 substrate with thickness 1.55mm.

For cost reasons standard FR4 with ε_r=4.4 and $tan\delta$=0.02 has been used throughout the design. A pin feeding solution has been selected for best integration with the RF frontend circuit. In order to have this remarkable size reduction of the radiating element, four capacitors with the same value were inserted in the design, thus obtaining an aperture loading effect but without the introduction of a reconfigurable element on it. These capacitors are connected on one side with the same ground reference of the antenna and then a copper wire has been used to connect them to the radiating element and at the same time to hold the microstrip antenna, as can be seen in Fig. 1, where the overall antenna structure is depicted.

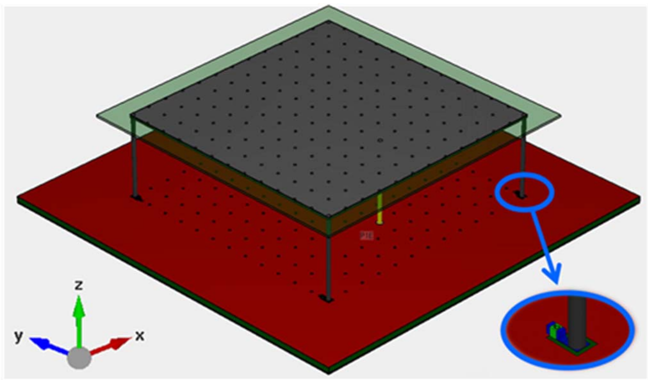

Fig. 1. Model of the microstrip antenna, including ground plane and end capacitors bonding. In the rounded box is shown a detail of the end capacitor´s connection to ground.

The resonance of the patch was adjusted by changing the value of the end capacitors (the four components have the same capacitance), in such a way that a high value of radiation efficiency was ensured in the entire frequency band of interest (i.e. 865 - 928 MHz).

B. Matching Network Design

Assuming that microstrip antennas have a radiation capability which is sufficient to guarantee a good performance level even outside the resonance, matching can be achieved in the EU band (865 - 868 MHz) and in the US band (902 - 928 MHz) by using switches for changing the values/type of components in the matching network.

It is noticed that UHF RFID adopts the Frequency Hopping Spread Spectrum scheme (FHSS) and for this reason the 26 MHz US band can be divided in sub-bands: this process can be done without losing system functionality because the reader knows exactly in which channel it is transmitting and thus the band can be changed accordingly. Under those conditions, an L shaped LC network has been selected for the purpose of this work: this is still true for covering the US band.

The switch is a key element of this design, therefore the high-linearity state-of-the-art Infineon SP3T switch BGSA13GN10 was chosen [10]. This component is critical for the overall performance of the matching network, because of potential losses and device parasitics. Moreover, the switch has slightly different behavior with respect to the active output that is chosen: in the present design this difference is taken into account and the matching components have been connected accordingly, in order to reach the best performance.

The LC matching networks, suitable for covering the EU and US bands, have been calculated using ADS (Advanced Design System), based on the available switch model and the S-parameter matrix of the antenna extracted from EM simulations. The ADS simulations have shown that a single switch solution was appropriate considering some compromises between the values to be used and by carefully setting up the switchable matching network topology.

The final matching topology is composed by a shunt capacitor, which remains fixed in all the three states, and by the switch which is placed in series. Then it allows to select three different inductors that match the EU band and the US band divided in two sub-bands (division was set at 915 MHz).

Finally, the designed matching network along with antenna feeding is placed on the bottom side of the main board, opposite to antenna ground plane. For better integration of the physical component, a 4 layer PCB is used for the main board, and a ground plane (short circuited with the antenna one by mean of vias) is placed at a distance of 0.25 mm from the feeding circuit.

III. Results and Discussion

The microstrip antenna including the complete switchable matching network model and aperture loading capacitors has been all simulated with EMPIRE XPU [11]. The resulting return loss including the three stages is shown in Fig. 2.

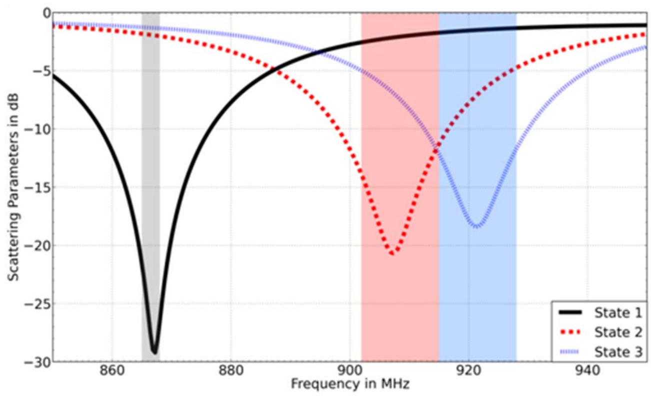

Fig. 2. Simulated reflection coefficient in the 3 different states of the switchable matching network.

It can be noticed that the matching is good in the bands of interest: the simulated S_{11} shows that the EU band (corresponding to State 1, highlighted in the grey shaded area in Fig. 2) and the entire US frequency range is covered, considering the S_{11}< -10 dB criteria. As previously discussed the US band has been split in two sub-bands, represented in Fig. 2 as a red shaded area for State 2, while the blue ones highlights State 3, corresponding to the second US sub-band. The presented matching network, in addition, allows to have a broad resonance which makes the design robust against component and fabrication tolerances.

It is worth to point out that the size of the patch is considerably less than half of the wavelength, and the resonance in a lower band is achieved due to the four end capacitors shown in Fig. 1. Nevertheless, by applying this aperture loading method, an antenna radiation efficiency better than 80% in both EU and US frequency bands was achieved.

Fig. 3 shows that the total efficiency is better than 70% in the UHF RFID frequency bands of interest. In particular the calculated total efficiency for State 1 is 70.8% and 71.6% at 865 MHz and 868 MHz respectively. For the first US sub-band simulated total efficiency has a minimum at 913 MHz with 74.4% (where State 2 and State 3 curves meet) and a maximum at 907 MHz, with a value of 77%, while at 902 MHz a total efficiency of 75% is reached. The State 3 efficiency curve shows the best performances. In fact this matching network, together with antenna, is capable to radiate up to 79.8% of the incident power, while the total efficiency at the end of the US band (i.e. 928 MHz) is 75.7%. Also in this case the minimum efficiency point is located in the intermediate frequency.

By comparing the stand alone antenna radiated efficiency (without matching network) with the reported total antenna efficiency it can be seen that a maximum loss of 12.4% is obtained by employing this method, however this is equivalent to an insertion loss of 0.6 dB, which is a value compatible with the introduction of a matching network at the feeding point.

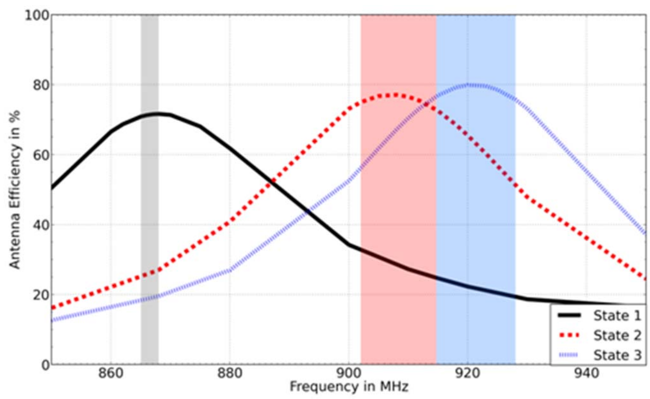

Fig. 3. Total radiated power of the antenna including the reconfigurable matching network in the 3 different stages.

Finally the antenna gain is also simulated and reported in Fig. 4 for one frequency 915 MHz (relative to State 3). The designed UHF RFID antenna reveals a minimum gain of 3.3 dBi at 865 MHz in the EU band, while in the US band the minimum value of gain is 4.1 dBi at 902 MHz, with a maximum of 4.4 dBi at 920 MHz.

It can be noticed that antenna gain is stable in the EU and US frequency bands, with a decrease of the gain relative to the lower frequency: these results are in line with the total efficiency outcomes already discusses.

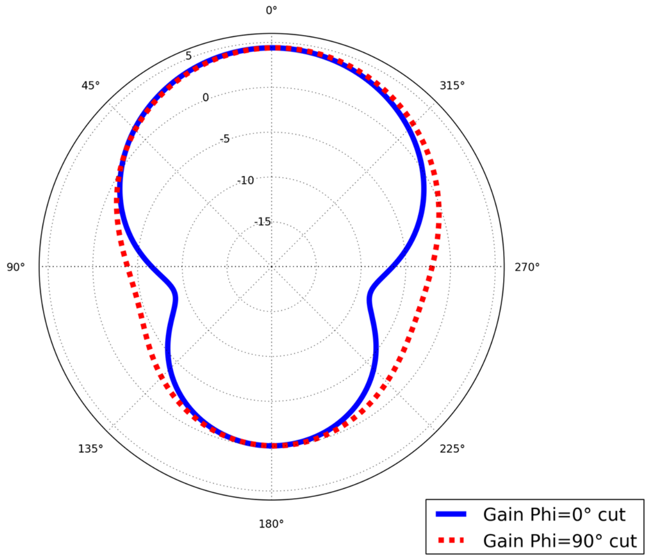

Fig. 4. Simulated RFID antenna gain at 915 MHz with State 3 enabled; the antenna ground plane is in the xy plane.

IV. Conclusions and Perspectives

In this paper a flexible and cost-effective reconfigurable antenna system for RFID readers employing a switching matching network suitable for narrowband applications has been presented. This design is particularly suitable for high power application, since CMOS switches can be used also when high voltages are present in the RF path, without introducing linearity problems. It was also demonstrate that by using the aperture loading technique in combination with the reconfigurable matching network method a compact microstrip antenna can be designed by employing fixed capacitors (instead of four variable ones like the standard aperture tuning approach), and only one switch can be used for achieving frequency agility. It is worth noting that a solution with a completely switchable L shape matching network would ensure maximum flexibility to the design, at the expense of employing two switches.

The next steps of the research activity are the realization of the desired antenna including the switchable matching network and further investigation on the antenna polarization adding the CP capability. Finally this approach can be easily extended to more complex and wideband matching networks.

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