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Dual-Band UHF-RFID Tags Based on Meander Line Antennas Loaded with Spiral Resonators

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***Abstract*— The purpose of this work is to implement dual-band tags for ultra-high-frequency (UHF) radio frequency identification (RFID) applications operative in Europe and USA. Since the regulated bands of UHF-RFID in Europe (867 MHz) and USA (915 MHz) are close, broadband tags might be also considered. However, it is demonstrated in this work that the performance of dual-band tags designed to operate at the frequency bands of interest is superior to that of broadband (mono-band) tags. A meander line antenna (MLA) has been considered for tag implementation. The dual-band functionality is achieved through a perturbation method consisting on coupling an electrically small resonator (a two-turns spiral resonator – 2-SR) to the antenna. The analysis, design and fabrication of a dual-band UHF-RFID tag has been carried out. The measured performance of the fabricated prototype is in good agreement with theory. Measured read ranges of 6 m and 8 m at the European and USA frequency bands, respectively, have been obtained.**

***Index Terms*— Radio frequency identification (RFID), spiral resonator (SR), dual-band, impedance matching, meander line antenna (MLA).**

I. Introduction

In recent years, the applications of radio frequency identification (RFID) passive tags operating in the ultra high frequency (UHF) band have experienced a progressive growth. These tags might be separated into two categories; (i) metallic tags, and (ii) inlays (which are based on plastic substrates). Metallic tags keep their functionality when they are attached on any object (including objects with metal surfaces [1]), have long read ranges and major robustness, although they have large dimensions. Inlay passive tags do not work over metallic surfaces [2], but they are of reduced size, lower cost and are flexible.

Inlay tags are usually designed to operate at a single frequency band. However, due to the different worldwide regulations, the UHF-RFID frequency bands have different locations in the spectrum, depending on the world regions. Thus, Europe operates at 866-869 MHz, USA at 902-928 MHz, and Japan at 950-956 MHz [3]. Therefore, there have been some efforts to design broadband tags [4],[5] to cover at least two of the regulated bands. However, it is difficult to obtain a balanced read range at these two frequency bands. Moreover, it has been recently demonstrated in [6] that better matching at the two considered bands can be achieved by using dual-band tags, rather than broadband ones. The main aim of this work consists on designing a dual-band UHF-RFID tag prototype able to operate in Europe and USA.

Tags are usually based on an antenna matched directly to the chip, in order to obtain maximum power transfer. In [6], an impedance matching network was cascaded between the antenna and the chip. Dual-band functionality of the matching network was achieved by means of a perturbation method applied to the characteristic impedance and electrical length of a transmission line, and achieved by coupling an electrically small resonator to the line. In this work, a meander line antenna (MLA) [7] has been designed and optimized to achieve high tag efficiency at the intermediate frequency. In order to obtain the dual-band functionality, a perturbation is then applied directly to the antenna, reducing the number of stages and hence the size of the overall tag (this is the main relevant aspect and originality of the present work).

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II. Design of a Dual-Band Meander Line Antenna (MLA)

A. *MLA Antenna design*

The use of MLAs in UHF-RFID is well known [8]. The topologies of MLAs are interesting for antenna miniaturization with an acceptable degradation of the radiation efficiency. The MLA is a dipole antenna where the arms are folded, producing a distributed capacitive and inductive reactance. Although these meanders help to improve matching by changing the input impedance, they reduce the radiation efficiency; hence it is not convenient to introduce too many meanders.

The designed meander is inspired by the work in [9], and it was simulated by using the input impedance of the chip as the reference impedance by means of the software *Agilent Momentum*. In a first order approximation, a linear variation of the chip impedance (real and imaginary parts) with frequency can be considered. Since the chip impedance values in the European and USA frequencies are known, we can easily infer from linear extrapolation the impedance value at the intermediate frequency (f_0 = 891 MHz). In the first step of the dual-band tag design procedure, f_0 is the selected frequency for the purpose of designing the antenna. The calculated chip impedance at the intermediate frequency is Z_{chip}= 20–j485 Ω (the *SL31001* from *NXP semiconductors* has been the considered chip). The chosen substrate was the *Rogers RO3010* with dielectric constant ε_r = 10.2 and thickness h = 0.127 mm.

The topology of the antenna was designed to obtain impedance matching and large efficiency at the intermediate frequency. The final layout is shown in Fig 1(a). The dimensions are 48 mm × 48 mm, and the strip width is 1.4 mm. The other relevant dimensions are l_m = 16.3 mm, w_m = 4.8 mm, d_l = 7.3 mm, d_r = 33.9 mm and d_f = 14.2 mm. The input impedance of the MLA was obtained and is depicted in Fig 2. At the intermediate frequency the reactance is 485 Ω, corresponding to the reactance of the *SL31001* chip with opposite sign. Although the resonance of the tag is obtained at this frequency, the optimum (i.e., conjugate) matching is not actually achieved since the real part of the MLA impedance does not coincide with the real part of the chip impedance. This is the main difference between the approach of this paper and the use of a matching network [6], where conjugate matching can be achieved. Nevertheless, the radiation pattern of the tag has been analyzed (different cut angles have been considered, as shown in Fig 3), keeping efficiency around 88%.

B. *Dual-band MLA*

A synthesis technique for dual-band RFID tags based on a perturbation method was proposed in [6], where an impedance matching network (a transmission line) was cascaded between the antenna and the chip. In a first step, the characteristic impedance and length of the transmission line were determined in order to achieve conjugate matching between the antenna and the chip at the intermediate frequency. To achieve conjugate matching at the two frequencies of interest, the line was then perturbed by coupling to it an electrically small resonator (a split ring resonator – SRR [10]) tuned at the intermediate frequency. This resonator modifies (perturbs) the characteristic impedance and electrical length of the line in the vicinity of the intermediate frequency, and by controlling the coupling level, resonator's quality factor and position in the line, the required values of characteristic impedance and electrical length necessary to obtain conjugate matching at the two operating frequencies can be obtained.

In this work, the main improvement and originality consists on coupling an electrically small resonator directly to the antenna. This can be done because the MLA is a dipole antenna which has an equivalent transmission line model [11]. Therefore, it is possible to reduce the number of stages, avoiding the impedance matching network. As a result, the size of the whole tag can be reduced. It must also be pointed out the use of a two-turn spiral resonator (2-SR) [12], instead of a SRR. The reason is that with the same resonance frequency the 2-SR has approximately half the size of the SRR. This feature is needed to introduce the resonator inside the MLA region and apply the perturbation method without modifying the size or shape of the final tag (Fig 1b).

As was pointed out in [6], the perturbation in the electrical length of the line depends on the geometry of the resonator and on its coupling to the line (determined by the distance to the line). A strong coupling between the 2-SR and the meander line will introduce large variations in the electrical length of the antenna (with opposite sign above and below the resonance frequency of the resonator). Such large variations tend to separate the resonance frequencies of the dual-band RFID tag, whereas a weak coupling produces a small split-off of both frequencies. Once the level of coupling is set, the relative position of the resonator along the line affects only the characteristic impedance, whereas the electrical length remains unaltered (as occurs in standard resonant antennas such as λ/2 dipole, λ/4 monopole, etc., the resonance frequency of the meander antenna is mainly determined by the total electrical length [11]). However, the impedance of the MLA is not substantially affected by the characteristic impedance of the line, and for this reason the resonator is placed in a convenient position to control the coupling to the line. The final dimensions concerning the 2-SR and its relative position in the antenna (shown in Fig. 1b) are l_r = 16.1 mm, w_r = 6.8 mm, s_h = 8.3 mm and s_v = 5.4mm. The strip width of the 2-SR is 0.5 mm and the separation between spirals is 0.3 mm.

The input impedance of the meander tag, including the resonator inside, is depicted in Fig. 4. The conjugate reactance (imaginary part only) occurs at the European and USA frequencies (867 MHz and 915 MHz). It can be also illustrated by means of the power wave reflection coefficient s (Fig 5). The fact that the unperturbed MLA shows good matching at the intermediate frequency (–8 dB), augurs similar behavior in the 2-SR loaded MLA. The reason is the small variation in electrical length needed to force dual-band behavior. In fact, the reflection coefficient of the dual-band antenna is better than –5dB at both frequency bands. This is a significant improvement with respect to [9], since a reflection coefficient of –3dB was obtained in that paper at a single frequency band.

III. Fabrication and Measurement

A. *Theoretical read range*

To determine the performance of the tags, it is necessary to obtain the read range [13], which can be calculated using the Friis free space formula as

$$r = \frac{\lambda}{4\pi}\sqrt{\frac{EIRP\ G_r\tau}{P_{chip}}} \qquad (1)$$

where λ is the wavelength, *EIRP*, determined by local country regulations, is the product of P_tG_t which are the transmission power and the transmission gain, respectively, P_{chip} is the minimum threshold power necessary to activate the RFID chip, G_r is the gain of the receiving tag antenna, and τ is the power transmission coefficient. The value of *EIRP* in European frequencies is 3.3W, whereas in American frequencies it is 4W. The power transmission coefficient is inferred from the simulation of the return loss of the antenna, using as port impedance that of the chip. The tag gain is also obtained from simulation, hence the theoretical read range can be calculated.

B. Measured read range and experimental setup

The RFID setup available in our laboratory consists on a N5182A vector signal generator which creates RFID frames. Such generator is connected to a TEM cell by means of a circulator. The tag under test is located inside the TEM cell and it is excited by the frame created by the generator. Then the tag sends a backscatter signal to a N9020A signal analyzer through the circulator. The RFID frame frequency is swept with a specific power. Once the operation frequencies are identified, the output power is decreased until the tag stops working. Finally, a probe is placed into the TEM cell in order to determine the incident electric field intensity E_0 at each frequency, which is related to the received power by the chip according to

$$P_{chip} = SA_{ef}\tau = \frac{|E_0|^2}{2\eta}\frac{\lambda^2 G_r}{4\pi}\tau \quad (2)$$

where S is the incident power density, A_{ef} is the effective area of the tag antenna, and η is the wave impedance (which is equivalent to $120\pi\ \Omega$). The measured read range can be inferred by introducing (2) in (1), resulting:

$$r = \frac{\sqrt{60 EIRP}}{E_0} \quad (3)$$

As indicated before, the *EIRP* European value is lower than the USA counterpart, so the read range in Europe would be roughly reduced by a factor 0.9 for the same incident electric field intensity.

C. Results

The meander line antennas depicted in Fig. 1(a) and Fig 1(b) have been fabricated by means of a standard photo/mask etching process and are shown in Fig. 6. The read ranges were measured following the procedure indicated in the previous sub-section, and are depicted in Fig. 7. In this graph, there are also shown the theoretical read ranges, which were calculated by means of (1), using the simulated return loss and gain of the MLA. The mono-band frequency tag is the tag designed to operate at the intermediate frequency (890 MHz). As expected, after introducing the 2-SR inside the meander, a dual-band behavior is achieved. It can be seen that the measured read ranges are slightly higher and lower at the upper and lower frequencies, respectively, as compared to those inferred from simulation. This fact is attributed to unbalance in the 2-SR loaded MLA, due to fabrication related tolerances. It must be also emphasized that the dual-band MLA efficiency decreases due to losses introduced by the 2-SR resonator. Whereas the mono-band MLA has an efficiency of 88%, the dual-band MLA has an efficiency of 66% and 70% at the lower and upper frequencies, respectively. However, the radiation patterns are almost the same at the three frequency bands. Finally, it can be seen that the read range of the mono-band MLA tag is roughly 4 m at the frequencies of interest, whereas almost 6 m and 8 m at the European and USA frequency bands, respectively, are achieved by means of the designed dual-band MLA. Thus, a significant improvement of the read range by using a dual-band MLA, instead of a broadband (mono-band) MLA, is obtained. This prediction, already pointed out in [6], is thus validated experimentally in this paper.

IV. Conclusion

To conclude, a dual-band UHF RFID tag based on a MLA loaded with a 2-SR has been designed and fabricated. The approach avoids cascading an impedance matching network, so that the dual-band functionality has been obtained by introducing a perturbation directly to the antenna. The simulated and measured read ranges are in good agreement. The dual-band tag can improve the read range at the Europe and USA frequency bands as compared to mono-band broadband designs.

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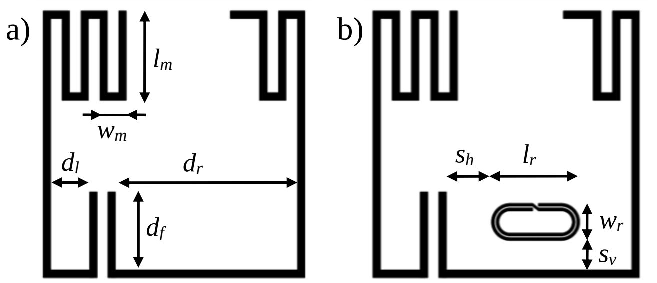

Fig. 1. Layout of the meander line antenna considered for tag implementation (a), and layout of the MLA perturbed by the presence of a coupled two-turns spiral resonator (b). The strip width of the 2-SR is 0.5 mm, and the separation between strips is 0.3 mm.

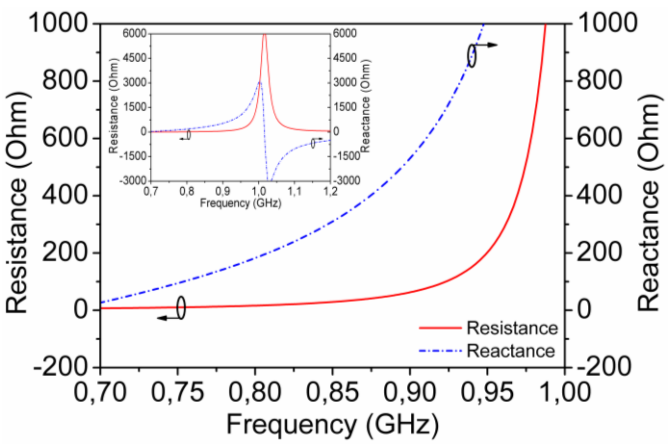

Fig. 2. Input impedance of the MLA depicted in Fig 1(a) in the region of interest (the inset depicts the input impedance in a broader band).

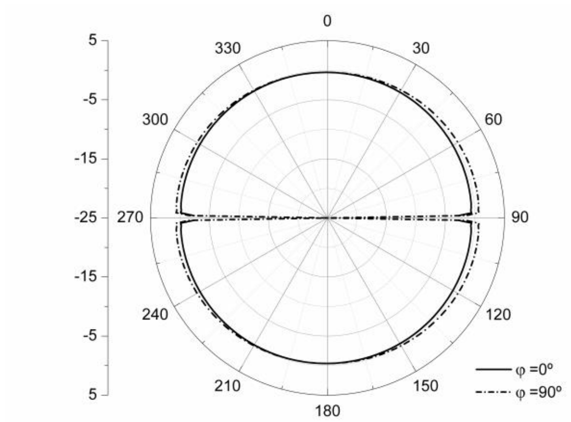

Fig. 3. Radiation pattern of the mono-band MLA for magnetic plane (φ = 0º) and electric plane (φ = 90º). An efficiency of 88 % is obtained. The dual-band MLA has the same radiation patterns at both frequency bands, although the efficiency in Europe decreases down to 66 % and in US down to 70 %.

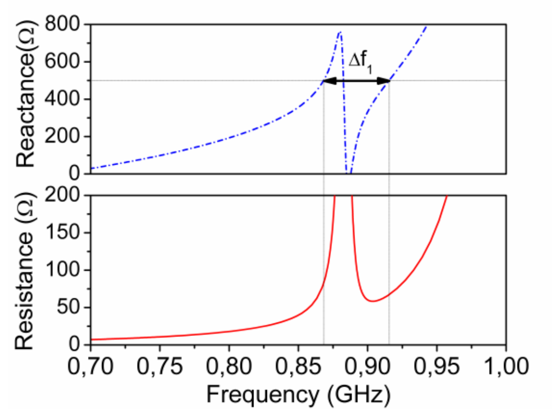

Fig. 4. Input impedance of the dual-band MLA with coupled 2-SR depicted in Fig 1(b). The frequencies where conjugate matching (imaginary part) is obtained, separated by Δf_1, are indicated.

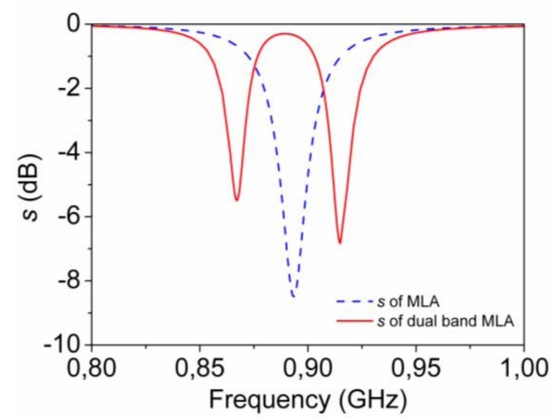

Fig. 5. Power wave reflection coefficient of the mono-band and dual-band meander line antenna.

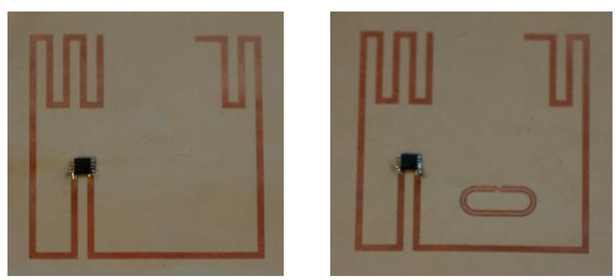

Fig. 6. Fabricated mono-band (left) and dual band (right) MLA RFID tags.

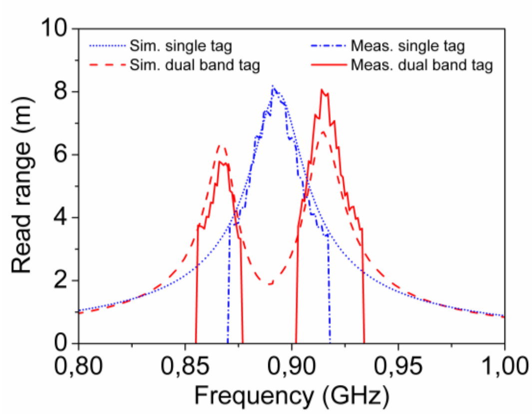

Fig. 7. Simulated and measured read ranges of the mono-band and dual band MLA RFID tags.