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An Approach for the Design of Passive UHF-RFID Tags Mounted on Optical Discs

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***Abstract*—In this paper, an innovative design strategy for UHF-RFID tags mounted on optical discs (such as DVDs) is presented. By using the metal layer of the disc as the main radiating element, it is possible to overcome the severe limitations of the existing tags for disc identification in terms of read range and bandwidth. The design and synthesis process, based on the proposed circuit model of the tag, is described. A worldwide UHF-RFID tag prototype, for direct mounting on a DVD disc, is designed and fabricated. The measured read range demonstrates that the presented method drastically improves the performance within the whole UHF-RFID band (840-930 MHz), in comparison to the DVD tags found in the available literature.**

***Index Terms*—DVD tagging, radio frequency identification (RFID), tags, antennas.**

I. INTRODUCTION

RADIO frequency identification (RFID) is a widespread technology that allows tagging of objects by using electromagnetic waves. In the last years, the use of such technology has experienced a rapid increase, whereas the cost of the tags has dropped down, and further penetration into the market is expected for the next years. Typical applications of this technology are smart inventory and item tracking, among others. Passive tags operating at the UHF-RFID frequency bands (840-930 MHz [1]) are especially employed for this kind of applications due to the significant achievable read ranges, low cost, small dimensions, and because such tags do not need batteries. A passive UHF-RFID tag consists of an antenna matched to an application specific integrated circuit (ASIC), which contains the information about the tagged item. A passive tag is capable of using the electromagnetic energy from the reader to activate the chip, which generates a modulated backscattered signal to the reader. Typical peak read ranges of UHF-RFID tags are in the order of 5-10 m, depending on the country regulations (i.e. maximum allowed EIRP value), tag characteristics (i.e. antenna design and chip sensitivity) and orientation, object material, and environmental conditions.

Whilst RFID technology allows labeling many kinds of items or objects composed by dielectric materials, it is well known that metallic objects, or objects containing metallic parts, can prevent the correct functionality of the tags [2]-[5], as they can cause mismatching between the tag antenna and ASIC, and degradation of the radiation efficiency of the antenna as well. Due to this effect, CD, DVD and Blu-ray discs cannot be labeled with standard passive UHF-RFID tags, since they contain a thin metal layer under the disc surface, which causes a severe degradation of the tag read range.

Some efforts have been made in the past by designing bending dipole [6] and meander and ring [7] antenna based tags to be placed in the small central area of the disc, which is metal-free. However, due to the proximity of the disc metallic layer and the reduced tag size, the achieved read ranges are in the order of 0.35-0.4 m, which are inadequate for many typical RFID applications. Moreover, this kind of tags typically presents complex layout geometries, and the design process is not fully explained. For this reason, there exists an important gap when comparing the performance of tags for disc identification to that of general purpose UHF-RFID tags.

Potential applications of optical discs RFID tagging include inventory systems in libraries, music and video stores, where such technology would provide a very powerful tool to monitor the position and the movements of every item individually. Efficient tagging of the optical discs would also allow item level tracking over the supply chain, and general retail applications.

In this paper we present a new method for the design and synthesis of UHF-RFID tags mounted on optical discs. Such approach leads to a drastic improvement of the read range over the whole UHF-RFID band, and is characterized by the simplicity of the design process and final layout. As a demonstration, a UHF-RFID tag for DVD discs is designed and fabricated, and the measured read range is presented.

II. DVD DISC STRUCTURE AND CIRCUIT MODEL

A. DVD Disc structure

The substrate of DVD discs is composed of two identical circular-shaped polycarbonate layers (0.6 mm thickness each) bonded together, which provide structural rigidity and protect the internal layers from mechanical damage (scratches) and oxidation caused by atmospheric agents (humidity, oxygen, dust, etc.) [8]. A very thin metal layer (50-100 nm) is grown

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between the two polycarbonate layers by means of sputtering deposition. The constitutive material of this layer can be aluminum, gold, silver, or silver alloys, depending on the disc type [8]. Such layer, which is found in all kind of optical storage devices (CDs, DVDs, BluRay discs), is necessary to reflect the laser beam during read and write operations of the data content.

Data layer material also varies depending on the disc type. Molded polycarbonate, organic dye or phase-changing metal alloy film is commonly used for DVD-ROM, DVD+R, DVD+RW, respectively [8]. Data is stored in this layer in the form of nanometer scale pits and lands, which modulate the intensity of the reflected laser beam detected by the reader photodiode. Some kinds of DVDs can also include a semi-reflective metal layer (e.g., double data layer DVDs) and even a labeling layer such as a thermal-printable, inkjet-printable, or silkscreen-printable layer [8]. However, in order to perform an electromagnetic simulation of the structure, it is possible to simplify the problem by modeling the disc considering only the substrate layers and the metal layer. This is because these are the most important layers in terms of electrical properties of the disc, as the other layers are very thin and do not present critical electrical properties (i.e., high permittivity or high conductance). This approximation can only be assumed in the case of single data layer discs only. Other DVD types should be modeled including additional metal layers.

B. Electrical model of the DVD disc

The main concept provided in this work is to consider the metal layer of the disc as an antenna. By properly exciting electrical currents on the disc surface, an oscillating dipolar moment can be generated, acting as the main radiating element of the system. Therefore, the tag can be designed to operate by coupling electromagnetic energy to the metal layer of the disc, resulting in a larger antenna size, as compared to the sizes of conventional CD/DVD tag antennas. Moreover, the radiation efficiency degradation due to the image currents, which occurs in the conventional disc tags, is avoided with this approach. The reason is that the disc metal layer is used as the main radiator, therefore image currents are not present.

Because electromagnetic (EM) coupling to the metal layer is required, the impedance matching between the antenna and the ASIC will directly depend on the input impedance of the disc metal layer. Therefore, in order to design the proposed tag, it is very useful to understand the electrical behavior of the disc in terms of its impedance. To analyze the frequency response of the disc, the *CST Microwave Studio* commercial software (the frequency domain solver) was used. The simulated structure, presented in Fig. 1, is a simplified model of a DVD+R disc, according to the approximations described in section II-A. The metal layer is modeled as an ohmic sheet with a square resistance given by

$$R_{\square} = \frac{\rho'_{Ag}}{t} \tag{1}$$

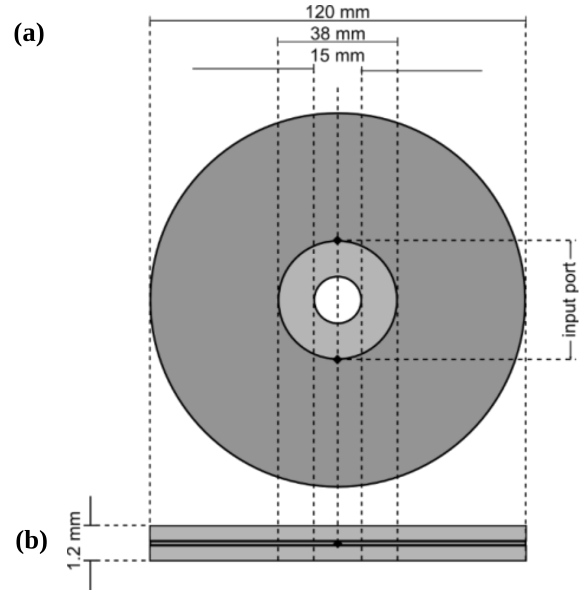

Fig. 1. Structure of the considered DVD disc: top view (a), lateral view (b). Dark grey represents silver, light grey represents polycarbonate. Layer thicknesses are not drawn to scale.

where ρ'_{Ag} is the effective resistivity of the silver film and t is the film thickness. It has been demonstrated that the effective electrical resistivity of thin metal films can vary depending on the fabrication process and the thickness of the deposited layer [9]-[10]; typically, the effective resistivity increases with respect to the material bulk resistivity as the film thickness decreases. This effect becomes very important when the thickness is in the order of the electron mean-free-path p of the conductive material [9]-[10]. The value of p for silver is roughly 50 nm [11] at room temperature. Hence, for a reflecting layer thickness of 50 nm, the thickness to mean-free-path ratio t/p approaches unity. It is possible to predict the effective resistivity ρ' of a thin metal layer, given the values of the bulk resistivity ρ and the ratio t/p [9]. Based on [9], the value of ρ'_{Ag} for $t/p = 1$ can be found as $1.5\rho_{Ag}$ (where ρ_{Ag} = 16 nΩ·m is the bulk resistivity of silver [12]), leading to ρ'_{Ag} = 24 nΩ·m. Therefore, according to (1) the square resistance value is $R_{\square} = 0.5\Omega$. The relative permittivity and dielectric loss tangent values used for polycarbonate plastic are $\varepsilon_r = 2.88$ and $\tan\delta = 0.012$, respectively [13]. It is important to remark that the electrical properties of the polycarbonate plastic and silver layers may vary depending on many factors related to the fabrication process. In this regard, and considering the wide range of different DVD manufacturers, the choice of one set of electrical parameters for the structure is arbitrary and slight variations in the tag performance can result for different brands.

In order to carry out the simulation, a differential input port is placed directly on the metal layer, and aligned to one of the infinite symmetry planes of the structure, as depicted in Fig. 1. The reason for choosing a symmetric position of the port is simple: the final structure (tag layout and DVD) should present (at least in a first order approximation) symmetry in order to prevent a displacement of the barycenter. Actually, unbalancing the rotating mass can cause read/write problems and physical damage of the disc and the reader.

The simulated input impedance Z_{disc} of the structure

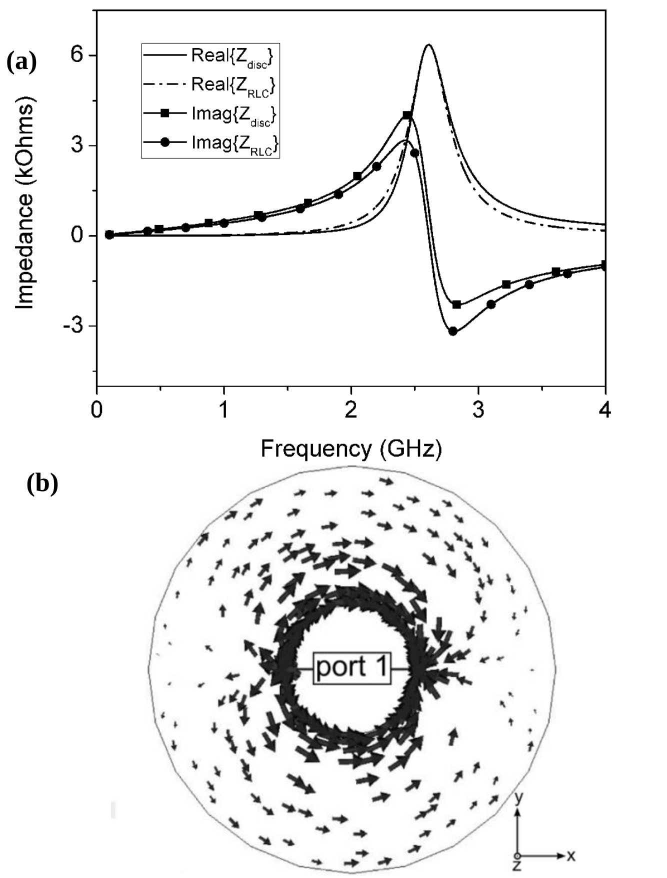

Fig. 2. (a) Comparison between the simulated input impedance of the DVD+R disc (Z_{disc}) and the input impedance inferred from the circuit model (Z_{RLC}). (b) Current profile on the metal layer at 885 MHz.

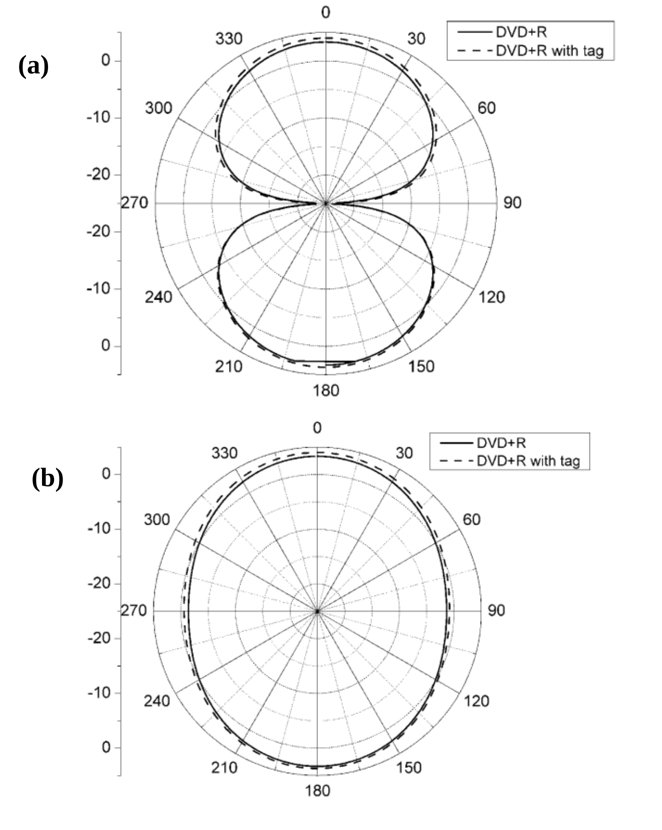

Fig. 3. Radiation pattern at 885 MHz for DVD+R and DVD+R with tag: (a) E-plane; (b) H- plane.

(depicted in Fig. 2(a)) shows a parallel-type resonance occurring at $f_0 = 2.61$ GHz, suggesting that a shunt RLC circuit model can be used to describe the disc impedance to a good approximation. Based on the resistive part of Z_{disc} and the reactance slope values at f_0, it is possible to perform a parameter extraction. The calculated values for the circuit parameters are $R_p = 6350\ \Omega$, $L_p = 57$ nH, C_p =65 fF. Good agreement between the circuit model and EM simulation is observed in Fig. 2(a).

Let us now discuss the expected radiation properties of the disc metallic plate. Since the excitation signal is applied over one of the symmetry planes of the structure (x-axis in Fig. 2(b)), a magnetic wall is expected to form along such axis. Moreover, the y-axis is also a symmetry plane of the structure, and a differential excitation is applied on its sides. Therefore, an electric wall is formed along the y-axis. Due to the symmetry walls generated in the structure, a first order cancellation of the fields radiated by the current components along y-axis is expected. Nevertheless, the x components of the currents flow in the same direction, resulting in a dipolar radiation along the x-axis. Given that the first self-resonance of the disc occurs at high frequencies, we expect a short dipole charge profile at the UHF-RFID band. Since the width of such dipole is comparable with the wavelength at the working frequency, the phase contributions of each element cannot be neglected. Therefore, the radiation pattern of the disc can be approximated by the radiation pattern of an array of short dipoles excited in phase. In terms of far-field radiation, as a first order approximation it is possible to model the system as an array of two infinitely thin dipoles, excited in phase, and separated by a distance d. The effective distance d between the two dipoles is a function depending on the current density profile along the section of the metal layer, and is comprised between the physical dimensions of the disc: 38 mm ($\lambda/10$ at 885 MHz) and 120 mm ($\lambda/2.8$ at 885 MHz). Such dipole array is thus expected to present a maximum directivity value higher than the single dipole, and the radiation pattern is expected to present a maximum at $\theta = 0°$ (direction normal to the disc plane). Moreover, a directional pattern is expected for the H-plane (yz), with a minimum directive gain at $\theta = 90°$ due to the destructive interference between the two radiating elements. However, since the two elements of the array are in-phase excited and their distance is smaller than $\lambda/2$, the directive gain minimum value on the H-plane is not expected to reach zero. Far-field polarization is expected to be linear, with E-field oriented along the x-axis (see Fig. 2(b)).

The simulated current pattern on the metal layer at the center frequency (885 MHz) is depicted in Fig. 2(b). As expected, each side of the disc exhibits a dipolar type current. The simulated radiation pattern (see Fig. 3) confirms the behavior of the disc as an array of two short dipoles, with a maximum directive gain value $D_0 = 3.3$ dBi at $\theta = 0°$.

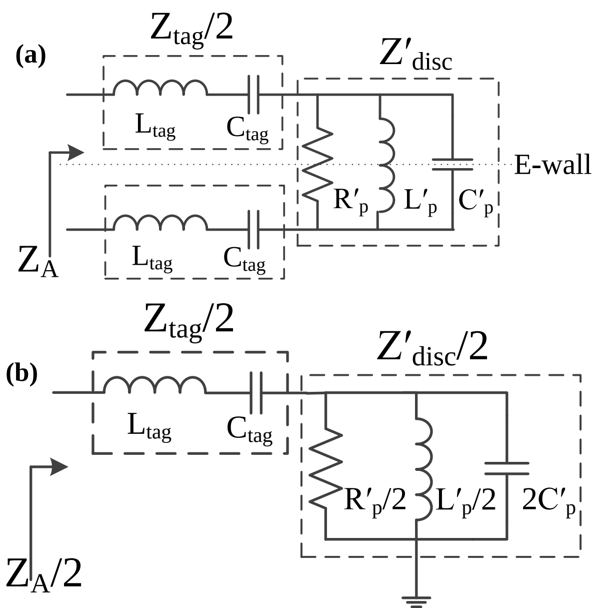

Fig. 4. Electrical model of the system composed by the DVD and the tag (a), simplified electrical model using electrical wall (E-wall) concept (b).

Minimum directive gain on the *yz*-plane is −1.4 dBi. Due to the width of the conductive path on the metal layer, the radiation efficiency is reasonably high, reaching the value of ε_{rad} = 25% at 885 MHz. It is interesting to quantify the losses in each part of the disc. The simulation results indicate that 85% of the dissipated power is due to ohmic losses in the metal layer of the disc. Dielectric losses in the polycarbonate layer represent a 15% of the total losses. Based on the simulated radiation pattern, the antenna gain is $G_0 = -2.7$ dB. This means that, providing a good impedance matching, it is possible to obtain a read range in the order of several meters. As an example, considering $EIRP = 4$ W (which is the maximum allowed value in many countries [1]), the read range is 7 m for ASICS with $P_{th} = -15$ dBm [14] and 10 m with $P_{th} = -18$ dBm [15], according to the well-known equation [19]

$$r = \frac{\lambda}{4\pi}\sqrt{\frac{EIRP \cdot G_r \cdot \tau}{P_{th}}} \quad (2)$$

where *EIRP* is the equivalent isotropic radiated power, λ is the free-space wavelength at the working frequency, G_r is the gain of the tag antenna and $\tau = (1-|s|^2)$ is the power transmission coefficient. This theoretical value corresponds to the read range in free-space, with both antennas (reader and tag) correctly oriented at the maximum gain direction.

III. Tag Design, Synthesis and Simulation

A. Design principles

In the previous section, the capability of a DVD to work as an efficient antenna at the UHF-RFID frequencies was demonstrated. In order to design an RFID tag capable of taking advantage of this potentiality, the coupling method problem has to be solved. In fact, coupling is necessary because the metal layer is not directly accessible in the DVD post-production stage, and a RFID tag can only be placed on top of the polycarbonate structural layer. The solution adopted in this work is to produce an electric coupling between the tag and the disc by means of a series stepped-impedance resonator (SIR) synthetized through semi-lumped elements. The capacitance between the tag metal (top layer) and the disc metal (inner layer), C_{tag}, provides electric coupling. The series inductance L_{tag}, realized through a thin line (e.g., 0.4 mm), forces a controllable series resonance, which provides a virtual short circuit between the ASIC and the metal layer of the disc.

An equivalent circuit model for the whole structure can be obtained by means of a series connection of the disc (described in section II-B) and the tag circuit model, as shown in Fig. 4(a). Notice that due to the series connection between the disc and the tag, the impedance seen from the ASIC is simply $Z_A = R_A + jX_A$, where $R_A = R_{tag} + R'_{disc}$ and $X_A = X_{tag} + X'_{disc}$. Differential excitation and symmetry considerations, allows us to apply the electric wall concept (Fig. 4 (b)). Although the disc can still be modeled by an RLC parallel resonator, the parameter values vary due to the presence of the tag. In particular, a shorter effective current path on the metal disc results as a function of the capacitor length l_c. Thus, the new values of inductance L'_p and resistance R'_p are smaller compared to L_p and R_p. The resulting disc impedance is designated as $Z'_{disc} = R'_{disc} + jX'_{disc}$. The tag capacitance C_{tag} and inductance L_{tag} can be controlled by means of simple geometrical parameters (e.g., the area of the semi-lumped capacitor and the width of the semi-lumped inductor). By working in the vicinity of the *LC* series resonance, it is possible to control the tag series reactance X_{tag}, which can be inductive or capacitive. Thus, the total reactance $X_A = X'_{disc} + X_{tag}$ can be adjusted in order to match the capacitive reactance X_C of the RFID chip (ASIC). Since ohmic losses of the LC resonator are omitted in the model, the resistive part of the antenna system R_A is directly equal to R'_{disc}. Its value cannot be easily controlled for impedance matching, since it presents a very small variation as a function of the tag geometry. However, according to the simulation results, the value of R'_{disc} at UHF is in the range of 8-12 Ohms, thus providing a good matching level with many ASICs available on the market, without the need for an additional matching network.

It is important to note that the circuit proposed above (Fig. 4) is a simplified circuit model which allows an easy design of the tag in the UHF-RFID band. In order to describe the impedance behavior of the system in a wider band, it is necessary to take into account an additional capacitance introduced by the presence of the tag conductors, which is in the order of 100 fF and is placed in shunt with the impedance Z_A.

B. Layout synthesis and simulation results

The tag presented in this work is an example of layout synthesis based on the concepts illustrated in the previous section. Although it is not possible (without an additional mass balancing element) to achieve a perfect symmetry of the tag that guarantees that the barycenter is located at the center

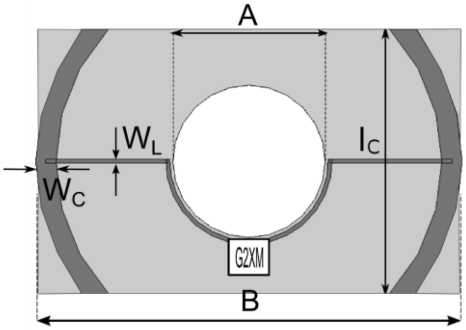

Fig. 5. Final tag layout to be positioned over the central zone of the disc. The metal is represented in dark grey and *RO3010* substrate in light grey.

of the disc, the layout design has been focused on optimizing it. The chip, which introduces mass unbalance, has been chosen to be placed as near as possible to the rotation center of the disc, i.e., adjacently to the inner hole of the polycarbonate structure, in order to minimize the barycenter shift of the system. The electrical connection between the coupling capacitance C_{tag} (at the edge of the tag) and the ASIC (at the center of the tag) was designed in order to work as the tag inductance L_{tag}, resulting in a very simple final layout (Fig. 5). The UHF-RFID chip used in the design is the *NXP UCODE G2XM* [14]; according to the manufacturer the input impedance is $Z_C = 16–j148\ \Omega$ and the threshold power level at 915 MHz is $P_{th} = –15$ dBm. However, the value of P_{th} for this ASIC has been experimentally measured over the UHF band [16], yielding results in the order of –13 dBm at the center frequency. A parallel RC type circuit model can be used to describe the ASIC input impedance in the whole UHF-RFID band [17]-[18]. Based on the input impedance at 915 MHz, the values were found to be $R_c = 1385\ \Omega$ and $C_c = 1.16$ pF. The substrate used for the prototype is the *Rogers RO3010* (with thickness $t = 0.254$ mm, $\varepsilon_r = 10.2$, $\tan\delta = 0.0023$), which has a structural function only. In fact, the high permittivity of the material does not have a role, neither in size reduction, nor in increasing the tag performance. On the contrary, the required dimensions of the capacitive part of the tag slightly increase when using any substrate, rather than directly print or grow the metal layer on the polycarbonate surface. This is due to the fact that adding a substrate on the polycarbonate layer decreases the capacitive coupling between the disc and the tag. An equivalent circuit model can describe the presence of the substrate as an additional capacitance in series with the capacitance between the disc and the tag. Indeed, the *RO3010* substrate was chosen as a mechanical support for fabrication, being the only thin substrate available in the laboratory. Commercial versions of the tag can be engineered without any substrate, i.e. screen- printing on the disc surface, in order to minimize the cost.

Once the layout strategy has been defined, the problem presents 3 degrees of freedom (l_C, W_C, W_L) in the geometry of the tag (Fig. 5). Obviously, many different solutions exist in order to obtain the required reactance. As a starting point, the value of W_C was fixed at 2 mm, an arbitrary value that ensures a minimal overlapping of the tag within the DVD graphical label layer. A proper combination of l_C and W_L was then chosen in order to obtain the matching peak at the desired frequency (885 MHz). At this stage it is useful to consider that, as a first order approximation, the capacitor length l_C controls the capacitance value C_{tag}, and the line width W_L controls the inductance value L_{tag}. Final values for the geometrical parameters are $W_C = 2$ mm, $l_C = 16.5$ mm, $W_L = 0.4$ mm, $A = 15$ mm (corresponding to the diameter of the DVD inner hole) and $B = 42$ mm.

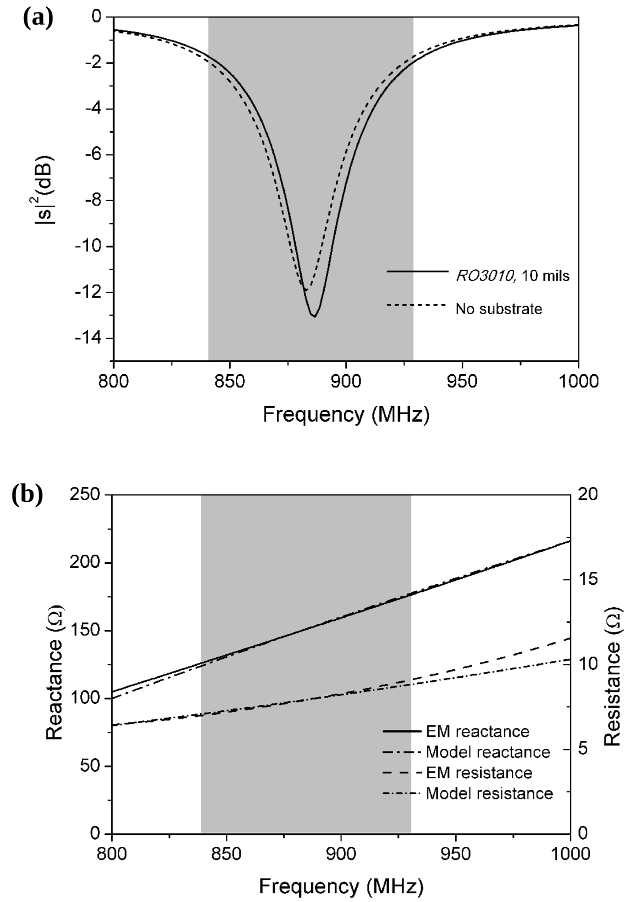

Fig. 6. (a) Simulated amplitude of the power reflection coefficient of the tag described in Fig. 5; (b) Comparison between the impedance of the circuit model and the one inferred from electromagnetic (EM) simulation (with *RO3010* substrate).

Simulation results, in terms of power reflection coefficient, are depicted in Fig. 6(a). As expected, good matching is achieved at 885 MHz ($|s|^2 = –13$ dB, corresponding to $\tau = 1-|s|^2 = –0.2$ dB). Based on the simulated input impedance of the structure, a parameter extraction for the electrical model was performed, in order to demonstrate its validity. The extracted circuital values are $L'_p = 19$ nH, $R'_p = 1500\ \Omega$, $C'_p = 58$ fF, $C_{tag} = 2$ pF, $L_{tag} = 20$ nH. Very good agreement between electromagnetic and circuital impedance in the UHF-RFID band can be observed in Fig. 6(b).

The radiation pattern for the whole system is very similar to that of the DVD alone, as depicted in Fig. 3, demonstrating that the tag is actually using the metal layer of the DVD as the main radiating element. Radiation efficiency for the system remains reasonably high, with a value of 23% at 885 MHz, resulting in a maximum gain value of –2.4 dB. According to these results, it is possible to estimate a maximum theoretical read range of 5.6 m (considering τ = –0.2 dB, P_{th} = –13 dBm and *EIRP* = 4W), on the basis of equation (2).

In order to compare the results, a simulation of the tag without the dielectric substrate was performed. The reflection coefficient amplitudes are very similar (Fig. 6(a)), and the upward shift introduced by the substrate is only 3 MHz. Antenna gain for the tag without substrate is –2.7 dB, resulting in a read range of 5.4 m.

It is worth to mention that, due to the degrees of freedom in the problem, infinite solutions for C_{tag} and L_{tag} do exists. However, each solution produces a different impedance behavior over the frequency band. More precisely, the bandwidth of the tag is strictly related to the choice of the final solution. Since the tag can be modeled as a series *LC* resonator, bandwidth is maximized by minimizing the inductance value, which it implies a very wide inductive section, and maximizing the capacitance value, which implies a very large coupling area. In practical terms, this means that a tradeoff between geometrical layout issues and bandwidth performance must be chosen.

IV. Fabrication and Measurements

A. Experimental setup and read range equations

The measurement setup consists of an *Agilent N5182A* vector signal generator, capable of generating RFID interrogation frames, connected to a TEM cell by means of a 50 Ω coaxial cable. A circulator is used to send the backscattered signal from the TEM cell to an *Agilent N9020A* signal analyzer, in order to decode the digital RFID frames generated by the tag, which is placed inside the TEM cell and oriented along the maximum directivity axis. To measure the tag read range, an RFID interrogation frame is sent to the TEM cell at different power levels, in order to determine the minimum power level P_{min} required to activate the tag, that is, to receive a backscattered response frame. An electric field probe is then placed at the tag position in order to measure the root mean square of the electric field E_{rms} generated by the interrogation frame at the power P_{min}. Therefore, E_{rms} is the minimum electric field required for the tag operation, and it is possible to calculate the read range directly from its value. In fact, the average power density *S* associated to a plane wave is determined from the value of the electric field E_{rms} according to

$$S = \frac{{E_{rms}}^2}{\eta} \quad (3)$$

Fig. 7. The fabricated tag, mounted on a DVD+R disc.

where η is the intrinsic impedance of free space. For a radiating antenna it is possible to calculate the far field Poynting vector module in a given direction as

$$S = \frac{P_t \cdot G_t}{4\pi r^2} = \frac{EIRP}{4\pi r^2} \quad (4)$$

where P_t is the total transmission power, G_t is the antenna gain and *r* is the distance from the antenna. Thus, the read range *r* can be obtained by equating (3) and (4), resulting in

$$r = \frac{\sqrt{30 EIRP}}{E_{rms}} \quad (5)$$

The method described above is then repeated for each frequency of interest (e.g., at 5 MHz steps) in order to obtain the read range in the whole UHF band.

B. Experimental results

To validate the simulated results, the layout described in section III-B was fabricated by means of a PCB drilling machine (LPKF-H100). The measurements (not shown) present a frequency shift of the tag response, with a read range peak at 955 MHz. This effect has been attributed to the intrinsic indetermination of the electrical properties of the DVD materials at the UHF band, and to the simplifications made in the modeling of the disc. In fact, unlike most substrates used for tag implementation, DVD disc materials are not intended for microwave design. Therefore, manufactures neither report nor control their electrical properties. Moreover, as discussed in section II-B, some geometrical parameters are not specified as well (e.g., the thickness of the reflecting layer).

Based on the measured results, a second layout of the tag was synthetized and fabricated in order to correct the frequency shift. The matching position has been easily adjusted by simply tailoring the length l_C of the tag capacitance. The corrected value of the geometrical parameter is l_C = 26 mm. The final tag, mounted on a DVD+R disc, is shown in Fig. 7.

The measured read range of the new layout, depicted in Fig. 8, shows the curve correctly centered around 885 MHz, with a

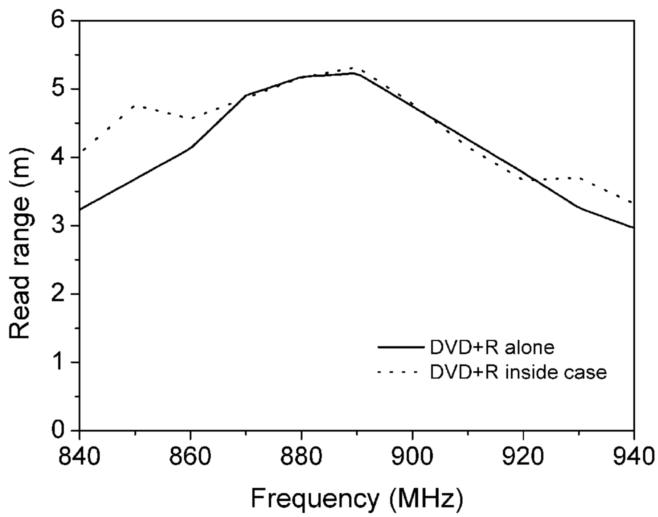

Fig. 8. Measured read range of the final tag mounted on a DVD+R disc.

peak value of 5.2 m, which is very close to the 5.6 m predicted from the simulation. Furthermore, the results reveal that the read range is above 3 m in the whole RFID-UHF frequency band, confirming that the tag is capable of worldwide operation with very good performance.

A second read range measurement involved the DVD+R placed inside its standard plastic case. Comparing the curves (Fig. 8), it can be concluded that the presence of the box has small effect on the final read range.

It is worth to mention that, although the design was aimed at simplifying the mass balancing stage (e.g. minimize the required mass, simplify the calculation of its position), the presented tag was fabricated without the balancing element. This was partly due to fabrication issues, and partly because our tag is intended to be a prototype, since it uses a microwave substrate and a very large RFID chip packaging (SMD-TSSOP).

V. Conclusion

In this paper, a novel strategy for the design of UHF-RFID tags mounted on optical discs has been presented. The main advantages of the described method are the substantial improvement in the read range and the simplicity of layout synthesis and geometry. Moreover, the radiating element is the metallic layer of the optical disc. As an example of application, a tag for DVD+R discs has been designed and fabricated. The experimentally measured read range has a peak value of 5.2 m, very close to the 5.6 m predicted by electromagnetic simulation. In addition, the read range is above 3 m in the whole RFID-UHF band, that is, one order of magnitude higher than the read ranges of conventional DVD tags reported in the literature [6,7]. These results confirm the validity of the proposed circuit model of the optical disc, the coupling strategy between the ASIC and the radiating element, and the equivalent circuits of either element, which are at the basis of the design approach.

The potential of the presented methodology is clear on account of the RFID chip used in the design (the one available in our laboratory), that has a relatively low performance in terms of activation power (–13 dBm), as compared to the latest commercially available ASICs (e.g. [15]). Therefore it is possible to significantly improve the read range by considering the latest RFID chips available in the market.

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