Laminated Glass UHF-RFID Antenna for Automotive Applications

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Abstract—This paper presents a new technique for UHF RFID antenna integration with a great impact on the automotive industry. The antenna has been optimized in HFSS and the prototype has been laminated and measured, in between two thin glass slices. The design takes into account the aspects related to the automotive safety glass, used for the windscreens in front of the automobiles. The paper proposes the use of aluminum sheets for the active element of the antenna together with three glass layers as substrates. This approach exhibits excellent results and could be applicable for vehicle long-range identification (AVI) or for cars tracking and localization.

Keywords—Antenna design, HFSS, UHF-RFID, RFID-antenna

I. INTRODUCTION

RFID technologies have tremendous potential in the automotive industry, a potential not yet exploited to the limit. The paper follows the ongoing efforts of some of the leading research work toward the next generation of RF sensing with many applications on the Internet of Thing (IoT) [1]. The focus of the paper is on the UHF-RFID antennas which are operating in the 860-960 MHz band. An antenna is a reciprocal device, although, the design technique follows different paths when one is going toward tags optimization or else toward active readers. Nevertheless in automotive engineering one has to take into account a totally different approach because of different environmental constraints. For example, using the windscreen as RFID antenna tags support, the space is not limited as in the case of passive tags usage for domestic applications. The antenna enlargement increases the effective area of the radiator and becomes more energy capable. The detection range increases as well with the antenna gain and size.

Laminated antennas are no longer under a patent claim since 1982. Nevertheless, some products in this respect have emerged in the automotive industry with many other domestic applications. Printed antenna technology has also a great potential using organic paper [2]. Laminated paper is also envisioned as a new material in the RFID domain with applications on contactless credit cards together with laminated polyesters. The polyester is mainly used for headlamps. The headlamp tags can be affixed to the front headlamp of vehicles. Although the headlamp technologies incorporate UV-coated windshields that may bounce back RF transmissions. The new RFID applications enable traffic management, another key issue for parking or for traffic fluency analysis. Specific applications are related to fleet management, traffic congestion, car rental or in anti-theft

protection mechanism. Mainly, these technologies are in use in Germany for the moment and some are under testing in other EU countries. An RF In-Car device enables transmission of telemetry data via ODB port from inside to outside the car using an ISO-18000-6C I2C chip (UHF RFID between 860 to 960 MHz). The paper proposes a new laminated antenna glass approach under the ISO 18000-6C/B regulation constraints. An archetypal RFID system consists of a reader device which could be mobile or fixed and a transponder known as “tag”. The antenna is integrated into the tag and could be both integrated or physically separated by the reader. The tag is passive and harvests the RF energy from the reader during the handshake process. A small IC device fed directly the RFID tag chip, the antenna being soldered directly to its terminals. The lamination process hides well the tag and shields the chip as long the glass remains intact. The code stored inside the tag can uniquely identify the car ID number and other information related to the year of fabrication. The UHF RFID radio band is resistant to the interference and the device can work in the proximity of the metallic objects. This is a very important issue. Another key element that stands in favor of the UHF RFIDs is the detection range. Unlike other similar RFIDs, here, one can interrogate a tag from the distance, and the connection is based on the reflections from the tag antenna not on couplings. The tag is not fed from the near field as it is the case of the NFC devices. Likewise, many tags can be detected one after another based on an enhanced dynamic framed slotted ALOHA algorithm. Having an anti-collision mechanism and being endowed with an authentication hash-based mechanism, the system, based on ISO-18000-6C protocol may be a good candidate for the automotive platforms.

II. DESIGN AND OPTIMIZATION

One of the most interesting applications of RFIDs in the automotive industry is closely related to the start and stop and/or close and open the car doors. A UHF-RFID system, based on a reader and a passive tag has an increased detection range up to 15 meters. The passive tag is located inside the owner key and the reader antenna is located under the dashboard of the car. Being located inside the car, the detecting range is diminished significantly. The most advantageous location is in this case inside the windscreen at the top, near the inside mirror. Accordingly, the antenna must be laminated between the glass layers. This location is the most liable from the antenna perspective near the car body. The metallic body of the car can be used in the design stage in order to contribute constructively to the antenna tuning

process and its radiation pattern. Nevertheless, the antenna must be shortened to confine inside 10x10 cm square. The design stage has to take into account some aspects related to the shortening and to the bandwidth enlargement. For shortening one of the most advanced technique is to use two inductive overloads at the middle of the dipole arms. This approach encounters some losses and bandwidth degradation. To counteract the effect of the inductive loads, one parasitic element has been added. This element is closely coupled with the radiator and will not increase significantly the antenna size if it would follow the geometry of the radiator. These design aspects have been

Fig. 1 UHF-RFID reader antenna with parameters (top view)

highlighted in figure 1. Meander line inserts an inductive load at the middle of the active element shortens the physical length and lengthens the electrical one to $\lambda/2$. The dipole is shrunk to its ends to confine to the 10x10 cm square area. Those 90 degrees bends insert a capacitive load to the ends and increase the electrical length [3][4]. The two coplanar lines in the middle are cut at the quarter wavelength (QW = 48.8 mm with $\epsilon_r = 5$) of the resonant frequency of the dipole and act as a balance to unbalance BALUN device. In this respect the line fed could be an asymmetric microstrip line. The feeding line stands on other layer and is coupled to the dipole through the electric field. There is no hole through from the feed line to the active element. The lamination technology forbids any vias between layers. The coupling at the feed point is strong due to the quarter-wave line which acts as a voltage 1:1 BALUN. In this way, the BALUN attenuates the common currents that flies through the ground plane and could radiate. The impedance of the quarter-wave coplanar lines is very high at the dipole feed point and does not change the input impedance of the dipole which tends to 50 Ω . This input impedance could be adjusted due to the parasitic couplings between the bends and the ground plain through x6 parameter. The distance x6 between the bends and the ground plane has a key role to adjust the input impedance. This model is valid only when the dipole is perfectly balanced and the currents along the coplanar quarter-wave line are equal and opposes to one another. This assumption is not true when the antenna is disturbed by objects located in its proximity, other than metallic ground of the car. The effect of the external object over the range of the reader has not been evaluated in the

paper. Without question, this kind of perturbation will diminish the detection range.

In Table I, are parameters' values which were used for antenna simulation in HFSS. All values are in millimeters.

TABLE I. ANTENNA PARAMETERS FROM FIGURE 1

x1 [mm]	x2 [mm]	x3 [mm]	x4 [mm]	x5 [mm]	x6 [mm]	x7 [mm]	x8 [mm]
100	90.2	12	70	30	10	17	23
x9 [mm]	x10 [mm]	x11 [mm]	x12 [mm]	x13 [mm]	w1 [mm]	w2 [mm]	w3 [mm]
40	18	9	7	16	5	3	2

In Fig. 1 the quarter wavelength line QW is cut at 48.8 mm taking into account the length of the wave in the dielectric (glass with $\epsilon_r = 5.5$). The QW parameter was optimized to counteract the effect of the dielectric involving three layers. The microscopic gap between layers fringes the electric field and changes the QW with few millimeters.

Fig. 2 Reflection coefficient in dB

In Fig 2 is down the evolution of the reflection coefficient at the feed point with frequency. One can easily see that the antenna is efficient in between 850 to 910 Mhz, a domain that includes the designated frequencies for EU.

Fig. 3 Input impedance at the feed point

In Fig.3 is depicted the input impedance. The two markers point to the resonance of the antenna. The reactance is almost

zero as long as the radiation resistance stands close to 50Ω up to 900 MHz.

Fig. 4 Input impedance at the feed point

In Fig. 4 is shown the evolution of the input impedance on the Smith chart with frequency. The result is in good agreement with the one depicted in Fig. 3 and Fig. 2. The plot trace gets closer to the middle of the Smith chart for the resonance. The loop in the middle emerges the effect of the parasitic element which increases the bandwidth by maintaining the radiation impedance close to 50Ω .

Fig. 5 3D Antenna radiation pattern

Fig. 5 reveals the radiation pattern of the antenna. The result stands in favor of the lamination technique that inserts an aluminum sheet between two glass layers. Between layer 1 and 2 stands the slice depicted in Fig. 1 and between layer 2

and 3 is the feed line. The antenna exhibits 4.8 dB gain and points toward the radiated beam along with the glass slices. That means that the dispersions favor the radiation and due to its position at the top close to the inside mirror bounce the wave outside in front of the car. The radiation pattern must be disrupted by the body of the car but this was not for the moment the focus of this paper.

Fig. 6 3D Feed line with the ground plane (bottom view)

In Fig. 6 is highlighted the bottom face with feed line in the middle and with ground planes. This is the second sheet which is laminated between layer 2 and 3 as it was mentioned previously. This slice is also made by a thin aluminum sheet.

III. PRACTICAL IMPLEMENTATION AND MEASUREMENTS

Lamination technology is a process of manufacturing material using multiple layers. In this respect, the resulted laminated material is stronger or could be more flexible. The aluminum sheet is very sensitive to cutting. First of all, one must reinforce the aluminum sheet in order to obtain a new sheet that would be more flexible and resistant. After many experiments, the lamination successfully improves the aluminum sheet resistance when has been done between two organic paper sheets. In the process a silkscreen (a termo-text screen) has been used and a fluid glue (liguix glue). The three sheets are pressed between two rollers and laminated under-hit and pressure. The result is a semiflexible sheet resistant at cutting the edges. The active element has been cut using a mask and a cutter 24 hours after the lamination process. With its margin cut, the lamination process continues with the three glass slices. Normally laminated safety glass used in the automotive industry is using a polymer sheet (polycarbonate or acrylic plastic for high-impact protective glass) instead the organic paper. Nevertheless some adjustments should be made in order to compensate the effect of every sheet material in-between. Here the effect of the lamination only can be seen in Fig. 7. As one can remark the working frequency is shifted to the right with approximately 140 MHz. This shift can be compensated by lengthening the antenna with few millimeters. The measurements are taken using an antenna vector analyzer and highlight the effect of the lamination. Marker 1 point to the frequency where the

impedance matching occurred. As one can see the return loss exhibits good impedance matching results close to $50\ \Omega$ as it is the case in the HFSS simulations.

Fig. 7 Measured -RL (return loss inverted) after lamination process – working frequencies are shifted to the right with 140 MHz

Fig. 8 Laminated UHF-RFID antenna on aluminum organic paper (first lamination process)

After the first lamination process made between organic paper and aluminum sheet the antenna is cut and placed between the two glass layers (see Fig. 8). The second lamination process proceeds on with the glass and with the aluminum laminated paper. The ongoing process is followed by the same procedure with the layer shown in Fig. 6 (the feed line). Finally, there are two glass layers and two aluminum paper layers laminated in two stages.

IV. RESULTS AND CONCLUSIONS

The presented work comes with achievements related to the lamination technique together with practical implementations of the UHF-RFID antenna in the automotive industry. The new technique presented in the paper is the result of many experiments and testing. The lamination process described in the paper is revealed in two stages involving organic paper with aluminum and glass as well as laminated aluminum paper. The organic paper has successfully been used at printed antennas in [6]. The aluminum sheet is a ubiquitous material which could be replaced easily with other sheets like copper, silver or gold. After the measurements, it is stated that the tuning frequency will be shifted with approximately 140 MHz to the right of the simulated one. The simulation process in HFSS could not emulate the lamination effect due to its complexity [7]. The paper studies, only its effect over the tuning frequency, and antenna bandwidth. Any other disturbance [8] like car body presence or other materials near the antenna body are neglected for the moment. The frequency shift does not bring many technical issues because it could be compensated easily by lengthening the antenna with few millimeters. There was no visible effect over the antenna bandwidth. Nevertheless the design process must have taken into account at least the lamination effect revealed by measurements. On radiation pattern, the effect of the lamination could be negligible but this is beyond any means without measurements in an anechoic chamber. The author of the study considers this effect the least rated, below the frequency shift effect as importance. Nevertheless tapper studies must be taken further to improve the technique, and to confine to the demands of the automotive expectations.

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