Bottle Packaged Wine Product Detection By UHF RFID Systems

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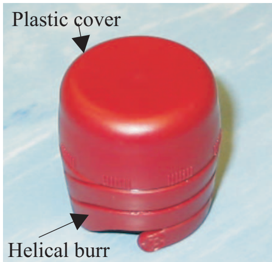
Abstract — **A new invention of wine closure is introduced. By means of this closure, a UHF RFID application for a bottle packaged wine product detection is realized. The application is realized by designing a tag based on a meander line dipole antenna, according to the shape of the new wine closure, so that the tag can be inserted into the closure with good radiation performance. Moreover, this is the first RFID tag using the meander line monopole antenna. The experiment shows that the bottle packaged wine product labeled by the tag can be detected at about 1.5m distance, which is much longer than previously reported on wine product detection.**

1 INTRODUCTION

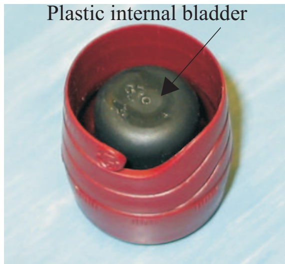
RFID is a type of automatic identification technology making use of radio waves. RFID systems have been widely used in many areas such as supply chains and airport luggage management. However, some items which are composed of moisture or metal, are very difficult to be identified by RFID systems, especially difficult by RFID systems operating at UHF band (860MHz-960MHz), because of the involvement of metal and water. Moreover, in supply chains, there are large numbers of such kind of items, e.g., coca cola can and wine.

This paper intends to provide a feasible way of detecting bottle packaged wine products by UHF RFID systems. Wine is usually packaged in glass bottles and sealed by a metal or cork closure. The packaging method and the fact that wine contains a large amount of moisture make the detection of wine by a UHF RFID system difficult. As we know, there are no publications discussing the detection of the wine sealed by either cork or metal closures via a UHF RFID system. The invention of a new closure by Zork Inc. [1], as shown in Figure 1, introduces the possibility of bottle packaged wine products' detection by RFID systems.

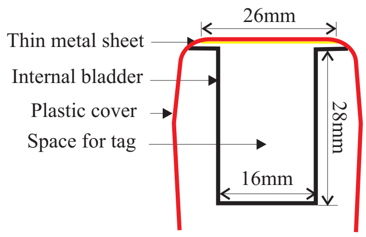
As shown in Figures 1(a) and 1(b), the Zork closure is composed of three parts, i.e. thin metal sheet, plastic internal bladder and plastic cover. The plastic cover is the only visible part when the wine is packaged. At the bottom of the plasitic cover, there is a helical burr for the convenient unpacking purpose. The wine is isolated from the outside atmosphere by the internal bladder which is a hollow cylinder. The thin metal sheet is involved here to further preserve the quality of the wine. As illustrated above, this closure is meant to 1) keep the wine in good condition, since the internal bladder and the metal sheet can isolate the wine from the air effectively. Even when the wine is unpacked, the closure can be reused and still works well; 2) unpack the wine easily by tearing the helical burr of the closure. The space in the internal bladder of the closure can be made use of for placing an RFID tag. Additionally, except the metal sheet, most of the materials composed of the closure is plastic which does not interfere with the operation of RFID tags. As mentioned before, the internal bladder is a hollow cylinder which internal diameter and height are 16mm, 28mm respectively as marked in Figure 1(c).



(a) Erect Zork closure



(b) Conversed Zork closure



(c) Scenograph of Zork closure

Figure 1: Illustration of the Zork closure structure.

Some research work on the closure in terms of RFID applications has been done by Leong [2]. He designed two antennas which can be inserted into the internal bladder of the Zork closure. One is a multi-turn coil antenna for the HF RFID application. The other is an electrically small loop antenna for the UHF RFID application. However, the maxi-

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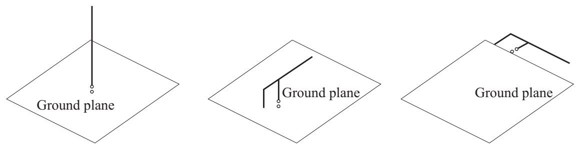
mum HF tag reading range based on the multi-turn coil antenna is only 150mm, because the HF tag is energized in the near field zone. Moreover, the UHF tag's reading range based on the electrically small loop antenna is also limited within 300mm, since the loop antenna's input resistance is usually much smaller than that of the tag chip attached. This incoherence leads to impedance miss matching condition and certainly poor power transmission from the antenna to the chip. The other factor impeding the long reading range is the metal sheet at the top of the Zork closure which can interfere with the radiation of the tag antenna.

The paper intends to design a new UHF antenna based on meander line monopole antenna (MMA) which can be inserted into the internal bladder of the closure and achieve a long reading range (>1m) with low price. Moreover, this meander line monopole antenna can also be used in other RFID applications which allow a compact three dimensional tag deployment rather than an unlimited two dimensional tag deployment. To our best knowledge, it is the first UHF RFID antenna based on meander line monopole antenna.

The outline of this paper is as follows. Section 2 introduces the basic features of meander line monopole antenna. In Section 3, the antenna optimization process and results based on simulation software Ansoft HFSS are discussed. In Section 4, the input impedance and reading range of the designed antenna and tag are tested respectively. Finally, in the last section, conclusions are drawn.

2 MEANDER LINE MONOPOLE ANTENNA

Monopole antenna (MA) has been invented for decades. The model of a monopole antenna is shown in Figure 2(a). The length of the monopole is about one quarter wavelength. The insertion of the ground plane allows the monopole antenna to radiate above metal surface which cannot be achieved by the dipole antenna. Meanwhile, the monopole antenna becomes a 3-dimensional structure because of the ground plane size, rather a 2-dimensional structure as the dipole antenna is. The 3 dimensional feature impedes the monopole antenna's application. In order to obtain low profile performance based on monopole antenna, part of the monopole is bent to be parallel with the ground plane as shown in Figure 2(b) [3], which is called Inverted F Antenna (IFA). For even further reduction of the IFA's height, a coplanar inverted F antenna (CIFA) is invented as shown in Figure 2(c) [4]. According to the analysis above, the developing trend of monopole antenna is to reduce its height, in other words, to reduce the volume of the antenna or transfer the monopole antenna from 3 dimension to 2 dimension. However, this reduction of the height of monopole antenna is at the expense of radiation efficiency and more significantly, the low profile feature of IFA and CIFA can only be achieved with relative large ground plane as shown in Figure 4. The ground plane of IFA and CIFA is hard to be fitted in the Zork closure as discussed in Section 1.



(a) MA (b) IFA (c) CIFA

Figure 2: Monopole antenna and its derivations

Half wavelength dipole antennas are commonly used in RFID tag antenna design. However, for UHF RFID, half wavelength is about 150mm which is too big to be implemented in most of the applications. Hence, minimized tag antenna design is desired. The size reduction of the dipole antenna is realized by loading a few meander lines on it, as shown in Figure 3 which is called meander line dipole antenna (MDA). The loaded meander line generates more inductance than the straight wire with the same length as the meander line does, therefore, the loaded meander lines can reduce the length of the half wavelength dipole antenna. Hence, the compactness of MDA is positively related to the meander's size and the number of meanders loaded. However, the added meander lines will bring extra loss resistance rather than radiation resistance, hence the radiation efficiency is negatively related to the the meander's size and the number of meanders loaded. The size of the internal bladder in the Zork closure is too compact to fix in an MDA with acceptable radiation efficiency.

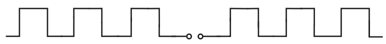


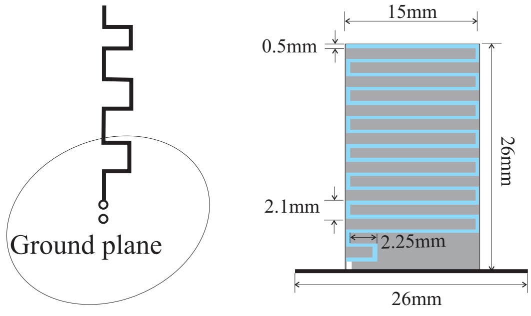
Figure 3: Meander Line Dipole Antenna.

This paper proposed an antenna form which is named as meander line monopole antenna (MMA) and is shown in Figure 4(a). Apparently, it is the combination of monopole antenna and meander line dipole antenna (MDA). The circular ground plane is adopted in Figure 4(a) according to the structure of the Zork closure. The type of antenna reduces one of its dimensions by expanding the other two dimensions (the size of the ground plane) compared with the length of the MDA. The MMA makes full use of the 3-dimensional space in order to keep the antenna size small and meanwhile the radiation remain efficient. Most importantly, the shape of MMA is more suitable to be fitted in the Zork closure's internal bladder than other candidates according to the illustration in Figure 1(c). The number and size of meander lines to be used is determined by the resonant frequency, desired input impedance and the size of the ground plane. The tag antenna based on this MMA antenna is meant to adhere to the Australian RFID standard which allows antenna to be operated within a 6MHz band from the centre frequency of 923MHz. The input impedance of the designed MMA should be around 13+j150 Ω to conjugate match the chip output impedance. The size of the ground plane should be as large as it can be fitted in the closure, since the larger ground plane can enable the meander line antenna above to achieve more inductance and thus reduce the meander line's size. The size and number of the meander lines loaded is optimized by the simulation software HFSS. The optimization process and results are discussed in Section 3.

3 ANTENNA DESIGN PROCESS

As introduce before, the antenna is designed based on the simulation software Ansoft HFSS. Since this antenna is meant to be fabricated on FR4 board, which thickness is 1.6mm, dielectric constant is 4.4 and loss tangent is 0.02, to achieve low price. The radiation element is composed of copper. In addition, the antenna's dimension is constrained by the internal bladder's size as illustrated in Figure 1(c). By inputting these parameters into the simulation tool and considering the dimension constraints, the antenna is optimized in terms of input impedance and gain at the center frequency 923MHz. As introduced before, the input impedance of the antenna should be around 13+j150 Ω and the gain should be the larger the better. The form of MMA shown in Figure 4(a) is optimized and shown in Figure 4(b). In Figure 4(b), the blue meanders present the radiation element composed of copper, the grey rectangular is FR4 board. The black bonded line at the bottom denotes the circular ground plane which diameter is 26mm. This MMA will be turned upside down when it is deployed in the Zork wine. The white rectangular between the terminal of the copper wire and the ground plane is reserved to attach an RFID chip. The size of this optimized MMA has been marked which can be fitted in the Zork closure according to the illustration of Figure 1(c).

The input impedance as the function of frequency is exported from HFSS and shown in Figure 5. The y axis presents the impedance which unit is ohm.



(a) Sketch of MMA (b) Optimized MMA

Figure 4:

The x axis presents the frequency which unit is MHz. The red curve denotes the imaginary component of the impedance and the blue curve denotes the real component of the impedance. The figure shows that the input impedance of this optimized antenna at 923MHz is 33+j150 Ω. The MMA's gain pattern is similar to that of the half wavelength dipole antenna and its maximum gain value is about 0.4.

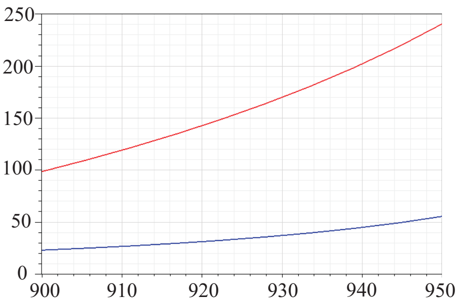


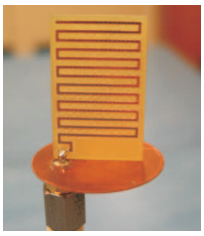
Figure 5: The input impedance of the optimized MMA as the function of frequency.

4 EXPERIMENT

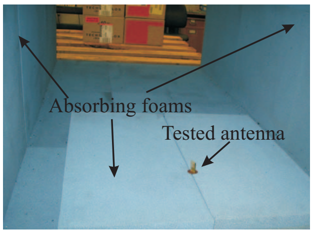
In this section, the MMA shown in Figure 4(b) optimized by simulation is fabricated and tested in terms of its input impedance and reading range in order to validate the design.

First, the input impedance of the MMA is measured by attaching it to a coaxial cable and connecting the cable to the network analyzer as shown in Figure 6(a). The fabricated antenna which has an extra substrate margin is slightly different from the one shown in Figure 4(b) which does have the margin. The extra margin is required by the fabrication process of the laboratory workshop which could be eliminated when it is manufactured elsewhere. It is believed that this minor difference is not able to affect the results.

Since the ground plane of the MMA is too small to avoid the effects from the underneath cable and the reflection from the testing environment should also be eliminated, the measurement is conducted in an electromagnetic shielding tunnel which is surrounded by some absorbing foams as shown in Figure 6(b). These absorbing foams are manufactured by the Emerson & Cuming company for the frequency range from 600MHz to 4GHz and can achieve maximum 22dB reflectivity around 1GHz. Two more this kind of foams are deployed beside the tested antenna to cover the coaxial cable. The input impedance of the MMA in the form of Smith chart is obtained and shown in Figure 7 in which at 923MHz, the tested impedance is about 45+j91 Ω. The value is reasonably similar to the simulated value 33+j150 Ω. The differences may come from inaccurate assumptions of the electrical parameters of FR4 board in simulation process.



(a) Fabricated MMA under testing



(b) Testing environment

Figure 6: Test on the fabricated MMA.

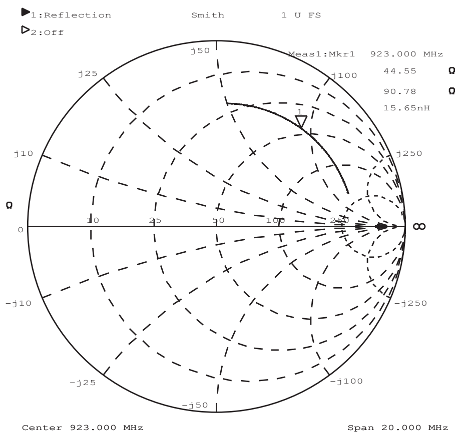


Figure 7: Smith chart in terms of the input impedance of the optimized MMA.

Secondly, the fabricated MMA is attached on a UHF RFID chip and both the antenna and chip compose a tag as shown in Figure 8. The reading range of this tag on the the bottle with wine is tested under the Australian Standard which allows the tag to work from 920MHz-926MHz and the maximum radiation power from the reader for detecting is 4W EIRP. The experiment shows that the reading range of the tag can reach 1.5m. This reading range is about 5 times more than that is reported by Leong [2].

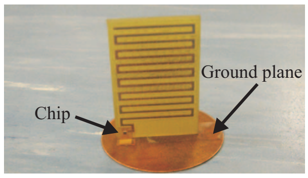


Figure 8: Antenna with chip on it.

5 CONCLUSION

The simulation and experiment show that the meander line monopole antenna could be one kind of antennas for RFID applications. Although it is a three dimensional structure, all those three dimensions are much smaller than the longest dimension of the commonly used two dimensional RFID tag antenna. This is a way of making use of space more effectively. It is suitable to be adopted in some RFID applications which allow three dimensional tag deployment but are difficult to be fitted in a two dimensional tag. Particularly, in the bottle packaged wine product detection, the long reading range detection is realized and tested based on the meander line monopole antenna combining with the Zork closure.

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