A SMALL PASSIVE UHF RFID TAG FOR LIVESTOCK IDENTIFICATION

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Abstract — RFID has its many applications, one use of this technology is for livestock identification. Animals such as cattle and sheep are tagged for purposes such as disease control, breeding management and also stock management. In this paper, a small passive RFID tag that can be attached to an animal's ear and operating at UHF is presented. This paper covers the theoretical design including simulations and the practical implementation of this tag. Significant results obtained from simulations and laboratory testings of an animal ear tag are included in this paper.

I. INTRODUCTION

A Radio Frequency Identification (RFID) system consists of tags, one or more readers (or interrogators) and a network system for data handling. The tags and readers communicate with each other via radio waves. RFID has existed for more than 20 years, but it is only in recent years that it has gained significant popularity for object identifications in various supply chains. RFID has also been applied to the livestock farming industry for disease control, breeding management and stock management [1].

The application of RFID in livestock identification has led to demands for small RFID tags that can be attached to or in animal ears (animals which are tagged are usually cattle and sheep). Existing RFID tags for this application are passive and mostly operate in the low frequency (LF) region [2]. However, LF tags can only be read at close range and may not perform well when multiple tags are simultaneously present in the interrogation field. Hence, attention is now turning to the use of UHF tags for livestock identification. UHF tags not only give better read range, but also support higher data rates.

In this paper, a small simple passive RFID animal ear tag operating in the frequency of 915 MHz (UHF) is presented. In the following section, a brief background theory on the tag antenna and chip used in our design, as well as the theoretical and practical design topology used is given. The third section contains simulation and laboratory testing results of the designed tag. This is then followed by a discussion of the strengths of the design and details of its practical implementation before conclusions are presented in the final section.

II. THEORY AND DESIGN

A. Tag Antenna and Chip Basics

The antenna chosen for the animal ear tag is a loop antenna. Fig. 1 shows a loop antenna with loop diameter D and wire of diameter d. A loop antenna is chosen since it does not have sharp edges and can be fitted on the sheep's ear relatively easily as compared to a rectangular or square antenna. An electric dipole antenna is also not as feasible as compared to a loop antenna. The problem with electric dipole is that a half wave electric dipole for the operating frequency would be too big in size. A small electric dipole can be used but experience shows that it is difficult to match.

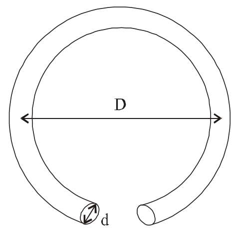


Fig. 1: The proposed loop antenna

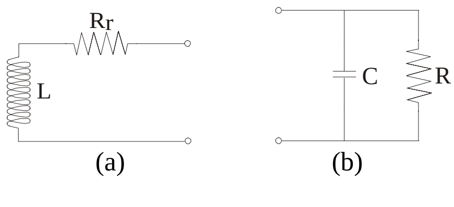


Fig. 2: Equivalent circuit for (a) a loop antenna; (b) RFID tag chip

The equivalent circuit of the loop antenna is as shown in Fig. 2a. Referring to this circuit, R_r is the radiation resistance of the loop antenna while L is the inductance of the loop antenna. On the assumption of uniform current flow around the periphery, the radiation resistance R_r of the loop antenna can be calculated using the expression [3]:

$$R_r = 20\pi^2(\beta a)^4 \quad (1)$$

On the assumption of skin currents flowing on the surface, the inductance L of the loop antenna can be calculated using the following expression [3]:

$$L = \frac{\mu_0 D}{2}\left[\ln\left(\frac{8D}{d}\right) - 2\right] \quad (2)$$

Fig. 2b shows the equivalent circuit of the RFID tag chip, which can be represented by a resistor R and a capacitor C in parallel. The value for R and C used in the analysis and design of the animal ear tag in this paper is 1.3kΩ and 1.15pF respectively.

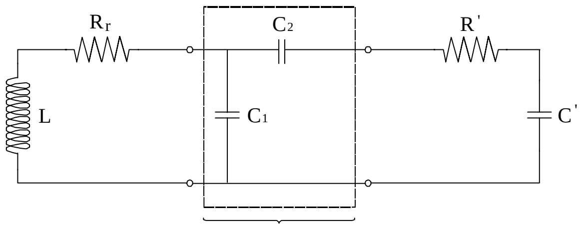
B. Tag Design

The operation frequency of the tag is in the UHF band. For the purpose of design calculations, the frequency of 915 MHz has been chosen. In the initial design, the loop antenna diameter was made approximately 2.2 cm using 0.2 cm diameter round wire (i.e. D = 2.2 cm and d = 0.2 cm). Referring to Fig. 2a and refering to equation (1) and (2), the radiation resistance R_r of the loop antenna can be calculated to be 0.39 Ω and the value of inductance L to be 34.24 nH.

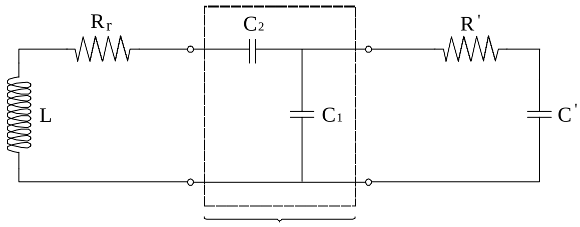
The parallel RC circuit for the RFID chip equivalent circuit, as shown in Fig. 2b can be transformed into the series equivalent circuit consisting a lumped resistance R' and a lumped capacitance C'. The R' and C' values can be calculated to be approximately 17.36 Ω and 1.17 pF respectively based on the R and C values stated above.

Hence, at 915 MHz, the source impedance, i.e. antenna impedance, $Z_{antenna}$ is 0.39 + *j*199 Ω while the load impedance, Z_{load} is 17.36 – *j*149.2 Ω. We know that, the maximum power transfer will occur when the source impedance is equal to the conjugate of the load impedance. Hence, a matching network is required to achieve a reasonable power transfer.

Fig. 3 shows two different matching networks topologies that are used in our design. The value of C_1 and C_2 can be computed numerically or using Smith Chart. The computed values of C_1 and C_2 for these two topologies that we considered are shown in Table 1.



(a)



(b)

Fig. 3: (a) A lossless L-matching network with a shunt capacitor (C_1) and series capacitor (C_2) for matching; (b) Another lossless L-matching network with different arrangement of C_1 and C_2.

Table 1: Numerical Values of C_1 and C_2 in matching networks

	Matching Network	
	Fig. 3a	Fig. 3b
C_1 /pF	0.743 pF	6.557 pF
C_2 /pF	0.148 pF	0.998 pF

C. Design for Practical Implementation

The design was started using a loop antenna and a matching network designed as discussed in the previous sections. The next step was to consider the practical implementation of the tag. It was decided to implement the design on a very thin substrate with copper layer on both sides. The front and rear view of the final product is shown in Fig. 4. The design utilises the matching network shown in Fig. 3b. This does not mean the matching network shown in Fig. 3b is better than that in Fig. 3a. Both matching networks are equivalent at the resonant frequency, the reasons the one shown in Fig. 3b was chosen was because it is easier to implement by the method used here.

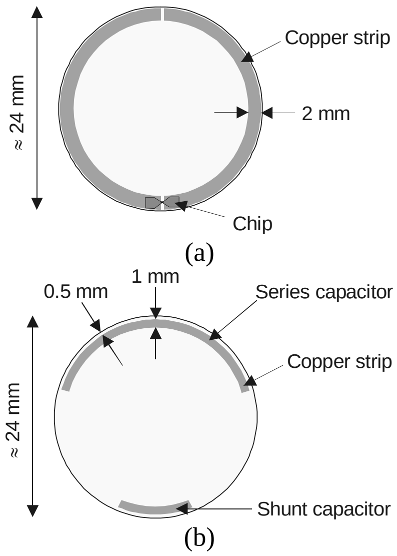


Fig. 4: (a) Front view; (b) Rear view of the sheep ear tag

The copper strips on the rear side are to provide series and shunt capacitance to the circuit, acting as the matching network. It can be trimmed during experiment to fine tune the circuit so that the antenna will resonate at the desired frequency, in our case, 915 MHz.

We also intended to design a tag that can be manufactured easily in huge batches. Our tag design can be made by using a copper etching process. The two strips at the rear are made to have a width of 1 mm, which is smaller than the 2 mm strip width at the front. Also, both strips are aligned about 0.5 mm from the edge. This is to allow a degree of both photo-plot and etching tolerances so that the total overlapping area would not be affected by the manufacturing process.

Our target is to produce an antenna with an impedance of approximately the conjugate of the tag chip impedance, or 17.36 + j149.2 Ω. Experience shows that a lower value of the real part of the impedance would allow the tag to perform better. Hence, the first design produced a tag with a total antenna and matching network impedance of around 6 + j150 Ω.

III. Simulation and Testing

A. *Simulation using HFSS*

Simulation was performed using the HFSS simulation software based on the designed tag antenna. The total impedance of the antenna and the matching network was simulated to be 6.5371 + j133.44 Ω and the radiation pattern is shown in Fig. 5.

The radiation pattern shows that the antenna we have designed behaves like a magnetic dipole, which was as expected, as the initial design was a loop antenna.

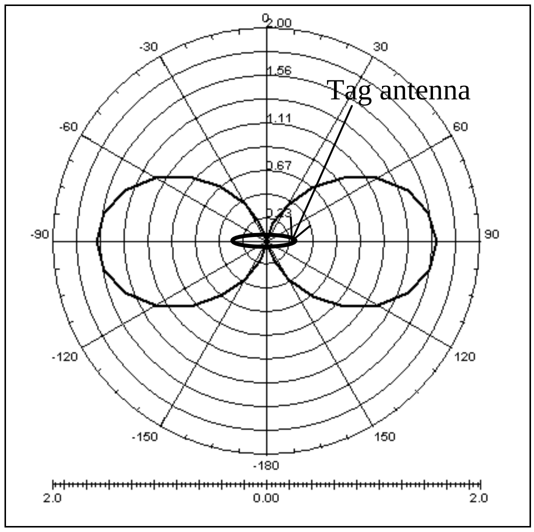


Fig. 5: Radiation pattern

B. Laboratory Testing Results

The tag was made according to the description in Part C of Section II. A network analyser was set to couple by means of a small loop to the tag, and to measure the reflection from that loop over the frequency range of 870 MHz to 930 MHz. Observing the pattern of reflection, the approximate resonant frequency of the sheep tag was determined. At the first few measurements, the resonant frequency was little over 870 MHz, which was a bit far away from the intended frequency of 915 MHz. This is because the length of the strips corresponding to the shunt and series capacitors had been intentionally made longer in order to allow adjustments to achieve a more accurate resonant frequency. The length of the strips was slowly reduced by cutting both ends of the strips, and step measurement was repeated. This process continued until the resonant frequency measured was about 913 MHz, which was considerably close to 915 MHz. At the frequency of 913 MHz, the measured return loss was approximately –3 dB using the small un-tuned 7mm diameter loop made from the centre conductor at one end of a short length of coaxial cable with +5 dBm output from the network analyser, which from experience, indicated that there should be enough power reaching the tag (and hence enough power for powering-up the tag chip).

Knowing that this animal ear tag is functioning as desired, the experiment then proceeded to find the read range of the tag (maximum distance between the reader antenna and the tag before the reader fails to detect the tag). A few polystyrene foam blocks were gathered and used for holding the sheep tag. The reader antenna radiated horizontally. The height of the tag was aligned to be at the centre-line of the reader antenna.

The distance between the tag and the reader antenna was varied to find the maximum read range of the tag. When the sheep tag was placed horizontally, the read range was about 1 m. When the orientation of the tag was changed to vertical, but the reader remained in the equatorial plane of the tag, the read range fell to slightly less than 1m. The reason that the vertical orientation was not as good was that the reader antenna was not perfectly circularly polarised (it was elliptically polarised). However, as predicted by the radiation pattern, when the tag was aligned with its axis parallel with that of the interrogator antenna, the reading distance was only a few centimetres.

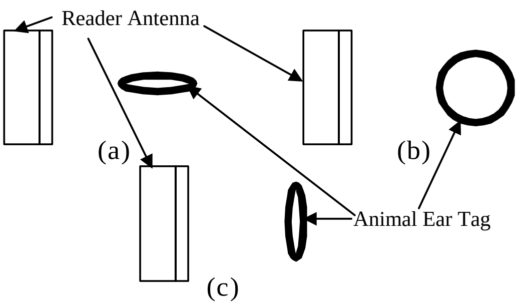


Fig. 6: Orientation of tag with respect to interrogating antenna: (a) Horizontal; (b) Vertical; (c) Parallel

The experiment was then performed in an anechoic chamber. The distance between the tag and the reader antenna was varied to find the maximum read range of the tag. When a tag was placed horizontally, the read range was about 1.42 m.

IV. Application

As mentioned before, the designed tag was intended to be used as animal ear tag (for animals such as cattle and sheep). The orientation shown in Fig. 7 was proposed for attaching tags on animal ears. As discussed in the previous section, the read range was around 1m when the tag was either vertically or horizontally oriented, as long as the planes of the tag and interrogator antenna were not parallel. Hence one of the best reader antenna locations for this application would be on top of a door arch where tagged animals pass through, with the direction of antenna facing down.

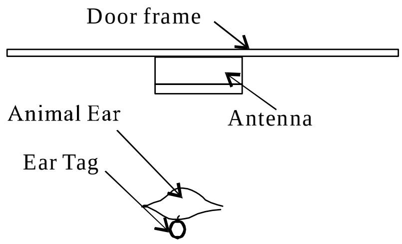


Fig. 7: Ear tag on animal ear passing through a door.

V. Conclusions

This paper has presented a simple design of a small passive RFID animal ear tag operating in UHF. This tag has been implemented and tested and the results found to satisfy the requirements of the intended application (a read range of approximately 1m with proper orientation). Future work on this animal ear tag design will include the fine-tuning of the presented design to account for possible non-linear characteristics of the tag chip used.

References

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