© 2019 IJSRST | Volume 6 | Issue 3 | Print ISSN: 2395-6011 | Online ISSN: 2395-602X
Themed Section: Science and Technology
Doi : https://doi.org/10.32628/IJSRST

Design of Thin T-Match Stub Structure Antenna for UHF RFID Tag Application for Billing System

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ABSTRACT

A thin passive tag antenna for Radio Frequency Identification (RFID) application for smart billing system over the counter using the Ultra High Frequency (UHF) range of 860-867 MHz is being presented in this paper. The structure of the tag antenna is a simple dipole antenna but with a tip loaded effect by widening the antenna ends on both sides to reduce the size of the tag. The antenna structure is further matched to the RFID chip impedance by the addition of a T-match shaped stub at the center of the antenna. Simulation is carried out using Ansoft HFSS software. The simulated result shows a good impedance matched antenna structure with reasonable return loss indicating the matching of complex conjugate impedance with the chip, strong radiation efficiency (88.1%), gain, and long range read range decent for billing system purpose.
Keywords : Antennas, Passive, Radio Frequency Identification (RFID), Tag

I. INTRODUCTION

In recent times, RFID has developed into a much advanced technology, installed in exponential rate, finding its way into various markets due to the research and development works being increasing performed in wireless and radio communication field. The success of finding its way into the market stream is due to the several advantages it poses as compared to other identification technologies such as non- line of sight operation, long read range distance, less power consumption, improved microchip for faster and multiple sensing technology, reduced human intervention etc. Some of the marketing sectors that utilizes the RFID technology are public transport system for ticket collection and booking, electronic wallet for secure cashless transaction, Smart identification cards, parking access in building, smart parking, automated tolling application, animal identification, smart libraries, smart fridge, hospitals and health care facilities, security and weapon detection etc. [1]- [3].

The RFID system is a part of the identification technology where any object attached with a tag can be identified wirelessly by the reader located some distance away. The object to be identified is provided with a RFID based microchip where the information related to the object of interest is entered in its database memory. The composition of the antenna and the chip can be collectively called as tag. On the other end, is the reader system where it has another antenna attached normally circularly polarized and continuously sent the radio frequency signals to the free space for identification of the objects. When the tag antenna arrives in the radio frequency range of the reader system, it sends the information signal back to the reader [4]. The reader decodes the information and passes the data to the middleware software for decoding and retrieving the useful information about the detected objects.

The RFID system is classified as Low Frequency (125-134 KHz), Medium Frequency (13.56 MHz), and Ultra High Frequency band (860-960 MHz) and microwave system (2.4 GHz). Both the low and medium frequency based RFID uses the inductively coupled communication where the read range distance are small (less than 1m), whereas for Ultra High Frequency (UHF) case, it uses the radiative properties of the wave and can read long distance upto 1Km [5]. Another way of classifying the RFID is the type of tag used- Passive, Semi Passive, and Active tag [6]. For this paper, the tag used is the UHF based passive tag antenna system. The reason to use the passive tag antenna is to reduce the cost factors and miniaturized size. The passive tag antenna system does not have its own power system or battery facilities, but it solely depends upon the power received from the reader antenna. Using the backscatter principle, the received power is used to turn on the chip and the tag, retrieve the information and sends the signal back to the reader using the same link.

For application in smart billing system at the shopping mall, it requires a long distance read range system, irrespective of line of sight communication, reliable and faster data exchange [7]. For longer read range, the tag antenna is modified using the concept of T-match stub for proper matching of the impedance of the chip with the tag antenna [8]. When complex conjugate has been achieved, more power can be transferred to the antenna and effectively improving the read range distance. Since the operation of the frequency used is UHF range of 860-867 MHz, radiative communication is used eliminating the line of sight deficiency. With the use of state of the art technology and high speed Alien Higgs-4 chip, it results in reliable use of the tag for smart billing system application. The antenna is thin with minimum height, perfectly mountable in the shopping cart without providing any obstacle. The goods selected by the customers can be automatically detected by the tag antenna designed, and send the information of the items selected, back to the counter. After having received the information from the cart, at the counter billing is done and the customer simply has to go and pay the bill without wasting any time. The works being carried out in this paper can be categorized into the following section: section II discusses the concept of the proposed antenna and the impedance matching procedure. In section III, the simulation and results are discussed, and finally conclusion are drawn in section IV.

II. ANTENNA DESIGN AND CONFIGURATION

The antenna designed in this paper is a typical dipole element having two terminals on either end with a chip attached at the center. But in RFID application, one of the major requirement is the reduced size factor for attaching to smaller objects. And for a dipole antenna, its resonating frequency is a function of half wavelength which for UHF band is too large i.e., for 866 MHz, the electrical length should be 17.3 centimeter (λ= c/f, length of the dipole antenna = $\lambda/2$), where c= speed of light (3×10^8), f = resonant frequency, and λ= wavelength [9]. Hence, for increasing the maximum current to flow and better radiation efficiency, the ends of the dipole antenna are tapered to increase the current flow area [10].

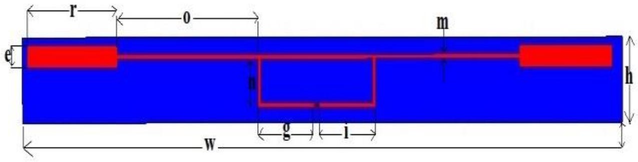

Fig 1. Structure of the UHF RFID Tag Antenna

Fig.1 shows the structure of a tag antenna made up of Taconic TLY substrate which is manufactured for properties of having a very light weight and rigid structure having Dielectric constant ε_r of 2.2, and Loss tangent, tan(∂) of 0.0009. The thickness of the substrate is 0.13mm, which is the requirement for the current application of thin tag. The length and width of the substrate used are 154mm and 10mm respectively. For radiating mechanism, the outer layer of the substrate is coated with a thin layer of copper deposits. The feeding point of the tag antenna located at the center is done with the help of Alien Higgs-4 chip attached having the impedance of (20.5 - j191) Ω at 866 MHz as per the specification [11].

The first step in any RFID tag antenna design is the complex conjugate matching of the impedance between the antenna and the RFID chip, the process which is tedious and a major challenge to obtain, as normally the antenna is matched to a 50Ω load. Hence to achieve the process of complex conjugate matching, a structure known as T-match stub is modified to the original dipole tag antenna [12]- [13]. By varying the length and width of the T-match network, the impedance of the antenna can be easily adjusted to attain the desired impedance [14]. The impedance of the microchip is generally capacitive reactance, while that of the dipole antenna is resistive. Hence using the T-match stub, the antenna impedance reactance can be tuned to make it more inductive till the impedance value matches that of the chip reactance [15]- [16]. After optimization process, these two reactance (capacitive and inductive impedance) cancels out each other leaving out only pure resistance allowing for maximum power to flow through the chip from the antenna and improving the read range parameter of the RFID tag.

After optimization process, the final geometry of the tag antenna is shown in table 1.

Table I. Geometrical Dimensions of the Tag Antenna

Parameter	Value (mm)
r	2.5
o	50
n	5.7
g	10.5
i	10.5
w	154
h	10
e	25
m	0.5

III. RESULTS AND DISCUSSION

The design simulation and measurement of various parameters of the antenna are being presented in this section to study the results and its application. The impedance of the antenna is shown in fig.2 which has been obtained after numerous parameter optimization being performed to observe the result of good conjugate matching with the RFID chip for improved return loss factor, and maximum read range distance. During optimization the parameter- n, g, and i of the T-match stub are being varied until the desired impedance are found.

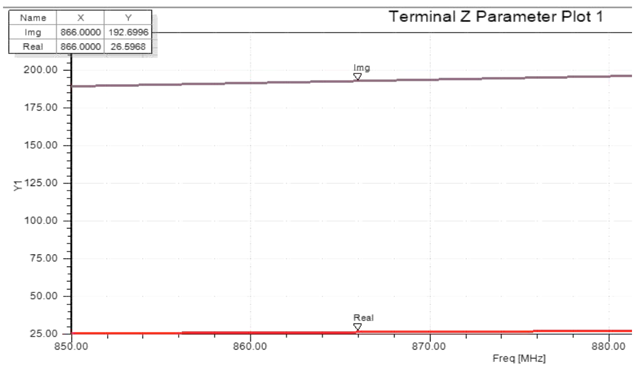

Fig 2. Tag Antenna Impedance v/s Frequency Plot

The final impedance value of the tag antenna obtained is (26 + j192) Ω, which is actually close to the chip impedance of (20.5 + j191) Ω. With this value the return loss of the resonant frequency simulated is shown in fig.3 having a value of -36.84 dB at 862.5 MHz, covering easily the range of UHF frequency band.

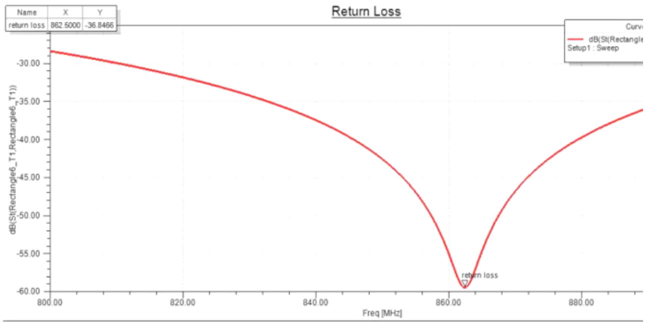

Fig 3. Reflection Coefficient of the Tag Antenna

Fig. 4 and fig. 5 shows the simulated 3-D gain of the dipole tag antenna which shows the gain of the tag antenna to be -5dB, and 2-D radiation pattern along the phi = 0° plane pattern which is directional. Also analyzing the antenna parameter in HFSS has shown that the antenna efficiency is about 88.1% due to the effect of tapering the ends of the dipole antenna indicating an excellent antenna performance overall.

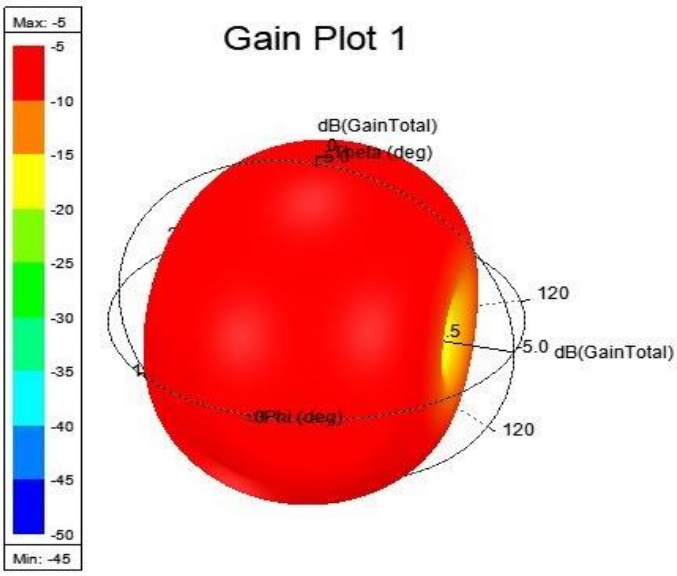

Fig 4. Simulated 3-D Gain

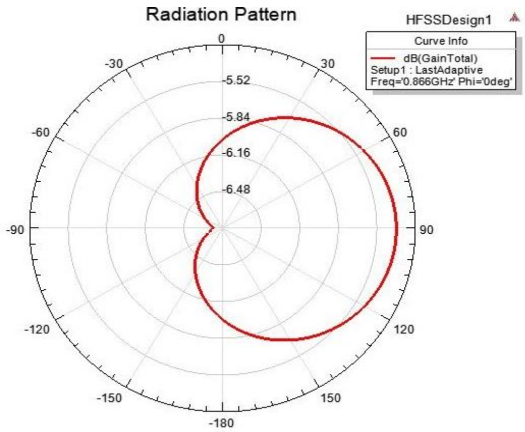

Fig 5. Radiation Pattern with Phi as 0 deg

The theoretical read range of the RFID tag antenna can be calculated by Friis free space transmission equation as given below [17]:

$$r = \frac{\lambda}{4\pi}\sqrt{\frac{P_t G_t G_a \tau}{P_{th}}} \tag{1}$$

In eq. (1), P_t and G_t are the power and gain of the reader antenna, G_a is the gain of the tag antenna, P_{th} is the threshold sensitivity of the RFID chip, and τ is the power transmission coefficient [18] whose equation is shown in eq. (2).

$$\tau = \frac{4 R_a R_c}{|Z_a + Z_c|^2} \tag{2}$$

IF we assume that $P_t G_t$ or the EIRP of the reader antenna to be 4W total; from the specification of the Alien Higgs-4 IC chip, and the threshold sensitivity of the RFID chip to be -18 dBm, and then calculating for τ from eq. (2) we can get the value as 0.986.

From eq. (1), the theoretical read range calculated for the designed RFID tag antenna is found to be 8.1 meter.

IV. CONCLUSION

This paper presents the design and study of antenna parameters using a thin RFID tag antenna which is a passive type performing over the UHF range of 860-

867 MHz is being presented in this paper. The tag antenna designed is a dipole antenna tapered at the ends for efficient antenna radiation of 88.1%. For complex conjugate matching a T-math stub is added to the antenna structure, optimizing the parameter which the final antenna impedance achieved is (26 + j192) Ω, as compared to (20.5 + j191) Ω which indicates a good conjugate matching of the tag antenna with the RFID chip impedance. The consequence of impedance which, the power reflection coefficient achieved at 862.5 MHz is -36.84 dB which is quite high as compared to the lower limit of -10dB minimum requirement for antenna to perform. The theoretical read range achieved is 8.1m, which is enough for use in application of the smart billing system in any shopping mall.

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Cite this article as :

P. Limameren Chang, Garima Saini, "Design of Thin T-Match Stub Structure Antenna for UHF RFID Tag Application for Billing System", International Journal of Scientific Research in Science and Technology (IJSRST), Online ISSN : 2395-602X, Print ISSN : 2395-6011, Volume 6 Issue 3, pp. 329-334, May-June 2019.
Journal URL : http://ijsrst.com/IJSRST196420

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