Progress In Electromagnetics Research C, Vol. 70, 175–182, 2016

SRR Loaded Compact UHF RFID Tag for Broadband Operation

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Abstract—An SRR loaded compact RFID tag for broadband operation over the UHF RFID band is presented. The tag antenna structure is composed of a dipole whose arms are symmetrically loaded with square split ring resonators (SRRs) along a short circuited strip between the SRRs. The antenna is made inductive and reduced in overall size by the SRR sections. The measured read range characteristics of the proposed RFID tag with an RFID chip Alien Higgs-3 are presented. The proposed tag operates over the entire UHF RFID band about a maximum read range of 7 meters in the entire elevation angular ranges and over wide azimuthal angular ranges.

1. INTRODUCTION

Radio frequency identification (RFID) in the ultra-high frequency (UHF) band and its supporting communication technology play a distinctive role in detecting and tracking items. This is due to its effectiveness in identifying the objects from a distance without requiring a line of sight and the ability of the RFID system to simultaneously read a massive amount of tags. RFID systems in the UHF band has become more and more popular in many applications such as access control, logistics, supply chain & product life cycle management in warehouse and many others [1].

An RFID system consists of a reader, a tag, a host computer and a supporting software system. RFID tag consisting of an antenna and a chip connected at the terminals of the antenna is the main component of the RFID system. The chip receives power from the tag antenna and responds by varying its input impedance and thus modulates the backscattered signal with respect to data stored in the chip. Proper impedance matching between the chip and the antenna is a prime requirement for achieving good read range characteristics for the tag.

Several papers on RFID tag design have been reported in literature. Rao et al. [2] presented a review of an antenna design for passive RFID tags. The design requirements, outline of generic design processes and practical applications of RFID tags were elaborated in this paper.

The main challenges in the modern RFID tag designs are to develop a miniaturized RFID tag antenna with appreciably good read range characteristics. Most of the commonly used RFID tag antennas are based on dipole structures. These RFID tags employ dipole structures with different shapes, slots and other shapes symmetrically or asymmetrically loaded in the arms of the dipole. A tag antenna designed [3] using printed dipole and H-slot matching for the UHF-RFID system was reported. Good impedance matching between the antenna and the chip was achieved by properly choosing the dimension of the H slot on the dipole antenna.

Diugwu et al. [4] presented the characteristics of an electric dipole and its complementary slot magnetic dipole for applications in RFID tag design. This paper also presented the effects of varying the strip or slot widths of an electric or magnetic dipole on radar cross-section. Comparing the performance of a designed tag with the available commercial tag was very important for the researchers to understand

Received 5 September 2016, Accepted 15 December 2016, Scheduled 10 January 2017

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the design limitations. Nikkari et al. reported the development of two dipole type RFID tags [5] with diverse geometries and compared their performance with each other and also with two commercial dipole tags.

Recently Manju et al. [6] reported an RFID tag consisting of a dipole antenna based on modified multi-fractal cantor arms for enhanced read range. Good impedance matching between the antenna and the chip was achieved by optimizing the iterated function system (IFS) transformation coefficients of the modified multi-fractal cantor arms. A dipole tag [7] with the feed areas made wider and thicker to produce a good read range performance was reported. A dipole structure [8] with a slot-coupled feed antenna for RFID tag was reported in which a dual operation was achieved by properly choosing the dimension of the coupled slot on the dipole antenna.

Many researchers have reported [9] a variety of folded dipole structures for RFID tag antennas in the UHF band. A simple UHF RFID tag antenna with a modified dipole structure was reported where the antenna had high input reactance with a simple configuration. When a small resistance and a large reactance were required for the tag antenna, a folded dipole with a closed loop structure was introduced [10]. The closed loop makes the conjugate impedance matching with the chip easier. Genovesi and Monorchio proposed [11] a three-arm folded dipole, mountable on metallic objects, which does not require any via or shorting plate in its basic configuration.

Another method was proposed in [12–14] where dipole antennas whose arms were meandered to produce a distributed capacitive and inductive reactance, and the overall dimension of the structure was slightly reduced. A meandered long patch antenna bent to several half wavelength radiating elements, mountable on metallic objects, was also reported [15, 16]. The surface currents of all the radiating elements are in phase, and this produces an enhanced gain. Important RFID tag characteristics are maximum read range and orientation sensitivity. A conjugate impedance matching between the antenna and the chip is highly essential to powering up the chip and maximizing the effective read range. It is usually desirable to have a small RFID tag printed on a single substrate with a conjugate match to the passive RFID chip.

A T-matching technique is widely used in the design of RFID tags which enables proper matching between the tag and the chip for maximum power transfer [17, 18, 26]. Split ring resonator (SRR) [19, 20] is a topic of immense interest in electromagnetics and was investigated by many researchers for various applications in antenna design. SRR consists of two concentric metal rings separated by a gap and both having splits at opposite sides. Magnetic resonance is induced by splits at the rings and by the gap between the inner and outer rings. Recently a few researchers introduced SRR models to miniaturize the tag size and produce better capacitive and inductive reactance in the RFID tag design.

A meandered dipole RFID tag with capacitive tip loading built-in with the SRR was reported [21]. The paper discussed about an antenna design with a compact size, trouble-free structure and elevated competence. The size reduction on the proposed tag antenna was done by adding a capacitive tip loading and two square SRRs. Zheng et al. reported [22] an SRR coupled compact loop antenna for mobile RFID applications. The coupling of the SRR element in the antenna miniaturized the size of the antenna.

An SRR based compact near-field antenna was reported [23] by some researchers for RFID applications. Through modifying the parameters of SRRs, researchers miniaturized the size of the antenna and operated on different UHF RFID bands. Designing an RFID tag working on a metallic surface was a challenge and was attempted by many researchers. Jalal et al. reported [24] a miniaturized RFID tag antenna which can work on metallic objects without significantly degrading the read range.

Braaten reported [25] a novel compact planar antenna for passive UHF RFID tags. Instead of using meander-line sections, much smaller open complementary split ring resonator (OCSRR) particles were connected in series to create a small dipole with a conjugate match to the power harvesting circuit on the passive RFID tag.

In this paper, we present a novel UHF RFID dipole tag in which miniaturization and broadband operation over the UHF band is achieved by symmetrically loading square SRR on both arms of the dipole and a short circuited strip in between the SRRs. The square SRR loading in the arms of the dipole antenna produces a similar effect of a series connected conventional meander-line sections, which is used in most of the RFID tags. The proposed tag operates with the entire UHF RFID bands with appreciably good read range (7 meter) in the entire elevation angular ranges and over wide azimuthal angular ranges. This novel tag is compact in size and broadband over the entire UHF RFID band for universal deployment.

2. RFID TAG DESIGN

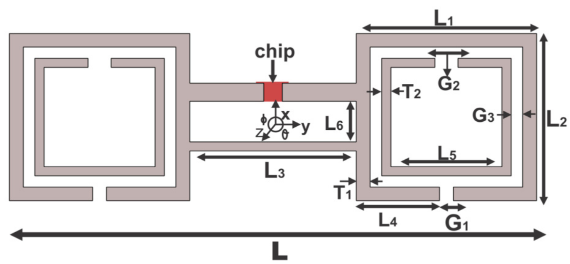


Figure 1. Schematic diagram of the proposed RFID tag.

The geometry of the proposed RFID tag antenna is shown in Fig. 1. It consists of a dipole structure whose arms are symmetrically loaded with square SRRs, and between these SRRs a short circuited strip is attached. RFID chip of impedance $27 - j212\Omega$ at 866 MHz is connected at the terminals of the antenna. The input impedance of an electrically small antenna is capacitive. Loading the SRR sections, the antenna can be made inductive, which will be a conjugate impedance match to the RFID chip. The inductance of an SRR structure is much higher than that of a conventionally used meandering section in the RFID tag, which enables miniaturization of the RFID tag.

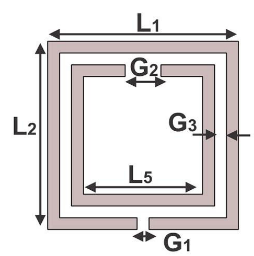


Figure 2. Square SRR structure with parameters.

The structure of SRR comprises two concentric square rings separated by a gap [19], both having splits on the opposite sides, as shown in Figure 2. A single SRR itself consists of capacitive and inductive loadings. The inductive loading 'L' is determined by the length of rings, and capacitive loading 'C' is determined by the gap between the two rings and the slit width of each rings. The capacitive and inductive loadings form an LC tank circuit, which produces good magnetic resonance and miniaturizes the tag antenna size. Several factors such as the slit width of rings G_1 and G_2, the gap between the rings G_3 and the thickness of the inner ring T_2 are important parameters of the SRR which can effectively tune the properties of the tag. The tuning of these parameters along with a short circuited strip between the SRRs is performed using the CST Microwave studio to get optimized parameters for the proposed design. The optimized parameters of the proposed RFID tag antenna are shown in Table 1.

Table 1. Dimensions of the proposed antenna.

Parameters	L	L_1	L_2	L_3	L_4	L_5	L_6	G_1	G_2	G_3	T_1	T_2
Value	55 mm	19.5 mm	19.5 mm	16 mm	9 mm	14 mm	4.5 mm	1.5 mm	3.5 mm	1.25 mm	1.5 mm	1 mm

The RFID tag with optimized parameters is printed on a 1.6 mm thick FR-4 substrate with a loss tangent 0.002 and relative permittivity $\varepsilon_r = 4.3$. The UHF RFID chip used in this design is Alien

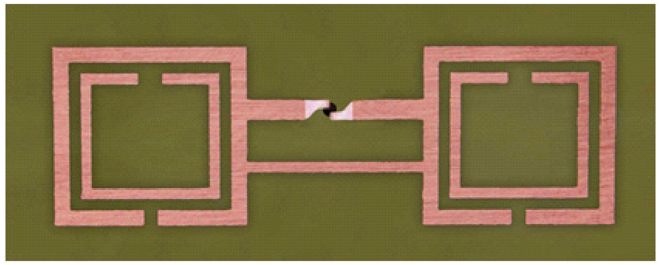


Figure 3. Photograph of the fabricated SRR loaded RFID tag.

Higgs-3 chip with impedance of $27 - j212\Omega$ at 866 MHz. Fig. 3 shows a photograph of a fabricated UHF RFID tag based on a SRR loaded dipole structure.

The read range measurements are carried out using an STA IR0507E reader with a receiver sensitivity of -80 dBm and RF power of 30 dBm with circularly polarized antennas. The maximum read range of the tag is determined by mounting the tag on a movable platform with an arrangement for placing the tag for different azimuth and elevation angles.

3. RESULTS AND DISCUSSION

The simulated results of the variations of the resistance and reactance of the proposed tag antenna with frequency are plotted along with that of the RFID chip in Fig. 4. The tag chip used in this design is Alien Higgs-3, which has an impedance of $27 - j212\Omega$ at the frequency of 866 MHz. In order to deliver maximum power to the chip, the input impedance of the antenna needs to be $27 + j212\Omega$ at 866 MHz. It is evident from the figure that a very close matching with the chip impedance is achieved at 866 MHz with a resistance value of 27 Ω and reactance value of 217 Ω.

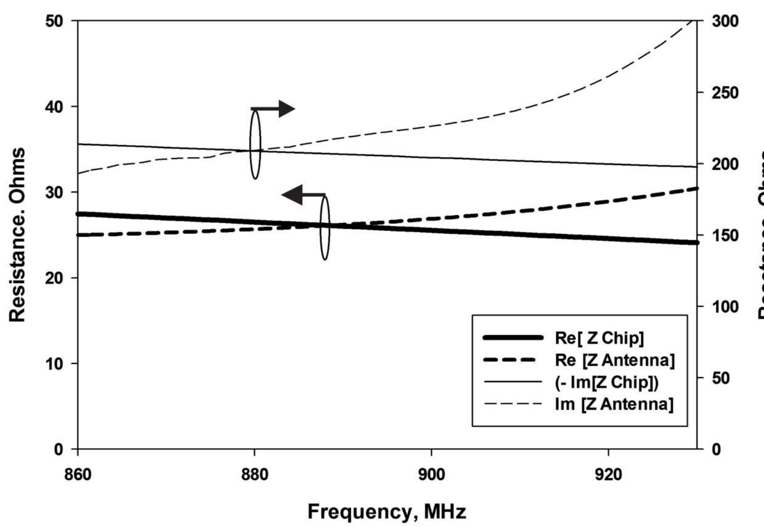
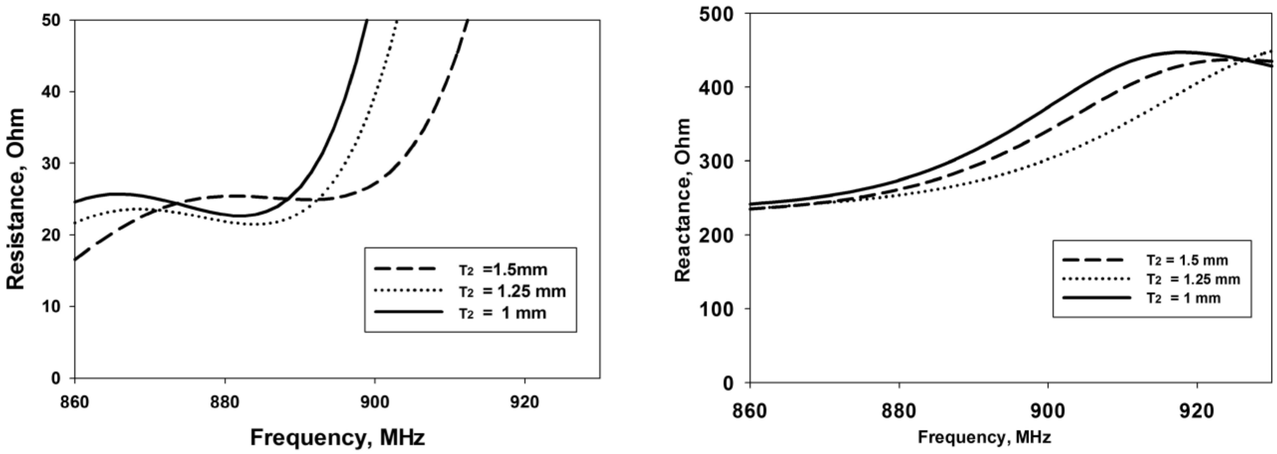


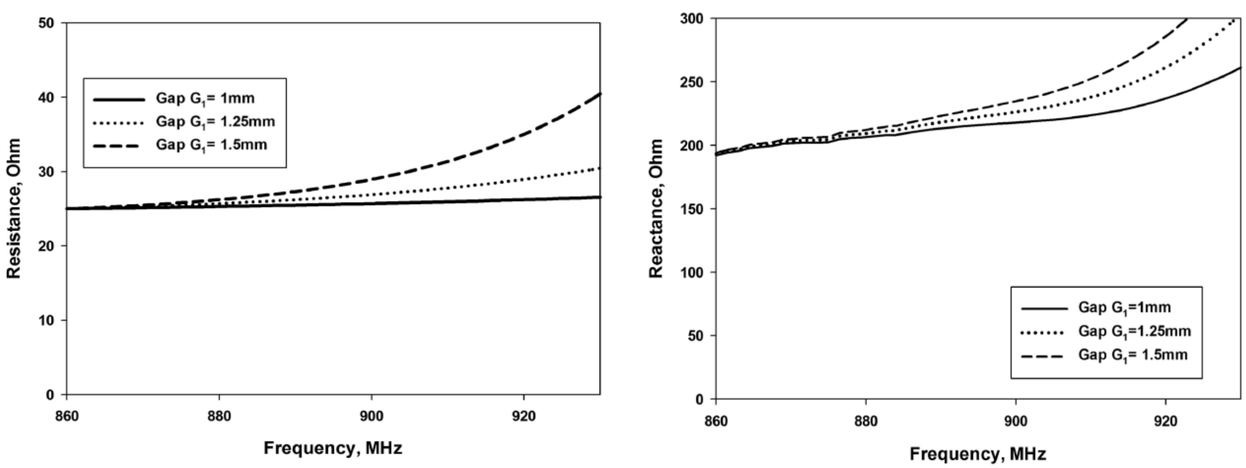
Figure 4. Simulated input impedance variation along with chip impedance for the proposed UHF RFID tag.

Figure 5 shows the effect of varying the width T_2 of the SRR on the resistance and reactance of the tag antenna with the parameters $G_1 = 0.75$ mm and $G_2 = 2$ mm. It is observed that if $T_2 = 1.5$ mm, the resistance and reactance values are 20 Ω and 239 Ω, respectively, which means that the required objective of conjugate matching cannot be attained with $T_2 = 1.5$ mm. When reducing the width of T_2, the result is an increased resistance and reactance value. When the width of T_2 is decreased to 1 mm, the input impedance of the antenna is $25 + j247\Omega$ at 866 MHz, and $T_2 = 1$ mm is fixed as the



(a) (b)

Figure 5. Variation of input impedance with frequency for different values of T_2 ($G_1 = 0.75\,\mathrm{mm}$ and $G_2 = 2\,\mathrm{mm}$). (a) Resistance Vs frequency. (b) Reactance Vs frequency.



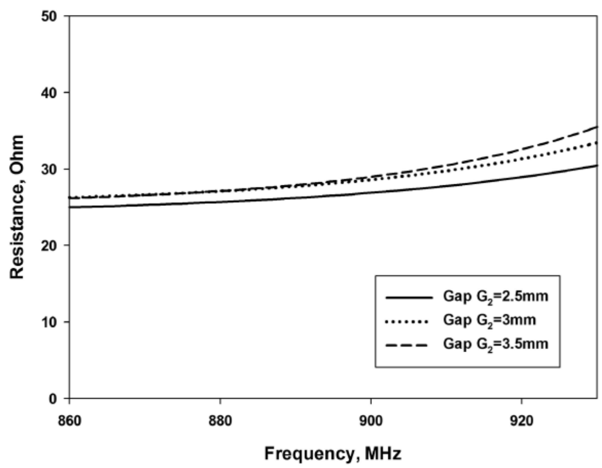
(a) (b)

Figure 6. Variation of input impedance with frequency for different values of G_1 ($G_2 = 2\,\mathrm{mm}$). (a) Resistance Vs. frequency. (b) Reactance Vs. frequency.

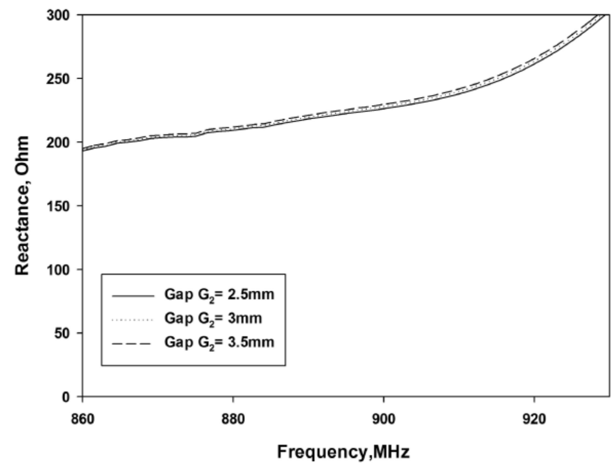
optimized value. The effect of varying the values of G_1 and G_2 on the resistance and reactance of the tag is studied, and the result is presented in Fig. 6 and Fig. 7, respectively.

Inductive and capacitive effect of SRR is created by the gap between the split rings and within the gaps of each split ring. For easy analysis, the outer ring gap is named as G_1 and inner ring gap as G_2. Fig. 6 plotted the parametric variation values of G_1 on the input impedance of RFID tag, when G_2 is fixed as 2 mm. It is seen from the graph that when the value of G_1 is varied, the resistance values are almost unchanged in the lower UHF RFID bands, and there is significant change in the higher UHF RFID bands. But the reactance values decreases to $200\,\Omega$ which is not an anticipated value.

Fig. 7 shows the variation of input impedance with frequency for different values of G_2 with G_1 kept constant at 1.5 mm. It can be seen from the graph that once the value of $G_2 = 3.5\,\mathrm{mm}$ the resistance and reactance values of the antenna are 27 ohm and 217 ohm, respectively, which is more close to the impedance of the RFID chip. From the result obtained, it is concluded that for achieving the desired input impedance and operating frequency, tuning and adjusting the parameters of G_1, G_2 and T_2 are required.



(a)



(b)

Figure 7. Variation of input impedance with frequency for different values of G_2 ($G_1 = 1.5\,\text{mm}$). (a) Resistance Vs frequency. (b) Reactance Vs frequency.

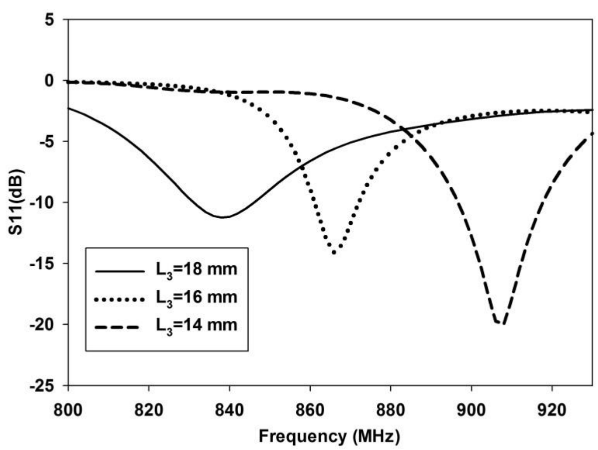


Figure 8. Simulated return loss of the proposed RFID tag antenna with parametric evaluation.

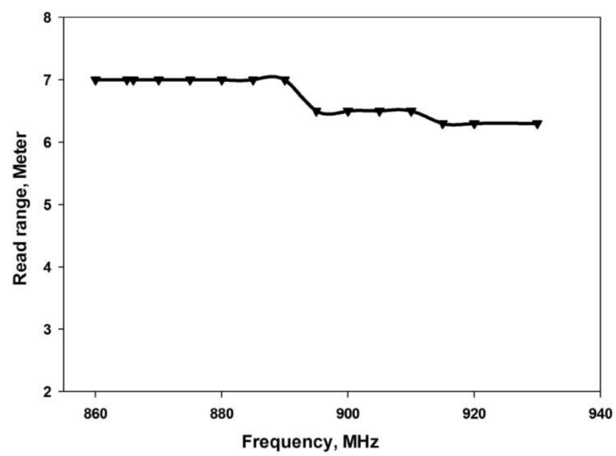


Figure 9. Measured read range of the proposed RFID tag with frequency for boresight with $\theta = 0°$, $\phi = 0°$.

Figure 8 shows the simulated results of the variations of return loss with frequency of the RFID tag antenna for different values of the short circuited strip between the SRRs. The parameter L_3 is significant in determining the operating frequency and overall size of the antenna. From the figure it can be inferred that as length L_3 decreases, the resonant frequency increases. It can be seen that the return loss of the structure is below $-10\,\text{dB}$ for a frequency band of 11.1 MHz (860.94 MHz–872.04 MHz) for $L_3 = 16\,\text{mm}$, which covers the European UHF RFID band (865 MHz–867 MHz).

Figure 9 shows the measured variation of read range for the proposed RFID tag with frequency. It can be seen that the measured range is 7 meter in the European UHF RFID band (865–867 MHz). When it comes to the North American (902–928 MHz) and Chinese (920.5–924.5 MHz) UHF RFID bands, it is slightly decreased but exhibits appreciable read ranges. The main advantage of this design is that the tag exhibits a good read range in all the three UHF RFID bands, which makes it suitable for applications for worldwide deployment.

Measured variation of read range with elevation and azimuthal angles is shown in Fig. 10. It can

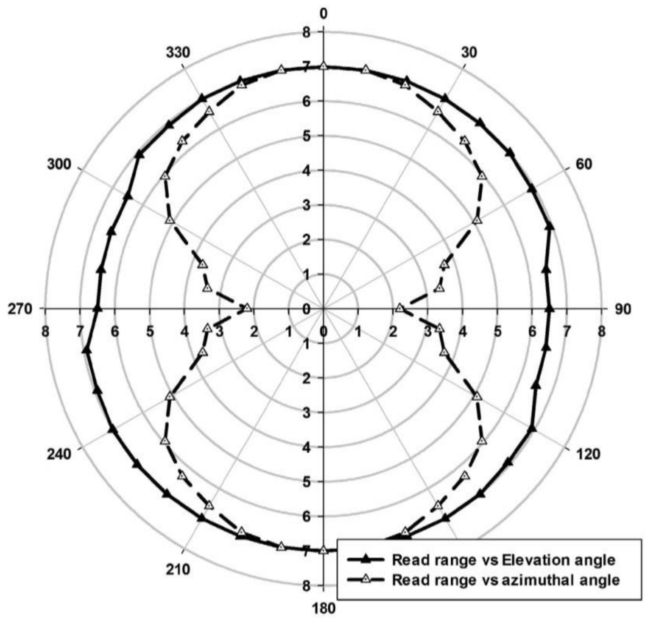


Figure 10. Measured variations of read range with angular ranges for the proposed RFID tag at in the UHF band 866 MHz.

be seen from the graph that the proposed UHF RFID tag exhibits almost constant read range over the entire elevation angular ranges and over wide azimuth angular ranges. The value of measured maximum read range is 7 meter for the proposed tag. Compared with the commercially available RFID tags, the proposed tag is compact and exhibits an enhanced read range characteristic.

4. CONCLUSION

The development of an SRR loaded compact RFID tag with broadband characteristics over the entire UHF RFID band is reported. From the measured read range characteristics it is clear that the proposed tag exhibits appreciably good read range in the entire elevation angular ranges and over wide azimuthal angular ranges. Employing an SRR loading in the RFID tag, miniaturization, good impedance matching, and good read range characteristics are achieved. This tag will find application in worldwide deployment of RFID tags.

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