A Flexible and Compact Metamaterial UHF RFID Tag for Remote Sensing in Human Health

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***Abstract*— This paper presents a miniaturized UHF RFID tag antenna with increased gain using meander line techniques and metamaterial (MTM). The designed tag operates in the UHF RFID frequency band ranging from 860 to 960 MHz. It comprises of meandered lines with two hexagonal split ring resonators (H–SRRs) MTM cells. It is designed on a photo paper as its substrate which is 0.27 mm thick, with a dielectric constant of 3.2 and loss tangent of 0.05. Next, an RFID tag (NXP SL3S1213 UCODE G2iL chip) with an impedance of 23-j224 Ω is integrated with the proposed antenna to assess its performance in terms of reflection coefficient, antenna gain and maximum reading range. The overall size of the tag is 92 mm x 26 mm.**

Keywords—UHF RFID, metamaterial, Bioelectromagnetics, Wearable Antenna and Antenna and Propagation,

I. INTRODUCTION

Radio frequency identification (RFID) technology has been widely used in today's applications in identifying and tracking objects attached with these tags using radio waves. Important applications of RFID include the transportation, supply chain management, logistic and inventory tracking in the retail sector [1]. Generally, an RFID system consists of three main parts – the reader, tags and back-end database. The tag consists of a chip that stores data, and the antenna which fucntions as a medium to transfer the data. Meanwhile, in a typical passive RFID system, the reader will transmit radio waves to activate and read information from the tag once within its coverage area.

There are currently four frequency standards for RFID technology – the low frequency (LF) band from 125 to 134 KHz, high frequency (HF) band centred at 13.56 MHz, the ultra-high frequency (UHF) between 860 and 960MHz and microwave band centred either at 2.4 GHz or 5.8 GHz [2]. This technology features several main advantages, which include the ability to track and identify without any line-of-sight and long reading range. However, the cost efficiency is slightly lower in comparison to barcode technology, for instance, especially when applied in tagging low-cost items [3]. To overcome this cost factor, low cost passive UHF RFID tag antenna using paper and paper tape as a substrate have been proposed in [4] and [5]. Besides that, another factor to ensure cost-efficiency is the size compactness of tag. This directly implies that the antenna and substrate must be miniaturized while being ensured to be able to operate efficiency.

For many decades, miniaturization of antennas have been performed by restricting their overall footprint while maintaining their required electrical length for proper operation. One of the most popular method to do this is by meandering the radiating arms, which enables high compactness in tag antenna designs [6]. Besides that, for its potential use on body, the tag must be designed in a planar form on flexible substrates. The body proximity causes absorption, diffraction and scattering of electromagnetic waves, which then changes in the antenna impedance, resonant frequency and read range [7]. Such performance variation may be alleviated by the integration of metamaterial elements in improving the tag antenna's performance [8]. Metamaterial are artificially engineered materials and have unique properties which cannot be found in natural materials such as negative permeability or negative permittivity. A negative effective refractive index can also be exhibited if both of the magnetic permeability and electric permittivity are negative, and this is also known as left-handed metamaterial or double negativity (DNG) [9].

The work presents the design a compact of tag antenna, with a focus on increasing its gain while maintaining its compact size using metamaterial elements. The meander line technique is adopted as the main method to ensure a miniaturized initial tag antenna size. Next, a hexagonal split ring resonator (H-SRR) structure which exhibits double negative (DNG) property is modelled and integrated with this tag antenna.

II. ANTENNA DESIGN

A. RFID Tag Antenna

The geometry of the proposed meander line tag antenna design is shown in Fig 1. The meander line structure is applied in this design to ensure a compact initial tag antenna size. The theoretical length of a conventional half-wavelength dipole is calculated as $\lambda 0/2$= 163 mm, with $\lambda 0$ is the free space wavelength. Due to this length requirement, the tag size would be very large for the RFID tag. For antenna to resonate at lower frequency, the antenna structure is folded. This will lead to an interruption of the current flow, and will increase the capacitance and inductance of the antenna.

The dimension of proposed tag is shown in Table 1. The proposed tag consists of two layers – the substrate layer, which is a photo paper layer (with a dielectric constant of 3.2 and loss tangent of 0.005); and the silver trace as the conductive element. This is then integrated with an RFID chip from NXP (model SL3S1213 UCODE G2iL), which features an impedance value of 23-j224 Ω. This chip is centred on the tag antenna. For simplification purposes, this chip is represented as a discrete port in simulations.

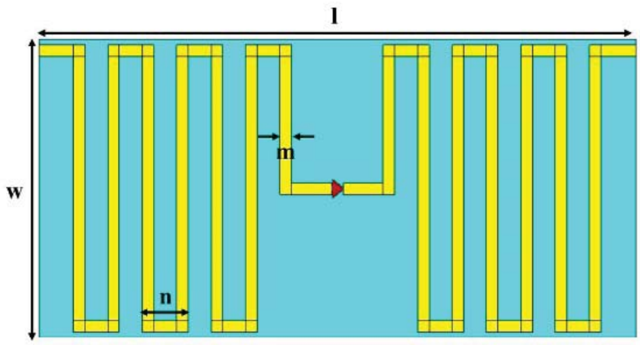

Fig. 1. Proposed RFID tag antenna

TABLE I. PARAMETERS AND DIMENSIONS OF TAG ANTENNA

Parameter	Dimension (mm)
l	52
w	26
m	1
n	4

The simulated reflection coefficient (S11) of tag antenna is shown in Fig 2. The S11 of lower than -10 dB indicates a satisfactory performance.

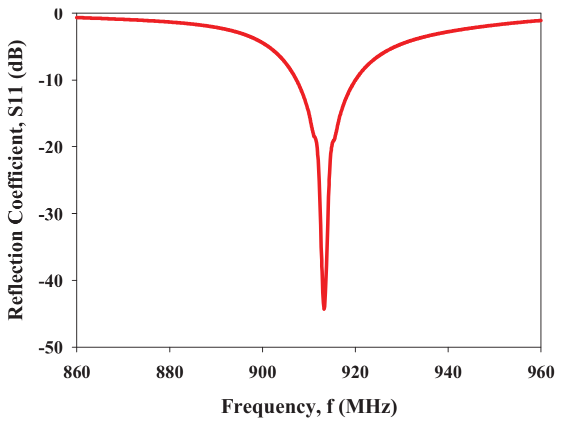

Fig. 2. Simulated magnitude of S_{11} for the proposed tag antenna

B. Hexagonal Split Ring Resonator (H-SRR) Design

The metamaterial element consists of a H-SRR which produces negative permeability, and a thin wire which produces negative permittivity. The combination of the H-SRR and thin wire will produce double negative characteristics. The design of the DNG metamaterial unit cell is shown in Fig. 3, and the dimensions of the DNG unit cell is summarized in Table 2.

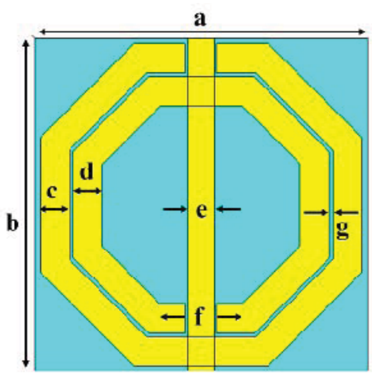

Fig. 3. Geometry of the H-SRR structure

TABLE II. PARAMETERS AND DIMENSION OF H-SRR DESIGN

Parameter	Dimension (mm)
a	21.00
b	21.00
c	1.85
d	1.85
e	1.70
f	2.00
g	0.23

The refractive index, permittivity and permeability can be calculated using the following equations:

$$S_{11} = \frac{i}{2}\left(\frac{1}{z} - z\right)\sin(nkd) \quad (1)$$

$$S_{21} = \frac{1}{\cos(nkd) - \frac{i}{2}\left(z + \frac{1}{z}\right)\sin(nkd)} \quad (2)$$

$$z = \sqrt{\frac{(1+S_{11})^2 S_{21}^2}{(1-S_{11})^2 - S_{21}^2}} \quad (3)$$

$$n = \frac{1}{kd}\cos^{-1}\left[\frac{1}{2S_{21}}(1 - S_{11}^2 + S_{21}^2)\right] \quad (4)$$

$$\varepsilon = \frac{n}{z} \quad (5)$$

$$\mu = n.z \quad (6)$$

where z is the wave impedance, n is a refractive index, k is the wave number, d is the thickness of the metamaterial unit cell, μ is the magnetic permeability and ε is the electric permittivity. The simulated transmission and reflection of the metamaterial design is illustrated in Fig. 4, whereas the effective parameters such as refractive index, permittivity and permeability of the proposed metamaterial unit cell is presented in Fig. 5.

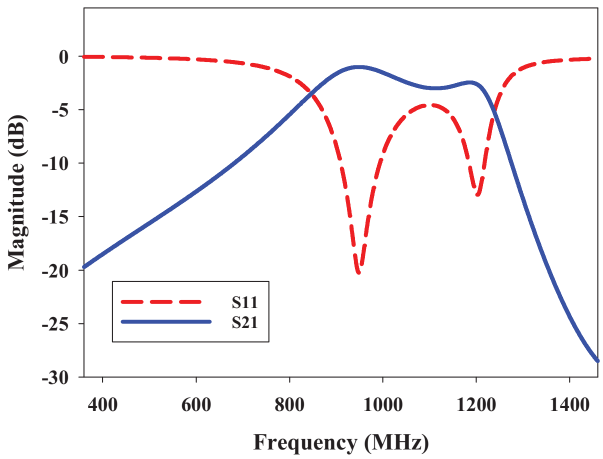

Fig. 4. S_{11} and S_{21} results of H-SRR unit cell

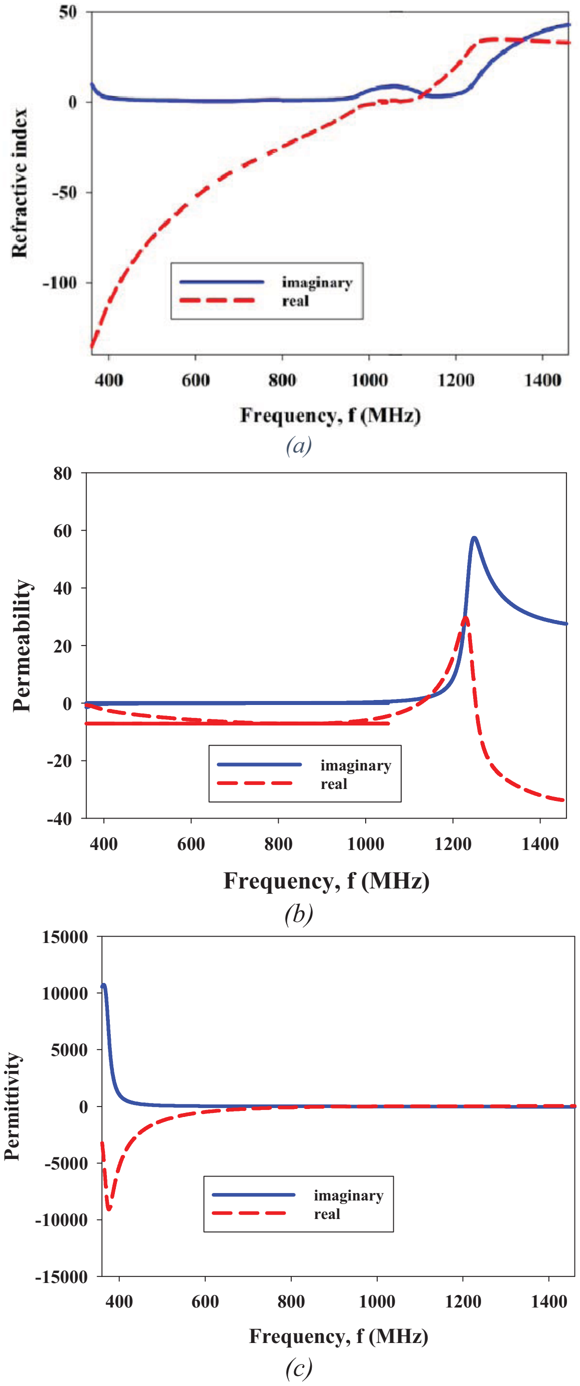

Fig. 5. Effective parameters of the proposed H-SRR: (a) refractive index; (b) permeability; (c) permittivity

C. *Integration of Tag Antenna with H-SRRs*

Fig. 6 illustrates the schematic of the tag antenna design when integrated with a pair of H-SRR elements, one at each end of the meander line. The overall size of this new structure is 92 mm x 26 mm, while maintaining the same thickness.

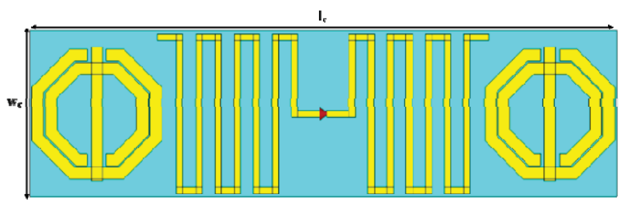

Fig. 6. Geometry of proposed tag antenna

III. RESULTS AND DISCUSSIONS

In RFID systems, the performance of the tag antenna directly affects their read range. The correlation between the tag antenna (and the passive RFID chip) with the read range can be estimated based on four parameters: its directivity, gain, radiation pattern and reflection coefficient. Fig. 7 shows the realized gain of the tag antenna without the H-SRR cells, which produced a value 1.03 dB. Meanwhile, Fig. 8 shows the realized gain of 1.47 dB with the integration of the H-SRR cells. This translate into an increment of 0.44 dB with the addition of the H-SRR on the tag antenna. Note also that the S11 is slightly shifted towards the lower frequency at 900 MHz when the H-SRRs is added to the tag antenna, as shown in Fig. 9. Despite that, the result still is still acceptable as the tag still operated within the required UHF RFID band from 860 to 960 MHz.

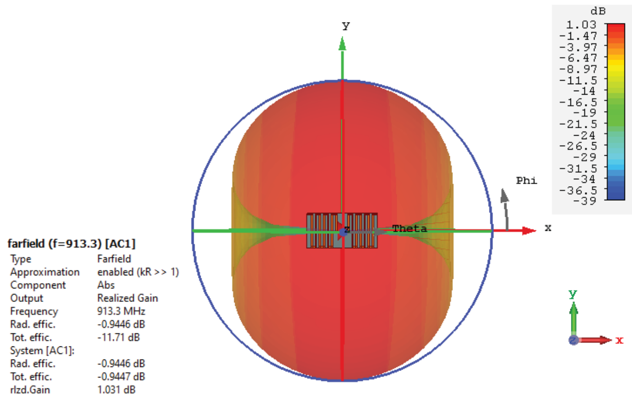

Fig. 7. Tag antenna gain without integration with the H-SRRs

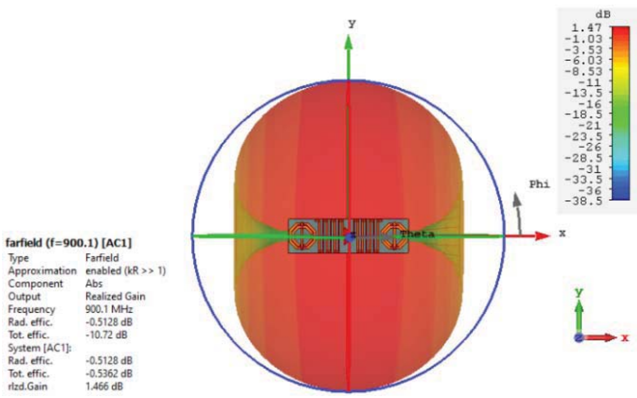

Fig. 8. Tag antenna gain when integrated with H-SRRs

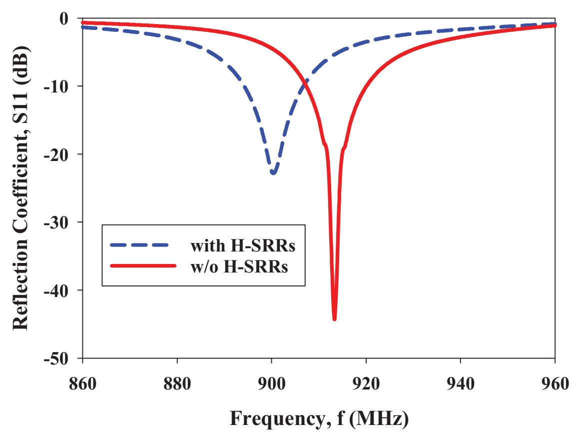

Fig. 9. S_{11} comparison between the antenna with and without the H-SRRs

Fig. 10 shows the simulated resistance and reactance for Za obtained at the frequency of 900 MHz with a value 26.43 + j222.83 Ω

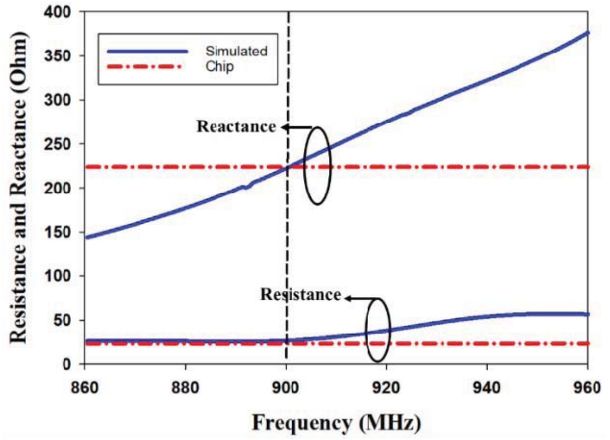

Fig. 10. Simulated impedance

The Friis free space equation in (7) is then used to calculate the simulated read range, r, for the tag integrated with and without the H-SRR elements [11], as follows:

$$r = \frac{\lambda}{4\pi}\sqrt{\frac{EIRPG_r\tau}{P_{th}}} \quad (7)$$

where λ is wavelength in free space, EIRP is an effective isotropic radiated power from the reader, and Pt is the power transmitted from RFID reader. Next, the power transfer coefficient, τ, which measures level of antenna impedance matching to the chip impedance, can be calculated using equation (8), as follows:

$$\tau = \frac{4R_cR_a}{|Z_c + Z_a|^2} \quad (8)$$

where Ra is the resistance of the tag antenna, Rc is the resistance of the RFID chip, Zc is the impedance of the RFID chip and and Za is the impedance of the tag antenna. The simulated read range for the tag antenna with and without the H-SRRs is 7.13 m and 6.08 m, respectively.

IV. CONCLUSION

A flexible UHF RFID tag antenna capable of operating in the UHF band has been designed and optimized via simulations. The proposed antenna is low-cost, compact in size and easy to fabricate. The meander line technique is implemented to reduce the antenna size. Next, the unique H-SRR DNG unit cell was introduced and integrated with the tag antenna. This resulted in improved gain and read range for the RFID tag. In future work, the performance of the proposed RFID tag antenna will be further analyzed under different bending conditions and the effects of its use on the human body will be examined.

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