A Voltage Dependent Meander Line Dipole Antenna with Improve Read Range as a Passive RFID Tag

Md. Mustafizur Rahman, Ajay Krishno Sarkar and Liton Chandra Paul

Abstract This paper presents a general outline for passive RFID backscatter transponder antenna in practical use. The read range of tag antenna is additionally investigated. Meander line dipole antenna (MLDA) has been proposed as a tag antenna due to its tiny size and greater radiation efficiency. The radiation efficiency, gain, input resistance, and loss power were investigated in accordance with the variation of material conductivity. In this letter, it was overlooked that the power loss is inversely proportional to the square root of the conductivity of the material. It is observed that the RF input power and tag received voltage are the deciding factors for making the read range maximum. The passive tag could achieve a range of 6 m by a voltage multiplier circuit with it. For example, the read range could be achieved 3 and 5 m when the voltage doubler and quadrupler circuit were used. The design and analysis of the proposed antenna have been performed utilizing simulation software FEKO.

Keywords Meander line dipole antenna · Radiation efficiency · Read range · RF input power · Tag voltage

1 Introduction

An RFID system consists of a reader, a transponder and a host computer is shown in Fig. 1. A reader sends a continuous signal that is reflected back by the tag. A passive tag is a huge cheaper than active tag due to the absence of battery [1]. Meander line antenna is a newly introduced antenna which is made from a dipole

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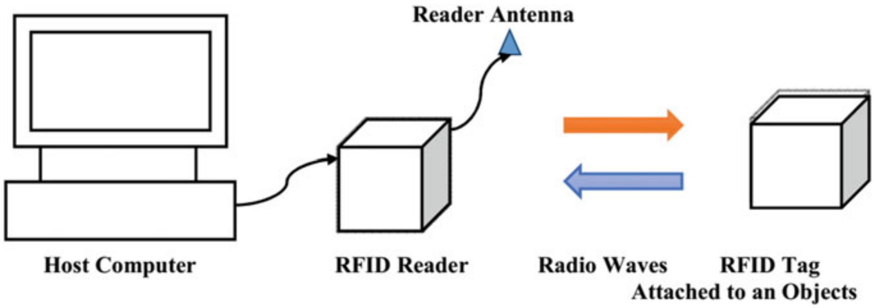


Fig. 1 Basic components of a RFID system

antenna by twisting the straight dipole. In RFID system for different applications, MLD antenna makes its remarkable consideration due to its efficiency and size. Some papers familiarized with the efficiency and gain of the antenna [2–5]. Lately, Koch fractal dipole antenna was a good choice for tag antenna, but low efficiency and complex arrangement has degraded its use [6]. Even though, design in [7–9] has depicted only the frequency and gain of MLD antenna. Therefore, a low profile MLD antenna with a small read range has been studied, but these reported letters have not given the proper idea about the tag voltage elsewhere in the open literature. Some factors are additionally important making an RFID tag antenna such as frequency band, size, objects, orientation, cost, and power for the tag. Notably, in this article, the material selection, read range, cost, and tag power have been discussed. Besides these criteria, the antenna matching technique was also discussed.

2 Analysis and Design of Meander Line Dipole Antenna

Meander line antenna is a repetitive structure of a dipole antenna as shown in Fig. 2. The length of the twisted dipole antenna is a bit lower than that of the straight dipole antenna.

In RFID system, the cost of tag must be low, thus depends both on antenna structure and materials for its construction. It is desirable to know how materials change the antenna performance. The chart is shown in Fig. 3 for better understanding the design process of a tag antenna.

2.1 Calculation of Efficiency

An RFID system, the antenna performance parameters are very important to choose the material for making the meander line dipole antenna. For MLD antenna, the current in parallel lines will always be equal and opposite in direction. From Fig. 4,

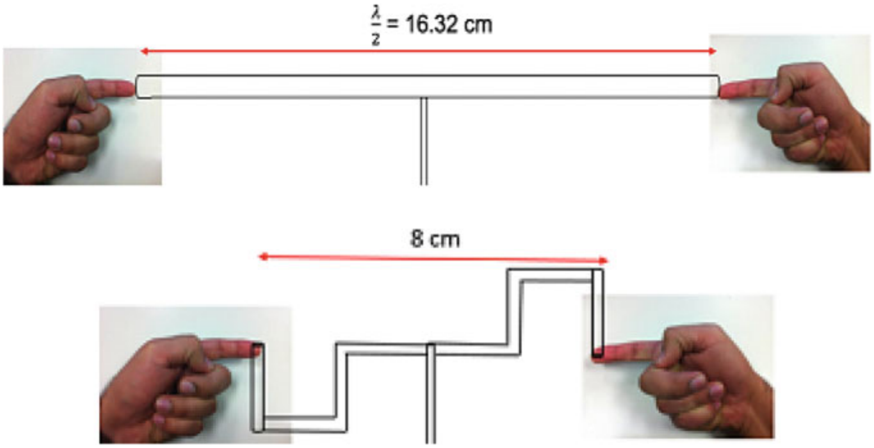


Fig. 2 Half wave dipole antenna before and after twisting

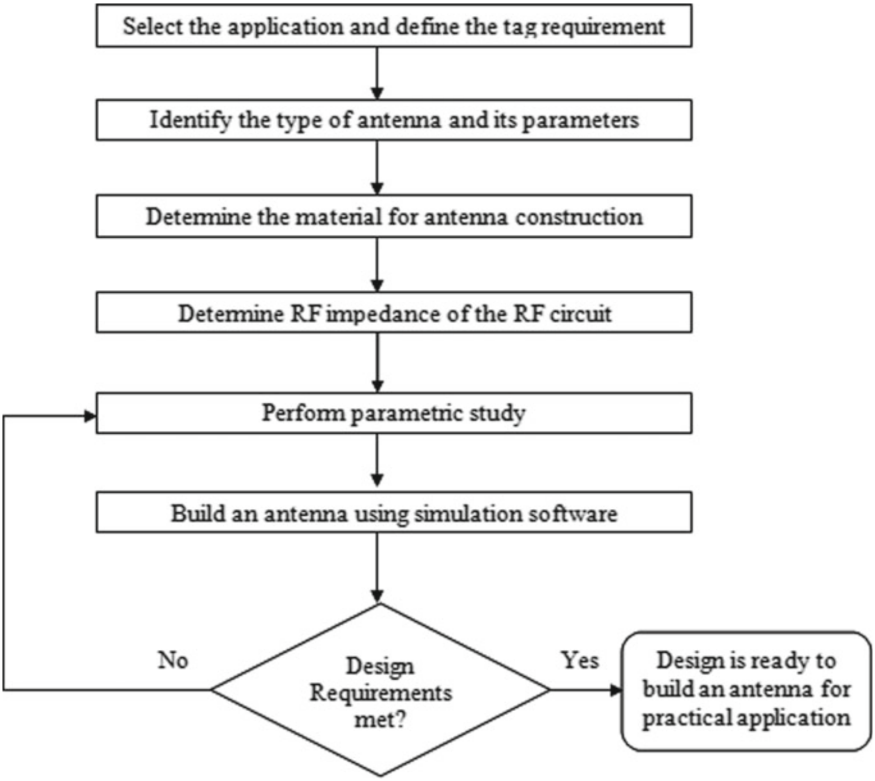


Fig. 3 Flowchart summarizing for RFID tag antenna design process

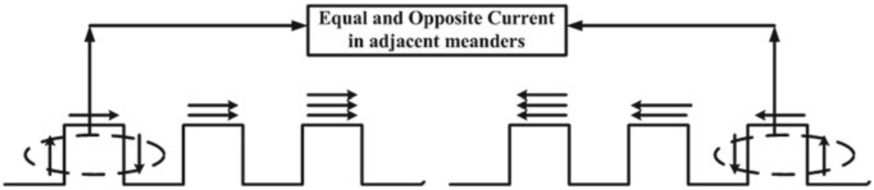


Fig. 4 Meander line dipole antenna indicating current distribution

it can be visually perceived that the current in parallel lines is always canceled out, and resulting in the radiation efficiency is only through the non-parallel lines [10–12]. The current distribution of MLDA is as follows:

$$I(z) = I_0 \sin k\left(\frac{L}{2} - |z|\right) \tag{1}$$

The resistance per length of the conductor is as follows

$$R_{\text{loss}} = \frac{1}{C}\sqrt{\frac{\omega\mu_0}{2\sigma}} \tag{2}$$

where C is the perimeter of the conductor. Total loss of power can be written as follows:

$$P_{\text{loss}} = \int_{\frac{L}{2}}^{\frac{-L}{2}} I^2(z) R_{\text{loss}} \mathrm{d}z = \frac{1}{2} I_0^2 \frac{L}{C}\sqrt{\frac{\omega\mu_0}{2\sigma}} \tag{3}$$

According to the T. Endo the radiation resistance is the product of the resistance of half-wave dipole antenna and the ratio of the total horizontal length of MLDA to the half wavelength of a dipole antenna.

$$\frac{R_{\text{radiation}}}{R_{\text{dipole}}} = \frac{L - 2wm}{\lambda/2} \tag{4}$$

Total radiated power by MLDA is as follows

$$P_{\text{rad}} = \frac{1}{2} I_0^2 R_{\text{radiation}} = \frac{1}{2} I_0^2 \left\{ \frac{2(L - 2wm)}{\lambda} R_{\text{dipole}} \right\} \tag{5}$$

Radiation efficiency is expressed as follows

$$\eta = \frac{P_{\text{rad}}}{P_{\text{rad}} + P_{\text{loss}}} = \frac{2\frac{(L-2wm)}{\lambda} R_{\text{dipole}}}{2\frac{(L-2wm)}{\lambda} R_{\text{dipole}} + \frac{L}{C}\sqrt{\frac{\omega\mu_0}{2\sigma}}} \tag{6}$$

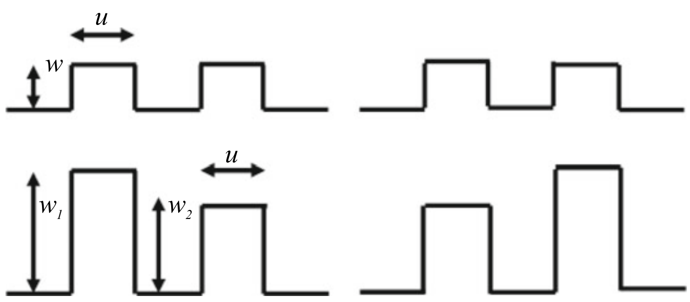


Fig. 5 Meander line dipole antenna with equal (above) and unequal (below) vertical length

where L is the entire length of the wire, w is the vertical length of the MLDA, m is the no of meander section, σ is the conductivity of the materials, μ is the permittivity of free space, and ω is the wavelength of the antenna [13–16].

From (6), it was observed that the radiation resistance does not depend on the conductivity of the materials, only the loss resistance depends on the conductivity. If the vertical length w of the MLDA antenna is not uniform, then the radiated power of the MLDA can be expressed as follows:

$$P_{\text{rad}} = \frac{1}{2} I_0^2 \left\{ \frac{2L}{\lambda} R_{\text{dipole}} - \frac{4w_1}{\lambda} R_{\text{dipole}} - \frac{4w_2}{\lambda} R_{\text{dipole}} \ldots \right\} \tag{7}$$

where the w_1, w_2 … are the vertical length of MLDA (see Fig. 5).

Two pictures are shown in Fig. 5, wherein the above figure, horizontal segments have equal length u and vertical segments have equal length w. Total length can be represented in terms of m, i.e., $L = (10u + 8w)$ when $m = 4$.

In other figures, all the horizontal segments are of equal length u and all vertical segments are of unequal length w_1, w_2, respectively. Total length L of the wire can be expressed in terms of number of meander section m, i.e., $L = (10u + 4w_1 + 4w_2)$ when $m = 4$.

2.2 *Determination of RF Impedance*

The major consideration of an antenna is the antenna's impedance. The antenna impedance must be in shape to the tag chip. An RFID tag will have a tag antenna and a chip, both with complex impedance (see Fig. 6). For example, if the calculated impedance of the IC chip is $Z_C = R_C - jX_C$, the antenna impedance should be $Z_A = R_A + jX_A$ for conjugate matching. Therefore, for the maximum amount of power delivered to the antenna, the load impedance must satisfy the conjugate matching condition [17–21].

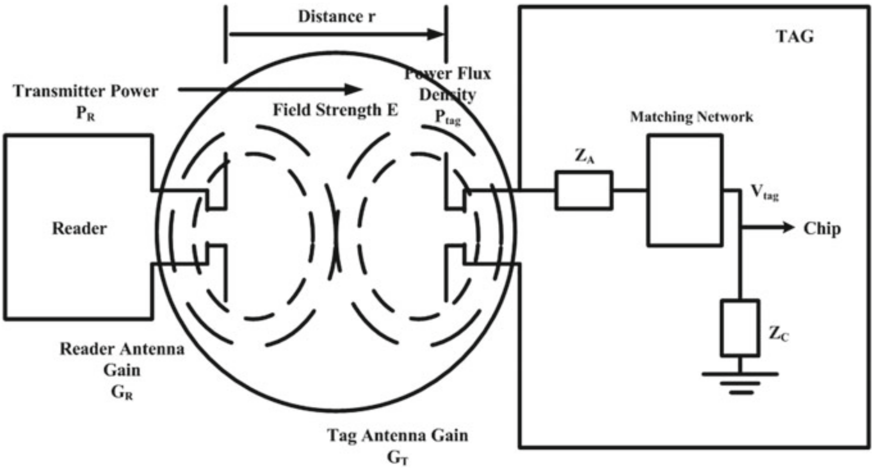


Fig. 6 Forward power transfer for RFID systems

$$Z_A = Z_C^* \tag{8}$$

2.3 Operating Read Range and Tag Voltage Evaluation for RFID System

Let P_R, G_R, A_R be the power, gain and effective area of the reader antenna and P_T, G_T, A_T be the same quantities for the transponder or tag antenna. The tag antenna has an effective isotropic radiated power and a power density at distance r is appearing in Fig. 6.

The isotropic radiated power and power density are expressed as follows

$$P_{EIRP} = P_R G_R \tag{9}$$

$$S_\tau = \frac{P_{EIRP}}{4\pi r^2} \tag{10}$$

The tag antenna extract power P_T given in terms of the A_T is as follows

$$P_T = S_\tau . A_T = \frac{P_R G_R A_T}{4\pi r^2} \tag{11}$$

The gain of the tag antenna is as follows

$$G_T = \frac{4\pi A_T}{\lambda^2} \tag{12}$$

where, λ is the wavelength. Therefore, the available tag power at the tag antenna can be expressed as follows

$$P_{tag} = P_T = \frac{P_R G_R G_T \lambda^2}{(4\pi r)^2} \tag{13}$$

This is called Friis transmission equation [16]. It is considered that the practical value of the chip resistance is R_C. Therefore, the tag voltage is predicated as follows

$$V_{tag} = \sqrt{P_{tag}.R_C} \tag{14}$$

The read range of the tag antenna has been initiated by the following Eq. (15)

$$r = \sqrt{\frac{P_R G_R G_T \lambda^2}{(4\pi)^2 P_{tag}}} \tag{15}$$

If Γ_t and Γ_r are the reflection coefficients of the transponder antenna and the reader antenna, respectively, and e_p denotes the polarization efficiency. Equation (15) can be rewritten as follows

$$r = \sqrt{\frac{P_R G_R G_T \lambda^2 (1 - |\Gamma_T|^2)(1 - |\Gamma_R|^2) e_p}{(4\pi)^2 P_{tag}}} \tag{16}$$

The maximum read range will be achieved if the P_{tag} is the minimum threshold power for the tag antenna.

$$r\text{max} = \sqrt{\frac{P_R G_R G_T \lambda^2 (1 - |\Gamma_T|^2)(1 - |\Gamma_R|^2) e_p}{(4\pi)^2 P_{th}}} \tag{17}$$

If antenna's impedance is almost matched to their source and load, an ideal form of (17) is defined as follows

$$r\text{max} = \sqrt{\frac{P_R G_R G_T \lambda^2}{(4\pi)^2 P_{th}}} \tag{18}$$

where $P_{tag} = P_{th}$.

Normally, the path gain factor is much less than 1. However, this path loss occurs in free space [22, 23].

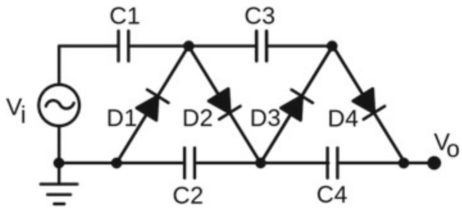


Fig. 7 Voltage multiplier circuit to power the tag chip

2.4 Reader Received Power and DC Supply Voltage for Tag Chip

In RFID systems, the received power by the reader is expressed as follows

$$P_{\text{Rreceived}} = \frac{P_{\text{R}} G_{\text{R}}^2 \lambda^2 \Delta s}{(4\pi)^3 r^4} \tag{19}$$

where Δs is the radar cross-section.

In the passive RFID system, there is no battery to power up the tag chip. Therefore, it is the desired necessary RF power and received voltage to power the tag. Tag voltage may be increased by way of the usage of voltage multiplier circuit (see Fig. 7).

2.5 Proposed Meander Line Dipole Antenna

In fact, RFID system consists of two parts, one is named the reader and another is named transponder or tag. The tag act consists of an antenna and a low power CMOS IC [16]. The IC has one very important part is RF to dc rectifier circuit. In Fig. 6, the antenna impedance $Z_{\text{A}} = R_{\text{A}} + jX_{\text{A}}$ must be equal to the chip impedance $Z_{\text{C}} = R_{\text{C}} - jX_{\text{C}}$ and the chip impedance varies with the frequency.

It is considered that the Hagg4 Alien series IC has a resistance of 1800 Ω and the capacitance is 0.95 pF. The IC has an operating frequency is varying from 840 to 960 MHz. In this composition, the designed antenna must have a frequency of which range is varied from 840 to 960 MHz. To attain this, the proposed antenna shape is viewed in Fig. 8. Dimension of MLDA is displayed in Table 1.

3 Simulation Result and Discussion

In this article, the design of the MLD antenna was done by the simulation software FEKO. After designing, the antenna performance parameters have been calculated by using the MOM method. The designed antenna and its dimension are revealed in Fig. 9 in which the gap between the arms of the dipole is 2 mm and the radius of

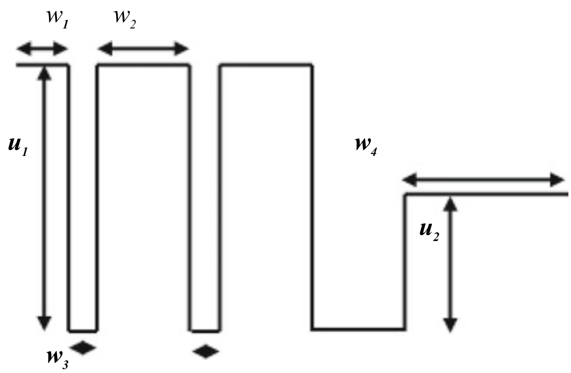


Fig. 8 Structure of meander line dipole antenna with half arm

Table 1 Antenna dimension with half arm

Meanders m	Horizontal length (mm)				Total physical length (mm)	Total wire length (mm)	Vertical length (mm)	
	w_1	w_2	w_3	w_4			u_1	u_2
4	2.7	5.4	1.4	12	34.7	144.7	20	10

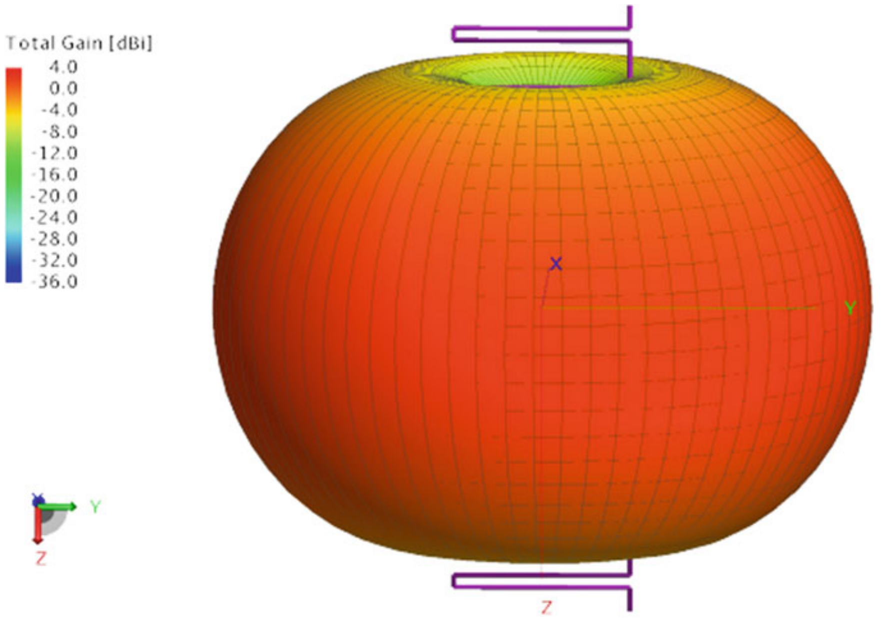


Fig. 9 3D view of a proposed meander line dipole antenna

the wire is 0.3 mm. First of all, the conductivity of the material was varied, ranging from 10^3 to 10^8 S/m. It was found that the efficiency of the antenna was increasing with the increase in conductivity due to the change of loss power (see Fig. 10). From (3), it was observed that the power loss is inversely proportional to the square root of the conductivity. From the simulation result, it was visible that the gain of the antenna withal incrementing with the incrimination in conductivity is exhibited in Fig. 11. The radiation pattern of the meander line dipole antenna is identical to the

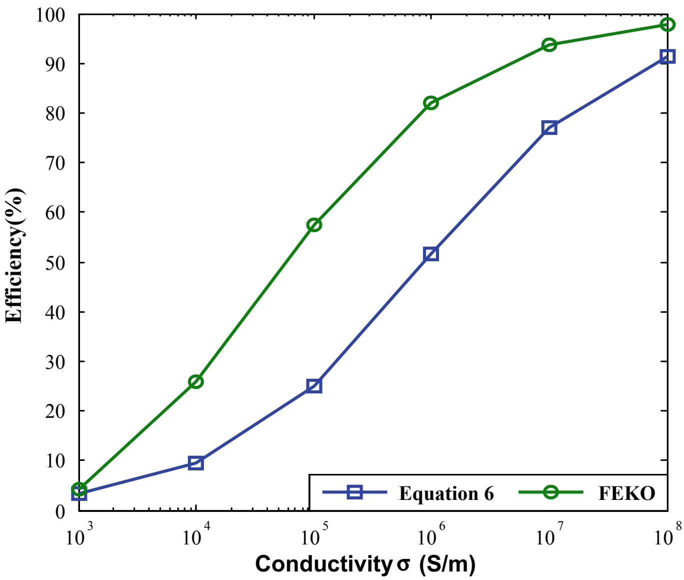
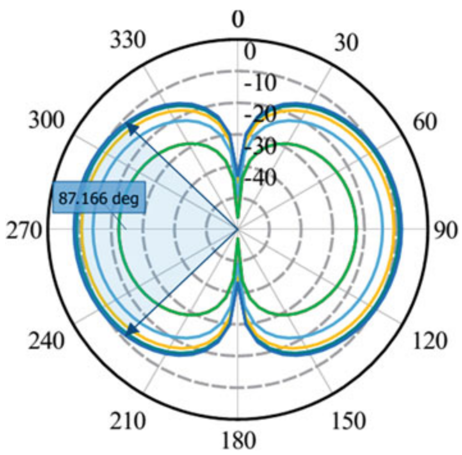


Fig. 10 Efficiency versus conductivity curve

Fig. 11 Simulation result of gain (dBi) of MLDA with the variation of conductivity



radiation pattern of the conventional dipole antenna. There are some materials which have a conductivity ranging from 3.5×10^7 to 6.30×10^7. Most of the materials such as silver, copper, gold, and aluminum are lying in this conductive range. In this article, it is important to identify what materials need to be used. Table 2 shows the antenna performance parameters. Those materials gave the better performance but their results are nearly the same. In Fig. 12, the curves of reflection co-efficient are superimposed with each other. Analogous results were shown in Fig. 13 for antenna impedance. Consequently, among these materials copper was preferred for making the antenna due to its lower cost.

From Table 2, it is noticed that the impedance of the antenna is $Z_A = 21.95 + 1.43j$ Ω and the impedance of the IC is $Z_C = 21 - 189j$ Ω if the frequency of the antenna is 920 MHz, where the value of the capacitor is 0.95 pF and the resistor is 1800 Ω. Hence, the matching network may be required. For matching load, 32.45 nH inductor is connected in series with the antenna impedance. Higher the reader output power,

Table 2 Antenna performance parameters

Material's name with conductivity σ (S/m)	Efficiency (η%)	Reflection co-efficient Γ (dB)	Impedance Z (Ω)
Carbon-Graphene (10^8)	97.91	−10.59	21.79 + 1.25j
Silver (6.30×10^7)	97.38	−10.67	21.92 + 1.40j
Copper (5.96×10^7)	97.31	−10.68	21.95 + 1.43j
Annealed Copper (5.96×10^7)	97.28	−10.68	21.95 + 1.43j
Gold (4.10×10^7)	96.77	−10.76	22.07 + 1.54j
Aluminum (3.50×10^7)	96.52	−10.79	22.14 + 1.61j

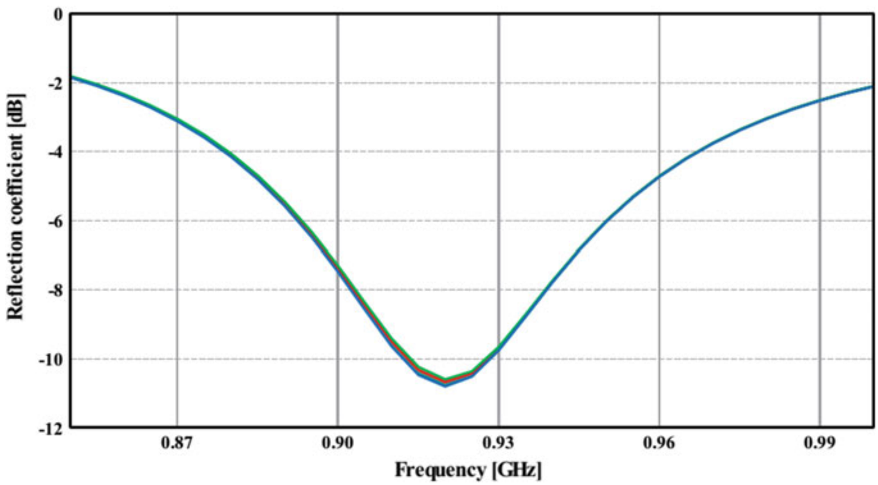


Fig. 12 Simulation result of reflection co-efficient for different materials

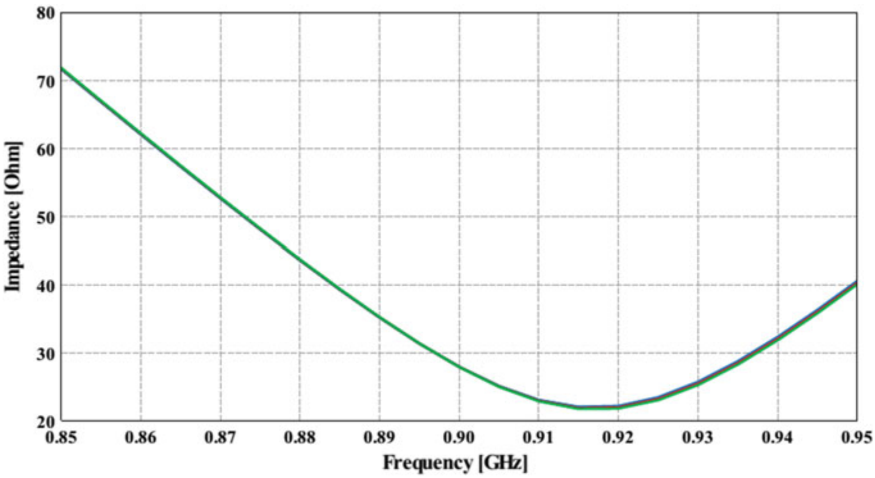


Fig. 13 Simulation result of impedance for different materials

the higher the read range. It is considered that the reader antenna is dipole antenna and then the isotropic radiated power of the reader antenna was found 29.15 dBm or 822.24 mW.

Alike, if the reader antenna is Yagi–Uda, the isotropic radiated power of the reader antenna was found 35.14 dBm or 3.26 W due to its higher gain. From (13), the tag available power versus distance for both two reader antennas is demonstrated in Fig. 14.

Besides this, tag received power is required to calculate the tag voltage. From (14), the tag voltage versus reader range is shown in Fig. 15 for both the reader antennas.

The RF input power within the range of 10 μW (−20 dBm) to 50 μW(−13 dBm) is obligatory to power on the tag. The minimum requirement of voltage V_{tag} is 1.2 V_{rms} for rectifying the signal. As mentioned earlier, for the maximum read range, two requirements have to be met. The read range must be 1.5 m for dipole reader when RF power is 1.23 dBm and 3 m when RF power is −8.30 dBm. Nevertheless, at this time, the tag voltages are 1.54 and 0.61 V, respectively (see Table 3). Additionally, 0.61 V is not sufficient to power on the tag, a modification is needed. A voltage multiplier (doubler) circuit can be used and the tag voltage could be maintained as 1.22 V. Therefore, the read range can be extended by using voltage doubler and quadrupler circuit. The read range will be 3 or 5 m if the voltage doubler and quadrupler circuit are used (see Table 3). To make the chip less weight and cost effective, voltage doubler circuit is appropriate for making the ac to dc converter circuit. In this case, the reader maximum read range will be 3 m (see Figs. 14 and 15).

Similar case is notified for Yagi–Uda reader (see Table 4) and the reader maximum range could be 5.5 m when voltage doubler circuit was used (see Figs. 14 and 15).

The received power by the tag has two parts including the reflected power and the available power. Therefore, a small fraction of energy returned to the reader antenna.

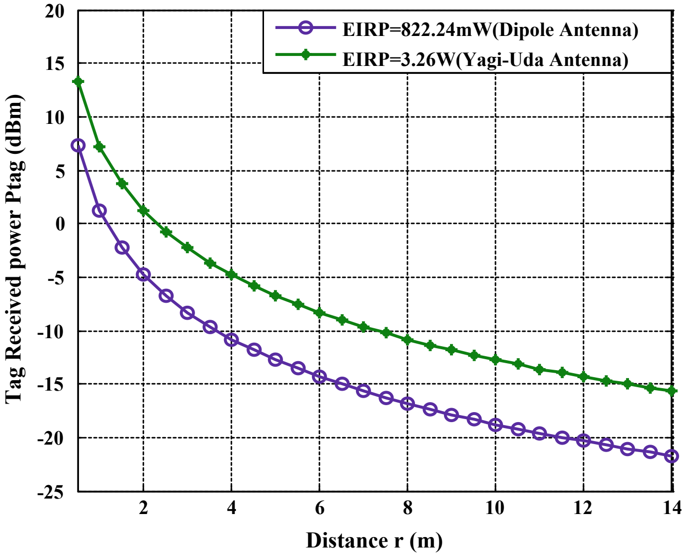


Fig. 14 Tag received power versus distance

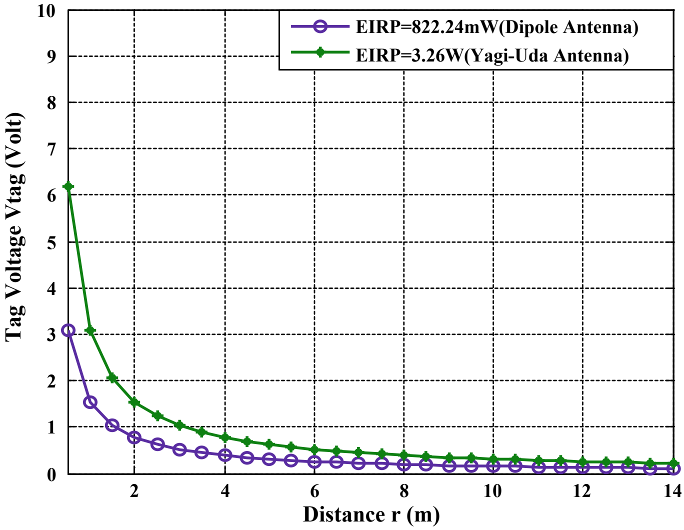


Fig. 15 Tag voltage versus distance

Table 3 Read range, tag received power, and tag voltage for dipole antenna

Read range r(m)	Tag received power P_{tag} (dBm)	Tag voltage V_{tag} (V)
0.5	7.25	3.09
1.5	1.23	1.54
2	−4.78	1.03
2.5	−6.72	0.77
3	−8.30	0.61
3.5	−9.64	0.51
4	−10.80	0.44
4.5	−11.82	0.38
5	−12.74	0.30
5.5	−13.56	0.28
6	−14.32	0.25
6.5	−15.01	0.23

Table 4 Read range, tag received power, and tag voltage for Yagi–Uda antenna

Read range r(m)	Tag received power P_{tag} (dBm)	Tag voltage V_{tag} (V)
0.5	13.26	6.17
1.5	7.24	3.08
2	3.72	2.05
2.5	1.22	1.54
3	−0.71	1.23
3.5	−2.29	1.02
4	−3.63	0.88
4.5	−4.79	0.77
5	−5.82	0.68
5.5	−6.73	0.61
6	−7.56	0.56
6.5	−8.32	0.51

From (19), the reader received power versus distance for both two reader antennas as seen in Fig. 16. From Fig. 16, it is seen that the reader received power for both two antennas are overlay with each other.

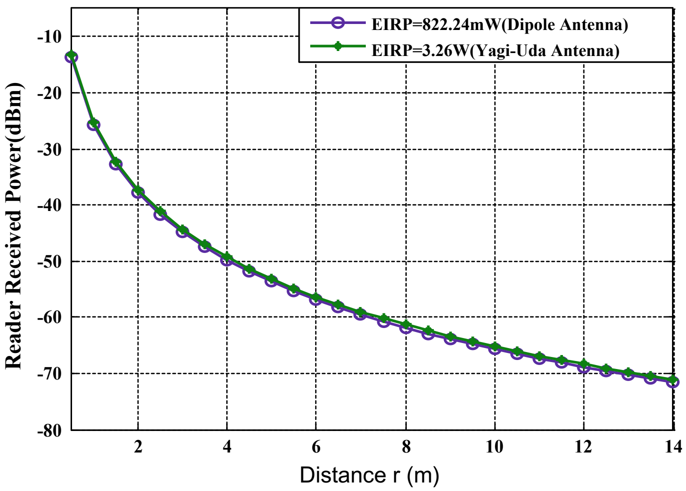


Fig. 16 Reader received power versus read range

4 Conclusion

This letter has demonstrated that the design procedure of RFID tag antenna with improving read range and higher radiation efficiency. A technique was proposed to increase the read range of tag antenna by using a voltage multiplier circuit. Read range of 3 m at the operating frequency of 920 MHz has been achieved by connecting the voltage doubler with the transponder circuit. An equation for calculating the radiation efficiency of MLD antenna that depends on the antenna's geometry and materials conductivity has been derived and presented. Analytical results are compared with the result obtained from simulation software FEKO. With a noble compromise between voltage multiplier circuit, RF input power and size of the tag antenna, the proposed tag antenna can be used in the different applications with a higher read range.

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