Journal of Physics: Conference Series

PAPER • OPEN ACCESS

# Near Field on Inductor Loops for Inductive Couple Fed Antenna

To cite this article: N Q Azmi *et al* 2022 *J. Phys.: Conf. Ser.* **2250** 012014

# Near Field on Inductor Loops for Inductive Couple Fed Antenna

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**Abstract.** This paper presents an evaluation on the near field of square loop and circular loop for inductive couple fed RFID Tag antenna. The loop is simulated with different diameter and width The turns number (N) of the loop is varies up to three number of turns for each loop length. The magnetic fields and inductance are simulated to estimate the signal strength that can be coupled to the tag antenna. To evaluate the performance, the inductive feeding loop is designed to operate at RFID UHF band (860 MHz – 960 MHz) and simulated using CST software. It is confirmed that 6 mm loop length of the square and circular loop has higher magnetic field values as the surface area of the loop is bigger. The loop with different overall dimension gives out different reactance, inductance and magnetic field, dipole antenna, CST, and loop antenna.

## 1. Introduction

Radio Frequency Identification (RFID) is rapidly developing technology which uses RF signals for automatic identification of objects. Now RFID finds many applications in various areas such as for inventory, electronic toll collection, supply-chain management and many more which requires long read distance. The types of RFID commonly identified based on the operational radio waves spectrum. There is low frequency (LF), high frequency (HF) and ultra-high frequency (UHF). LF (125-134 kHz) and HF (13.56 MHz) normally used for short range applications while UHF (433 MHz, 860-960 MHz) for longer range [1].

Globally, each country has its own frequency allocation for RFID. For Example, RFID UHF bands are 866-869 MHz in Europe, 902-928 MHz in North and South America, and as for in Malaysia the range is between 919 – 923 MHz as
Standard Radio System Plan (SRSP) states [2]. RFID systems comprise of interrogators and tags. The tags can be active or passive. Active tags contain an internal power source (battery) while passive tags are powered by the radio frequency energy transmitted by the interrogators.

Proper impedance match between the antenna and the chip is of paramount importance in RFID. Dipole antenna is commonly used in UHF RFID tags due to its simplicity and omnidirectional properties. The length of the total wire, which is
being used as a dipole, equals half of the wavelength (λ/2). Such an antenna is called as half-wave dipole antenna. This is the most widely used antenna because of its advantage which will give reasonable antenna length that matches the size and directivity. For the RFID chip, it will be connected to the dipole arms and a good conjugate matching between the antenna impedance, Za and the chip impedance, Zc is a must to have efficient energy transfer. There are numbers of matching techniques reported such as T-shape and inductive coupling [3].

The available loop dimension that is widely used in UHF RFID tag antenna is 6 mm x 6 mm. Therefore, this paper reports the evaluation on the square and circular loop with lower than the available loop existed which is 4 mm x 4 mm and 5 mm x 5 mm. However, when the loop length is smaller, the energy coupled to turn on the chip will be lower. Hence, the main purpose of this study is to evaluate the magnetic field and the inductance of the smaller loop and increase the flux by increasing the number of turns (N). As when the flux increases, the energy coupled will increase and also increase the read range distance.

## 2. Inductor loop

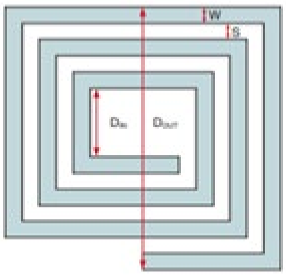
An inductor is basically a passive electrical component which normally built in the form of coil wire. Inductor takes the advantage of the relationship between magnetism and electricity where induced current can be produced with certain condition on magnetic field. The loop inductance calculation can be found in [4] with different shapes. In this paper, the study of square and circular loop with smaller size is chosen due to its less surface area to be occupied in the RFID tag antenna. However, from the Equation 1, it is proven that the surface area is perpendicular with the magnetic field. The smaller loop will be disadvantageous as when the magnetic field is decrease, the energy coupled to turn on the chip also will be decrease.

$$\text{Magnetic flux} = \Phi = B\ XA \tag{1}$$

As for the solution due to the lower magnetic flux, the number of loops turns will be increased to increase the flux hence increase the energy coupled. So, this paper will evaluate the square and circular shape with two and three number of turns with the proposed overall loop dimensions as mentioned.

### *2.1. Square loop*

Figure 1 shows the square inductor loop and the respective coefficient for inductance calculation. Equation 2 shows the equation of inductance calculation.



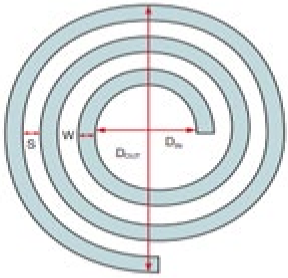
| | |
|---|---|
| $C_1$ | 1.27 |
| $C_2$ | 2.07 |
| $C_3$ | 0.18 |
| $C_4$ | 0.13 |

**Figure 1.** Square inductor loop and the coefficients [4].

Figure 1 shows the Din which is the inner diameter, Dout is the outer diameter, w is the loop width and s is the loop spacing. Dout is the parameter which will be varied from 4 mm, 5 mm and to 6 mm respectively. An inductance, L of a square inductor loop (Figure 1) can be calculated by Equation 2 below. Where N is the number of turns, $\mu_0$ is the vacuum permeability, 4π×10−7; ρ is the fill ratio, (DOUT−DIN)/(DOUT+DIN); DAVG is the average diameter, (DIN+DOUT)/2; and $C_1$=1.27, $C_2$=2.07, $C_3$=0.18, and $C_4$=0.13. Based on the equation, theoretically the inductance value is physically depending on the fill ratio and average diameter of the loop.

$$L = \frac{\mu_{0N^{2D_{avg}C_1}}}{2}\left[ln\frac{(C_2)}{\rho} + c_{3\rho} + c_4\rho^2\right] \tag{2}$$

### *2.2. Circular loop*
For the circular loop, the inductance calculation is similar with the square loop. However, the coefficients of the circular loop are different as shown in Figure 2.




| | |
|---|---|
| **$C_1$** | 1.00 |
| **$C_2$** | 2.46 |
| **$C_3$** | 0 |
| **$C_4$** | 0.20 |

**Figure 2.** Circular inductor loop and the coefficients [4].

### *2.3. Inductance*
The operating frequency for the RFID tag is at 920 Mhz. The inductance of the RFID tag at operating frequency can be calculated by Equation 3.

$$L = \frac{1}{(2\pi f)^2 C} = \frac{1}{(2\pi 920)^2 (1.44 \times 10^{-12})} = 20.783 \times 10^{-9}\, H \quad (3)$$

Hence, the inductance of the loop must be approximately to the above inductance by emphasizing the coefficients value for both shapes in the calculation (Equation 2). The inductance calculation is calculated by PTC Mathcad. The calculation of the 4, 5 mm and 6 mm square and circle inductor loops is approximately equal to the theoretical calculation from Equation 3. On the calculation, the value of w and s is adjusted and the respective value of w and s is used in the simulation to verify the magnetic field value as shown in Figure 3 below.

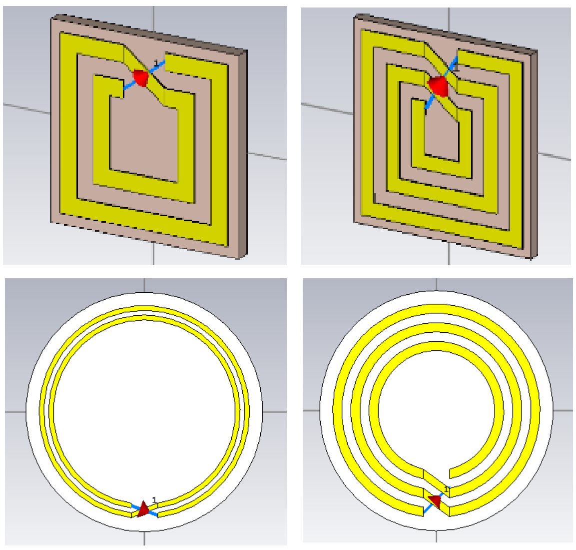


**Figure 3.** Simulation on CST with respective w and s values.

Table 1 and 2 will show the overall inductance for square and circular loops with LCalculated = LCalc.

**Table 1.** Inductance calculations of square loop

| Dout / mm | Coefficient | Number of turn (N) | Loop width (w) / mm | Loop spacing (s) / mm | $X_L$ / Ω |
|---|---|---|---|---|---|
| | | SQUARE INDUCTOR LOOP | | | |
| 4 | $C_1$= 1.27<br>$C_2$= 2.07<br>$C_3$= 0.18<br>$C_4$= 0.13 | 2 | 0.22 | 0.22 | 118 |
| 5 | | | 0.35 | 0.35 | 117 |
| 6 | | | 0.50 | 0.50 | 113 |
| 4 | | 3 | 0.28 | 0.28 | 120 |
| 5 | | | 0.395 | 0.395 | 120 |
| 6 | | | 0.52 | 0.52 | 119 |

From the previous introduction, we all know that an RFID chip can be connected to the two arms of the dipole which will be turned on for data transfer once enough energy is captured by the dipole and transferred to the feed point. A good conjugate matching between the antenna impedance, Za and the chip impedance, Zc is a must to have efficient energy transfer. The inductor loop is studied in term of the inductance value at different dimensions. Once the impedance of the loop is known, it is connected to the RFID chip. The antenna then is designed to have conjugate impedance of the loop and the chip for matching purposes at the required frequency. The Impinj Monza R6 chip will be used for the tag and there several specifications will be taken out such as the Cp and Cmount values from the Monza R6 datasheet [5]. Cp value is 1.23 pF and Cmount is 0.21 pF. Equation 4 and Equation 5 will be used to calculate the value of $X_L$ and Xc of the loop and chip itself.

$$XL = 2\pi f \times LLoop \tag{4}$$

$$XC = \frac{1}{2\pi f \times C} = \frac{1}{2\pi(920M)(1.44p)} = j120\Omega \tag{5}$$

$$; C = Cp + Cmount$$

The calculation is continued with the inductance calculation of the circular loop and the results are shown on Table 2.

**Table 2.** Inductance calculations of circular loop.

| Dout / mm | Coefficient | Number of turn (N) | Loop width (w) / mm | Loop spacing (s) / mm | $X_L$ / Ω |
|---|---|---|---|---|---|
| | | SQUARE INDUCTOR LOOP | | | |
| 4 | $C_1$= 1.00<br>$C_2$= 2.46<br>$C_3$= 0<br>$C_4$= 0.20 | 2 | 0.18 | 0.18 | 115 |
| 5 | | | 0.3 | 0.3 | 114 |
| 6 | | | 0.42 | 0.42 | 117 |
| 4 | | 3 | 0.25 | 0.25 | 120 |
| 5 | | | 0.36 | 0.36 | 120 |
| 6 | | | 0.48 | 0.48 | 117 |

### *2.4. Reactance*

The impedance of the loops also one of the vital parameters to be taken into evaluation. Each loop with different length is simulated and the reactance shows that the higher the number of loops turns, the higher the reactance values. Figure 4 evaluate that reactance is perpendicular to the number of turns for both loop shapes.

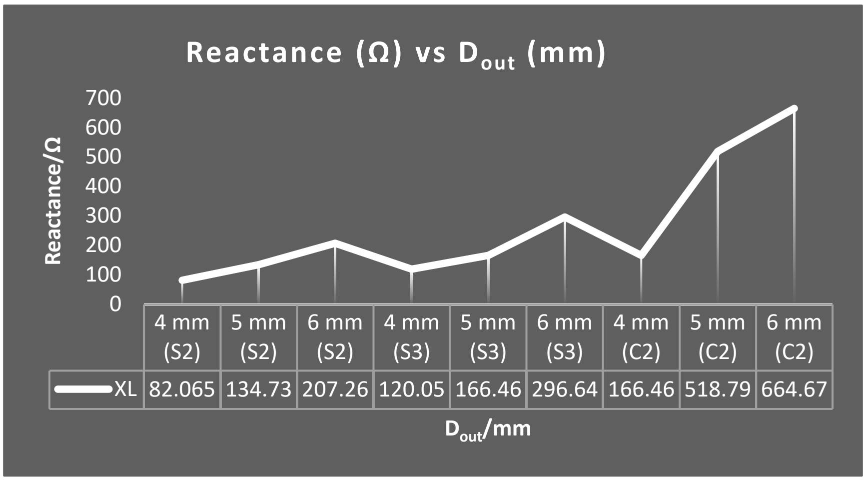



**Figure 4.** Reactance values of square and circular loop.

**Table 3.** Simulated reactance of inductor loop.

| Size (mm) | N | Reactance (Ω) |
|---|---|---|
| **4** | 2 | 82.065 |
| **5** | | 134.73 |
| **6** | | 207,26 |
| **4** | 3 | 120.05 |
| **5** | | 166.46 |
| **6** | | 296.64 |
| **4** | 2 | 166.46 |
| **5** | | 518.79 |
| **6** | | 664.67 |
| **4,5,6** | 3 | Too high |

*2.5. Magnetic field*

A magnetic field is a vector field that describes the magnetic influence on moving electric charges, electric currents and magnetic materials [6]. In electromagnetics, the term magnetic field is used for two distinct but closely related vector fields denoted by the symbols B and H. In the International System of Units, H, magnetic field strength, is measured in the SI base units of ampere per meter (A/m).[7] B, magnetic flux density, is measured in tesla (in SI base units: kilogram per second2 per ampere),[8] which is equivalent to newton per meter per ampere. H and B differ in how they account for magnetization. In a vacuum, the two fields are related through the vacuum permeability as in Equation 6 but in a magnetized material, the terms differ by the material's magnetization at each point.

$$B = \mu 0 H \tag{6}$$

In this paper, the relation between magnetic field and the size of the loops has been explained on the previous section. As the loops being simulated on CST, we know that theoretically the magnetic field is proportionally to the surface area. It means that when the size increases, the magnetic field also increases. From the further simulation, the simulated result obeys the theory. The results will be shown from Figure 5 until Figure 7.

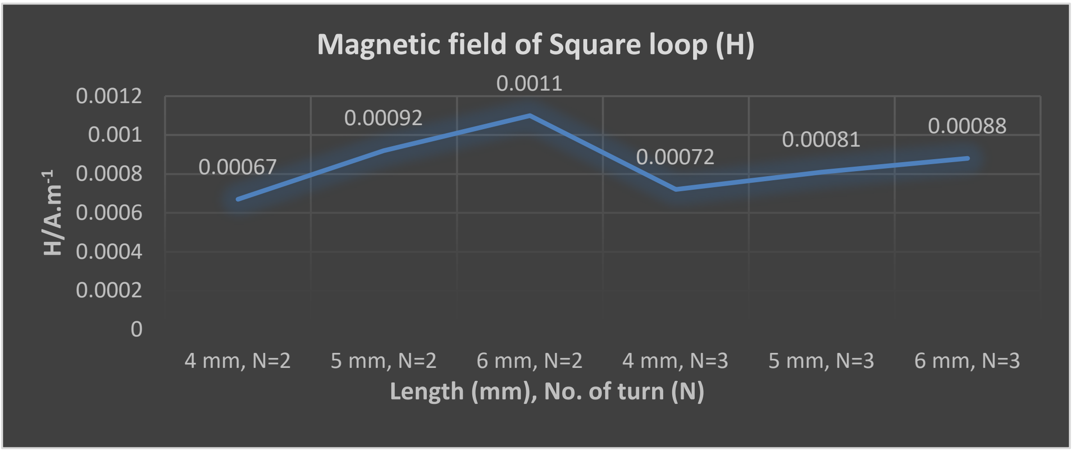



**Figure 5.** Magnetic field of square loops.

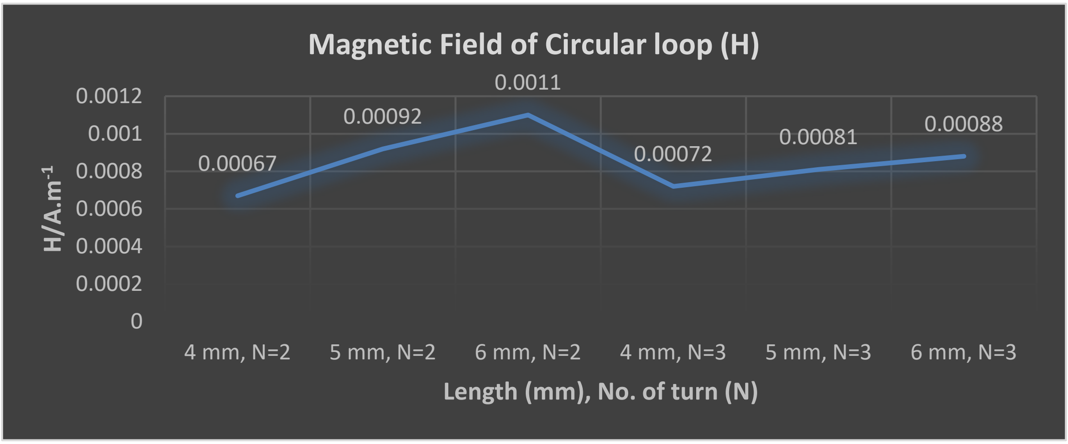



**Figure 6**. Magnetic field of circular loops.

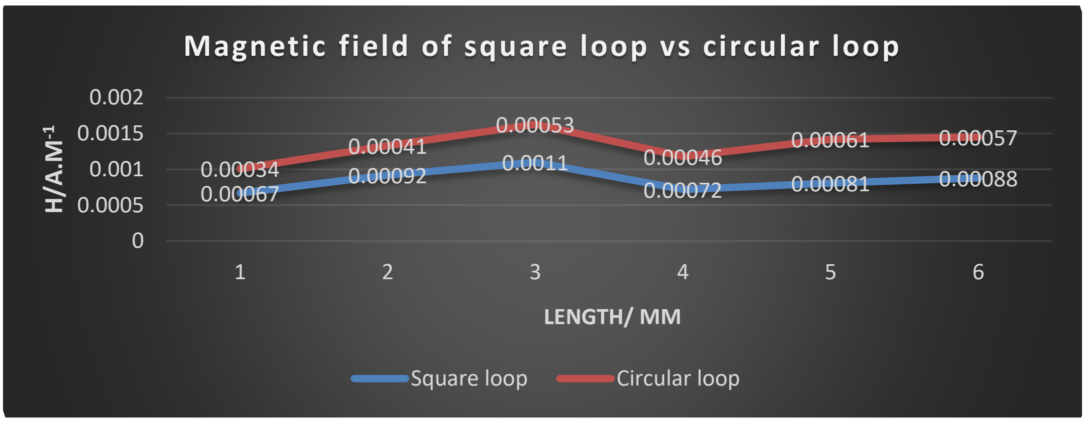



**Figure 7.** Magnetic field of square and circular loops.

## 3. Analysis

The inductance of the loop at operating frequency 920 Mhz is 0.22 nH as calculated in [Eq. 3]. Based on the equation, theoretically the inductance value is physically depending on the fill ratio (p) and average diameter of the loop (Davg). The loop width, w and the loop spacing is varied to achieve the inductance value at operating frequency 920 Mhz. The longer the length loop, the longer the length of w and s of the loop and the higher the value of XL. The value of XL must be matched with the value of XC of Monza R6 which is XC= j120.135Ω. Two different vectors are in use to represent a magnetic field: one called magnetic flux density (B) and the magnetic field strength (H). The magnetic field H might be thought of as the magnetic field produced by the flow of current in wires and the magnetic field B as the total magnetic field including also the contribution made by the magnetic properties of the materials in the field.

From the square loop and circular loop simulation, it shows that the higher the value of w and s of the loop, the higher the magnetic field strength (H). However, as the number of the turns increases, the H increases. It can be determined by the magnetic value of two loops of square and circular loop, it has higher magnetic field than the three loops.

## 4. Conclusion

A single loop IC module is evaluated to fed a wire embedded meandered dipole antenna for UHF RFID tag. A proper matching should be considered to ensure optimum couple energy to turn on the chip. The size reduction does not affect the magnetic field so much and to increase the magnetic flux, number of turns can be added.

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**Acknowledgments**

The authors would like to acknowledge the support from HID GLOBAL Sdn. Bhd., Advance RF and Microwave Research Group, School of Electrical Engineering and Universiti Teknologi Malaysia under grant number 21H69.