EE 492

Senior Design Project Midterm Report

ESTIMATION OF THE EFFECTS OF MATCHING LAYER ON WEARABLE AND IMPLANTABLE ANTENNAS USING NEURAL NETWORK

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I. Introduction

Wireless wearable and implantable devices are becoming popular within various areas such as medical, fitness, business operations, video games etc. Wearable devices can be in the form of glasses, watches, or any kinds of tools which are worn. These devices are used to track the user's movement, location, vital signs, calorie expenditure, sleep, and some other specific information. Implantable devices are more precision and usually require surgery; however, they can obtain information which cannot be accessible to sensors externally placed to the body. In the medical field, wearable and implantable devices have applications of monitoring, diagnosis, and treatment of various diseases.

Body centric wireless communications (BCWC) are established using wearable and implantable devices which provide wireless communication link between human body and the surroundings via wearable and implantable antennas. There exist mainly three different communication types in BCWC such as *on-body* communications, which occur between on-body devices, *in-body* communications, which are formed within implanted devices, and *off-body* communications, which occur between on-body and off-body devices [1]. The Fig. 1 shows a schematic of the mentioned communication types.

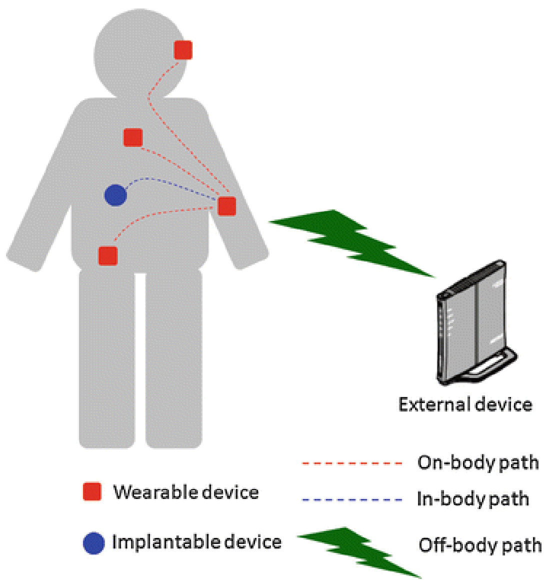


Fig. 1. A schematic of body centric wireless communications [1]

The antennas used in these devices are very sensitive to their surroundings. The properties of the implanted antenna such as average transmitted power, return loss, resonance frequency, bandwidth, etc are highly impacted by the presence of the body due to the fact that the human body is formed by highly lossy materials for radio frequency propagation [2]. These negative effects are mainly stemmed from path losses, which are caused by the impedance mismatch between the propagation environments (air and the body), near field losses and reflection. These factors result in an inefficient power transmission of the radio wave in the in-body communications and the on-body communications. Therefore, in order to improve the quality of the in-body and on-body communication links, a *matching layer* can be placed. By altering the permittivity and width of the matching layer, the quality of the in-body and on-body communication links can be enhanced.

II. Objectives

The determination of the matching layer parameters is accomplished by the means of simulation tools such as ANSYS HFSS. Also, where to place the antenna is a part of the design problem since the permittivity of the human body is not constant and it affects the performance of the antenna. Thus, in order to decide the optimum matching layer parameters and the location of the antenna, the simulation should run for a very long time.

The antenna which is simulated is determined as a circular loop antenna which works at 2.4GHz. So, the first objective is to design a circular loop antenna in the HFSS environment and to simulate in order to generate the training data for a neural network.

The aim of this project is to build a neural network which can estimate the antenna's transmitted average power, return loss, and resonance frequency in terms of the permittivity and width of the matching layer and the permittivity of the human body.

III. Approach and Methodology

As a first step of the project, the circular loop antenna theory will be examined and a circular loop antenna at a resonance frequency of 2.4GHz will be designed via HFSS. After obtaining the antenna, the literature about the artificial intelligence (AI) used in the field of the wearable and implantable antennas will be investigated. The knowledge of how the neural networks are constructed and which models are used will be obtained. After gaining an insight on the approach of neural network, a data set should be generated in order to train and test the constructed network. The data set will be generated by running simulation of the designed antenna in the HFSS with some predetermined parameters of matching layers and human body. Finally, with the adequate data set, the well-constructed network will be trained and tested.

IV. Work Completed

Loop antennas are one of the basic and cheap antenna types, also they are not complicated in production and analysis [3]. The loop antennas can be in the shape of rectangle, square, triangle, ellipse, circle and some other configurations. In the project, a circular shape is considered and the design procedure and the formulations of the textbook of Antenna Theory Analysis and Design [3] are followed to obtain a circular loop antenna whose resonance frequency is at around 2.4 GHz.

A. Design Procedure of the Antenna

The circular loop antenna is designed in HFSS. First, a circle with a radius of *wire_rad* is placed at a distance of *torus_rad* from origin. Then, it is swept around the origin by the amount of

$$\frac{2\pi torus\_rad}{2\pi torus\_rad + port\_gap} * 360$$

degree. After obtaining the torus with the given *port_gap*, a line is drawn with length of 2*wire_rad* across the center of wire. Then it is also swept around the origin by the amount of

$$\frac{port\_gap}{2\pi torus\_rad + port\_gap} * 360$$

degree in order to obtain the excitation port.

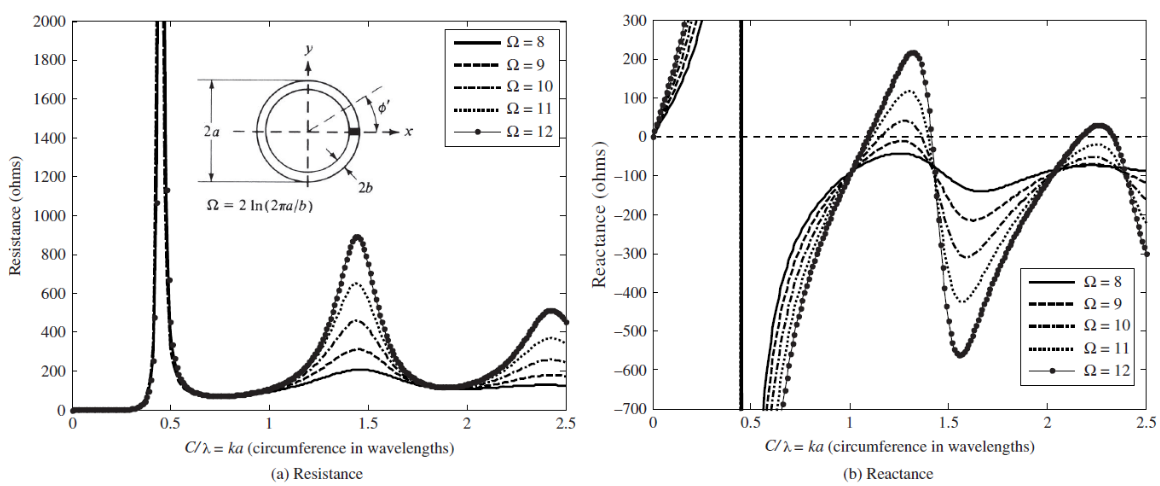


Fig. 2. Input impedance of circular loop antennas[3]

The circumference of the circular loop antenna where the self resonance occurs is selected. By referring the input impedance of circular loop antennas, which is shown in the Fig. 2, and choosing $\Omega = 12$, Lommel–Weber function [3], the circumference of the loop is approximately 1.089λ.

So, the *torus_rad* can be found at the frequency of $2.4GHz$ as following:

$$r_{torus} = \frac{1}{2\pi} 1.089 \frac{c}{f} = \frac{1.089}{2\pi} \frac{3 * 10^8}{2.4 * 10^9} \approx 2.15cm$$

The radius of the wire is obtained as following expression [3]:

$$\Omega = 12 = 2ln\left(\frac{2\pi r_{torus}}{r_{wire}}\right)$$
$$\rightarrow r_{wire} = 2\pi \frac{2.15cm}{e^6} \approx 0.0335cm$$

The *port_gap* of the antenna is selected as a value of $0.0335cm$, comparable to the *wire_rad*. The evaluated values of the antenna dimensions are implemented in the HFSS environment.

The Fig. 3 shows the constructed model in HFSS.

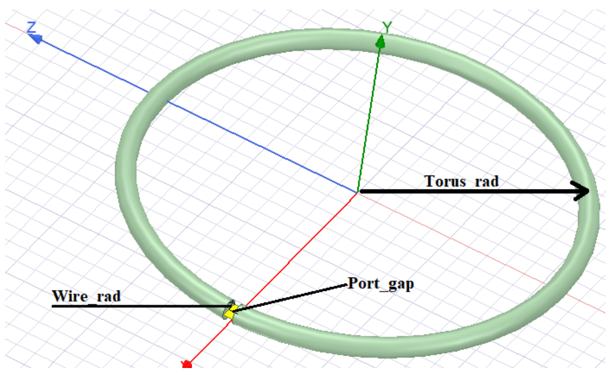


Fig. 3. Model in HFSS

The yellow plane is configured as a lumped port and the material of the solid loop is selected as perfect electric conductor (PEC).

B. Simulation Results

The simulation of the model which is proposed in the previous section with *torus_rad* of $2.15cm$, *wire_rad* of $0.0335cm$ and *port_gap* of $0.0335cm$ is run, and the 3D and 2D radiation pattern of the antenna are given in the Fig. 4.

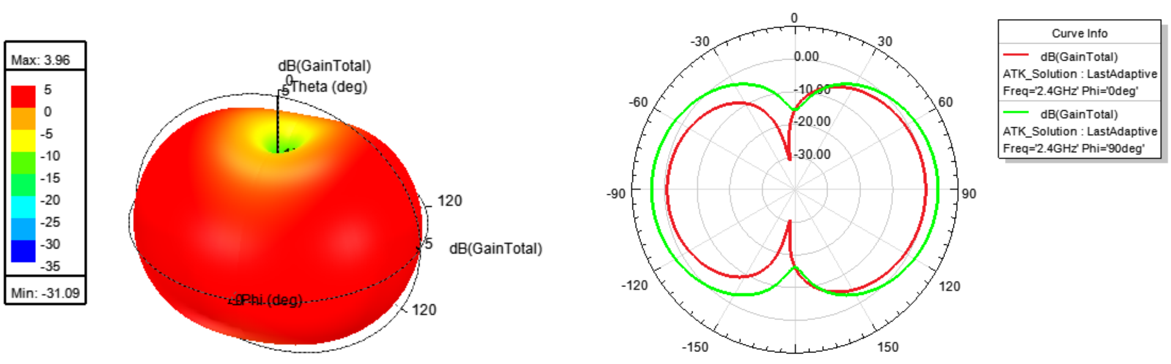


Fig. 4. The gain plots of the antenna

The return loss graph of the simulated antenna is shown in the Fig. 5.

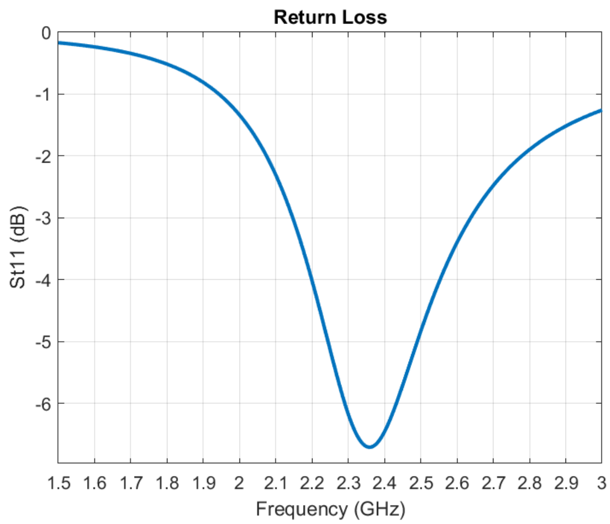


Fig. 5. The return loss graph of the antenna

These values are not as expected to be since the return loss curve should be below at least $-10dB$ at the resonance frequency of $2.4GHz$.

The effects of changing *torus_rad*, *wire_rad*, and *port_gap* are analyzed:

1) Torus Radius: The torus radius of the antenna is altered from $1.8cm$ to $2.4cm$ by the increments of $0.1cm$ while setting the wire radius and port gap as $0.1cm$, and the Fig. 6 shows the return loss of the selected parameters.

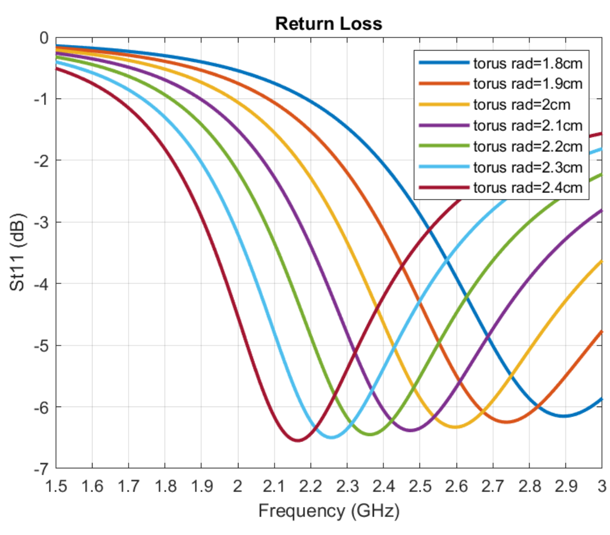


Fig. 6. The effects of changing torus radius on the return loss

So, it can be observed from the above figure that the implemented design behaves like an antenna since as its dimension increases, its resonance frequency becomes lower.

2) Wire Radius: Two sets of parameters are simulated to observe the effects of varying the wire radius. The first one is to change the wire radius from $0.01cm$ to $0.05cm$ by the increments of $0.01cm$ while setting the torus radius as 2.15cm and port gap as 0.03cm, and the Fig. 7 shows the obtained results. The second one is to change the wire radius from 0.1cm to 0.5 by the increments of 0.1cm while setting the torus radius as 2.15cm and port gap as 0.1cm, and the Fig. 7 shows the obtained results.

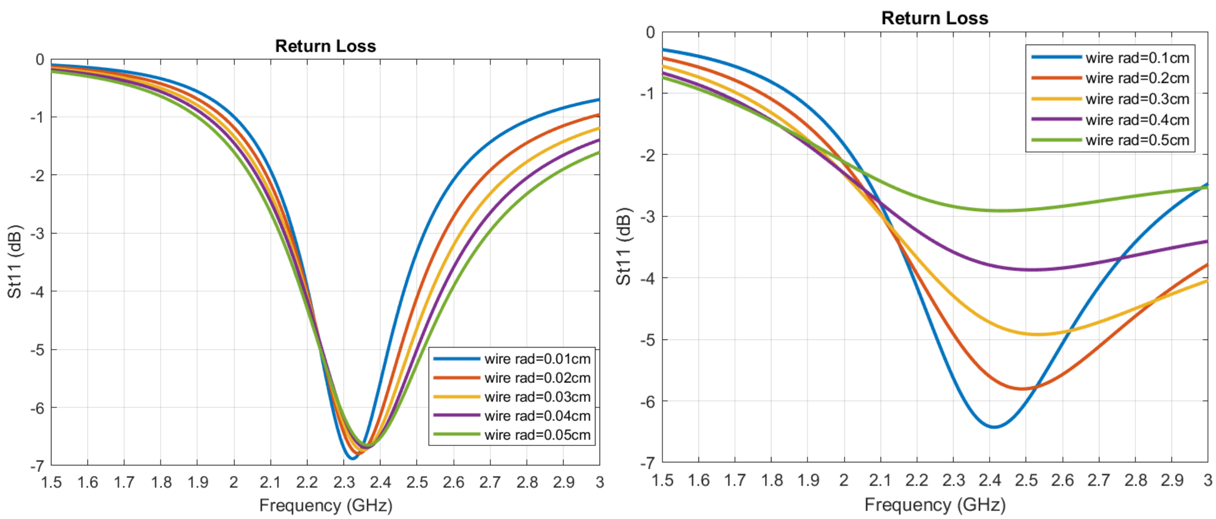


Fig. 7. The effects of smaller and larger increments of the wire radius on the return loss, respectively

In fact, it is expected that the change in the wire radius will improve the return loss results; however, the estimated impacts of the altering the wire radius does not occur in the above findings.

3) Port Gap: Similarly, two sets of parameters are simulated to observe the effects of varying the port gap. The first one is to set the port gap 0.03cm, 0.05cm, and 0.1cm while setting the torus radius as 2.15cm and wire radius as 0.03cm, and the Fig. 8 shows the obtained results. The second one is to change the wire radius from 0.1cm to 0.5cm by the increments of 0.1cm while setting the torus radius as 2.15cm and port gap as 0.1cm, and the Fig. 8 shows the obtained results.

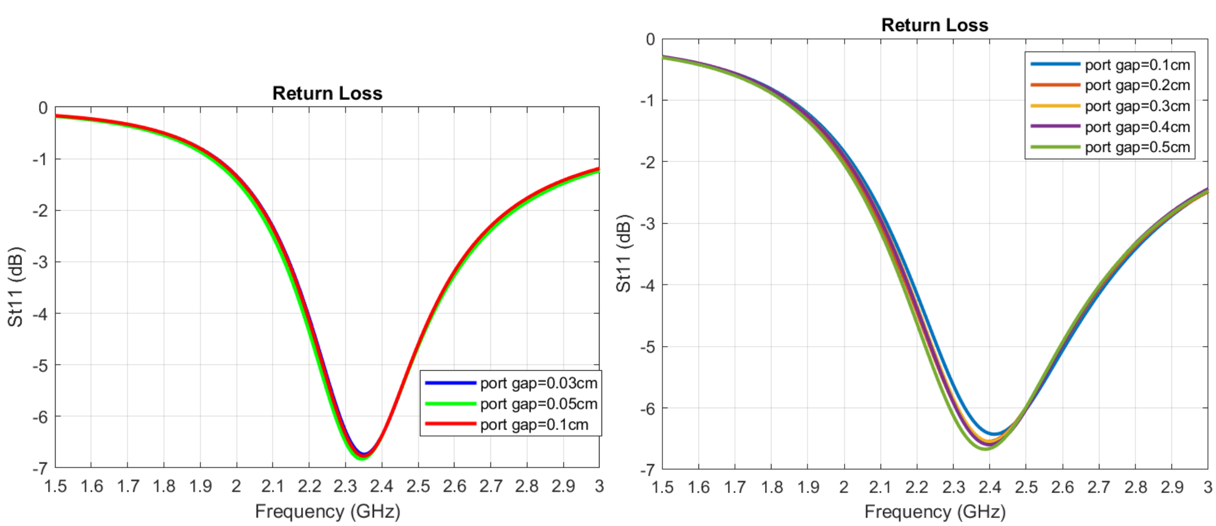


Fig. 8. The effects of smaller and larger increments of the port gap on the return loss, respectively

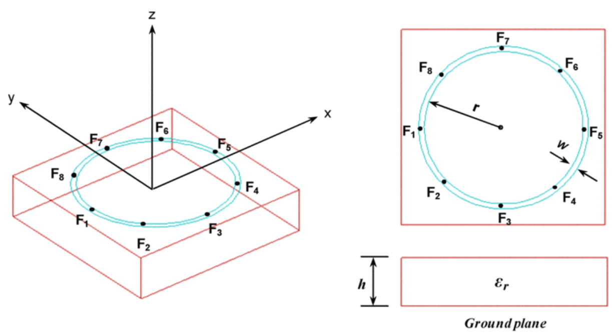
C. Conclusion

An attempt of designing a circular loop antenna which works at the frequency of 2.4Ghz is made; unfortunately, the expected results can not be obtained by altering the wire radius of the antenna. In fact, the change in the torus radius affects the results as expected. In order to match the antenna, a change in its excitation can be made rather than altering its dimensions. Therefore, a literature review about the matching a circular loop antenna is done in order to observe different implementations of the antenna.

D. Circular Loop Antenna Examples

In the implementation of a circular loop antenna, the input impedance matching to 50Ω is a challenge for antenna designers; therefore, they overcome this issue by taking different approaches to the antenna design.

1) Circular Loop Antenna with 8 Feed Points: The proposed antenna [4] is composed of a conductor strip loop of inner radius $r = 19.09mm$ whose strip width is $w = 1.5mm$ and thickness of $h = 12mm$ which is shown in the Fig. 9.



(a) (b)

Fig. 9. Circular loop antenna with 8 feeds: (a) Perspective view and (b) Top and side view

The antenna is fed at 8 feeding points F_1, F_2, F_3, F_4,F_5, F_6, F_7, and F_8 which are placed symmetrically over the circular loop with an angular spacing of 45°. Due to the symmetrical shape of the antenna, except for the directions of the beam, the performance of antenna is the same for all the feed locations. Thus, only one feed configuration, F_1, is analyzed and all other configurations are assumed to yield the same results.

The antenna is analyzed for configuration F_1 and its return-loss for 50Ω input impedance is shown in Fig. 6. The antenna resonates at a frequency of $f_0 = 4.4GHz$. As shown in Fig. 10, antenna shows a -10 dB bandwidth of $550MHz$ range from $4.2GHz$ to $4.75GHz$.

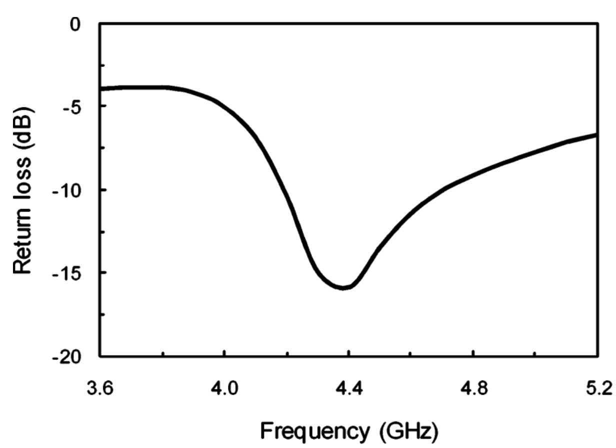


Fig. 10. Return Loss

2) Partitioned Circular Loop Antenna with Insertion of Five Capacitive Elements: The loop of the proposed antenna [5] is partitioned into multiple segments and loaded with capacitive elements at selected locations so as to decrease phase variations in the current flow and thereby increase the radiation efficiency. A total of five capacitors are used to achieve stable current flow, resulting in phase variations of $< 12°$. A thin-wire circular loop antenna of radius $r = 7.0mm$, circumference $C \approx 44.0mm$ $(0.85\lambda_0)$ and wire segments of radius $a = 0.5mm$ was designed for operation at 5.8 GHz. A total of 24 nodes deforming 24 wire segments comprise the antenna geometry, as shown in Fig. 11.

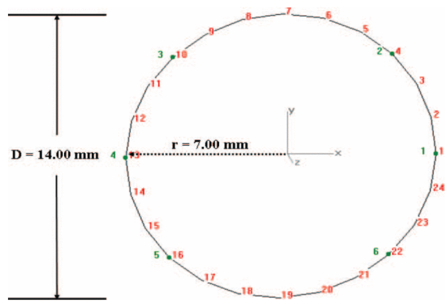


Fig. 11. Thin wire model of partitioned circular loop antenna with wire nodes (red) and lumped series ports (green) indicated

Five capacitive elements were inserted at the following node locations to cancel out the net inductance of the wire loop: 0.086 pF (nodes 4 and 22), 0.042 pF (nodes 10 and 16), and 0.047 pF (node 13). The antenna was simulated in transmission mode in free space from 1 to 10 GHz, resulting in an input impedance of $49.3 - j0.05\Omega$, a corresponding input admittance of $20.3 + j0.02mS$, and a return loss of 43.4 dB at 5.8 GHz, as shown in Fig. 12.

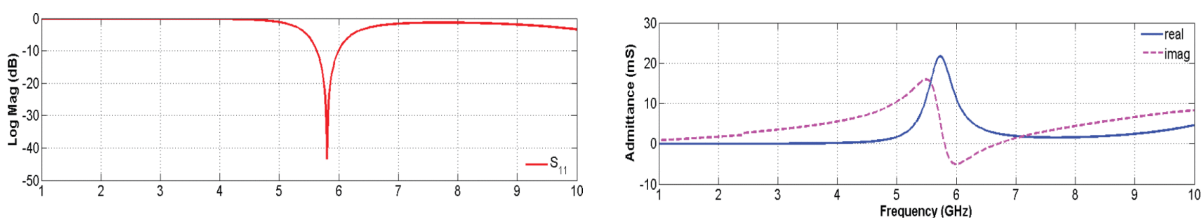


Fig. 12. Simulated return loss and input admittance for the thin wire partitioned circular loop antenna (5.8 GHz)

The simulated current magnitude and phase on the thin wire loop antenna, with and without lumped capacitors, are plotted in Fig. 13. The total phase shift with capacitive loading is on the order of 12°, which indicates good stability of the current phase over the entire length of the loop.

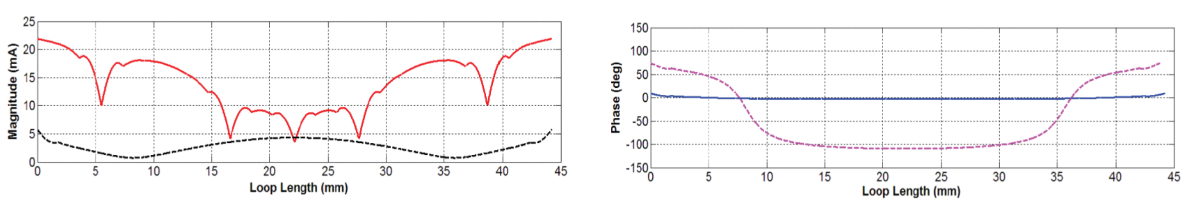


Fig. 13. Simulated current magnitude and phase on thin wire circular loop antenna with (solid) and without (dashed) lumped capacitors (5.8 GHz)

With the insight of the above circular loop antennas, a capacitor will be connected in the designed antenna in order to match the input impedance with the 50Ω.

V. Work To Be Completed

After completing the literature review about the artificial intelligence (AI) used in the field of wearable and implantable antennas, a neural network will be constructed. Then, with the designed antenna, a data set for the training a neural network will be generated by running simulation in the HFSS with some predetermined parameters of matching layers and human body. Finally, with the adequate data set, the well-constructed network will be trained and tested.

VI. Realistic Constraints

How many hours on a week are required to accomplish this project and the current level of knowledge of mine are the main constraints of the project. I plan to work 16 hours on a week but it might lengthen or shorten depending on other things. Another restriction is my knowledge about this field, I need to spend a couple of weeks on reviewing the literature to gain an insight on the neural network approach to the wearable and implantable antenna field.

A. *Social, Environmental and Economic Impact*

The estimation of the effect of matching layers using neural network can save the time which is spent on the determining the parameters of matching layer using simulation tools. So, the antenna designer will have more time to work on the other aspects of the antenna.

B. *Cost Analysis*

There exist some computer tools to realize the project such as, a simulation tool, ANSYS HFSS will be used and its licence is provided by the university; a platform to run the neural network algorithm, Google Colab is used and it's free.

C. *Standards*

The project will comply with IEEE, IET, EU and Turkish standards and the engineering code of conduct will be followed through the project.

References

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