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## Design and Analysis of Printed Square Loop Antenna and Solenoidal Loop Antenna for Pill Shaped Bio-implants Object

**Abstract-** This paper deals to design and investigated two proposed loop antenna for pill shaped bio-implants objects such as wireless capsule endoscopy. In additional it's help in developing an understanding of how the fields decay with distance. The first proposed loop antenna is the planar printed square loop antenna with outer dimensions 9 mm and inner dimension 0.45 mm, 6 turns, width 0.5 mm and 0.25 mm of space which can be easily integrated with a system-on-chip technology. The second proposed loop antenna is the solenoidal loop antenna where the solenoid had 9 turns, a pitch of 1 mm and a radius of 5 mm and can be easily wound in the form of a coil and encased within the pill shaped object. For both antennas the electromagnetic field was solved at 1MHz. From the radiation patterns results it can be observe that the surrounding pattern gain around the antennas is constant and conform the omnidirectional pattern associated to such loop antennas that fit the capsule endoscopy randomly movement within the human body in different directions. The design simulations and results are performed and validated by using commercial High Frequency Structure HFSS software.

**Keywords-** printed antenna, bio-implantable devices, Wireless Capsule Endoscopy, inductive coupling links.

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### 1. Introduction

Over the last few years and with the increased sophistication of medical implants, there is a growing need for flexible high-speed communication between external components and the bio-implantable devices [1]. The bio-Implantable devices are electronic devices fixed inside the human body for the treatment, diagnosis and long-term monitoring of certain diseases. These implants can be implanted in various ways such as cochlear implants, retinal implants, implanted micro-system stimulator and Wireless Capsule Endoscopy (WCE), among others. Bio-implantable devices are designed with the smallest possible size and occupy small area are to be implanted depending on the propose of use [2].

For the pill shape, implants object all the circuitry including antenna normally measures (10 mm \_ 25 mm). The frequency should be low for absorption of radiated fields by tissues [3]. Therefore, a dipole's length ( $l$ ) is usually much smaller than the wavelength ( $\lambda$ ) [4, 5]. The wireless capsule endoscopy (WCE) is based on a pill size, which captures the images of the digestive tract, while it is transported passively by peristalsis. Figure 1 shows the WCE structure which consists of battery, microelectronic circuits, an image sensor, radio frequency transmitter and planar loop antenna [6].

The WCE is used to perform a painless diagnosis inside the gastrointestinal tract. During the transit, the pill takes images from the CCD camera system, which is transmitted to an antenna placed outside the patient's body.

The new generation of WCE uses magnetic fields generated for controlling the capsule from outside the body in certain directions. The received electromagnetic energy using the near-field RFID is converted into a power supply for the capsule that is capable of localizing the device and determining the location of the pill inside the patient's body [7]. Hence, complementary information to this understanding will be the radiation pattern of a loop antenna in the near-field. In the near-fields, simple coils used in the implantable devices are planar square coil, planar circular coil and planar polygon coil (octagon coil, and hexagonal coil) [8]. These analytical expressions are used to compare the inductance value obtained by simulations.

Many researchers designed the coils that can be used for devices planted inside the human body.

The implanted spiral rectangular coils with dimensions 25 x10 mm with operated frequency 13.56 MHz is designed where the coil size is the issue [9]. Implanted spiral square coils with 20 x 8 mm of dimensions were designed for 1-5 MHz

operating frequencies, the size and relative short-range coupling still need to be considered [10]. Implanted circular coil with outer dimensions  $d_{out} = 18$  mm, and inner dimension  $d_{in} = 16$  mm was designed with an operating frequency of 742 KHz. Though, this design will increase the printed circuit board (PCB), and occupy a relatively large area within implantable devices [11]. Another spiral coil (pancake) to be used for implantable micro-system stimulator with dimension  $d_{out} = 11.6$ ,  $d_{in} = 5$  is designed by [12] where the human tissue depth is limited the coil applications. For wireless capsule endoscopy a solenoidal loop antenna is designed with  $10 \times 13$  mm [13] where the antenna dimensions is the issue.

This paper, intended to choose the most suitable radiating structure from various shapes and sizes of loop antennas possible to be for wireless capsule endoscopy. The structures that are to be analysed are: firstly; Printed square loop antennas with outer dimensions  $d_{out} = 9$  mm and inner dimension  $d_{in} = 0.45$  mm, 6 turns, width 0.5 mm and space 0.25 mm, this coil dimensions fit the pill dimensions as given in Figure 1. Secondly; Solenoidal loop antennas had 9 turns, a pitch of 1 mm and a radius of 5 mm is design to be used for same application. The electromagnetic field solution was obtained at a

solution frequency of 1 MHz. The proposed structures use the generated magnetic fields (MF) for controlling and powering the WCE circuits from outside the body in certain directions.

The reasoning credited for choosing to analyze these shapes is the practicality associated with these antenna shapes. The printed square loop antennas can be easily integrated with a system-on-chip (SOC) technology. A solenoidal loop antenna can be easily wound in the form of a coil and encased within the pill shaped object. HFSS aids in providing a solution to the complex electromagnetic fields surrounding the antenna. This will help in developing an understanding of how the fields decay with distance.

The aim of this analysis is to determine the inductance value of the printed planar square loop antenna and the solenoidal antenna. This is followed by the observation of the near-field radiation pattern and the decay of the electromagnetic fields with distance. In additional, the antennas performance and return loss for the square antenna is presented. The appropriate structure among the two is suggested for use in the near-field baseband wireless communication system for bio-implanted pill shape object.

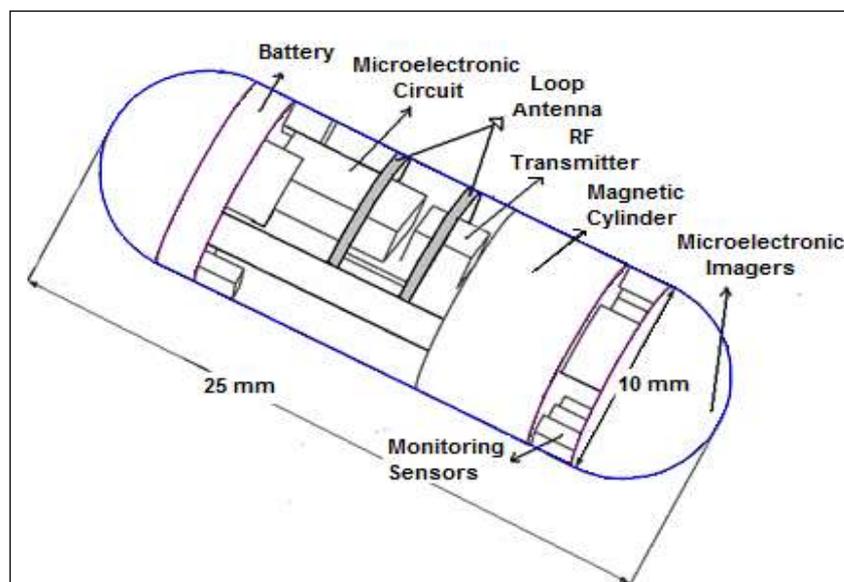


Figure 1: Drawing simulator represents the wireless capsule endoscopy structure

## 2. Printed Square Loop Antenna

The printed loop antenna is square in shape. A printed square loop antenna is characterized by the number of turns in the loop and substrate properties such as dielectric constant and thickness. The planar inductor can be directly printed on the printed circuit board (PCB). The copper track can be considered as the windings of

the planar inductor. Figure 2 shows the layout of a simple square planar inductor with its dimensions. It can be observe that the square inductor is totally specified by the number of turns ( $n$ ), turn width ( $w$ ), and the turn spacing ( $s$ ). Arithmetic geometrical averages like the average diameter ( $d_{avg}$ ) and the fill ratio defined as ( $\rho$ ) have to be computed as given in Eq. (1) and Eq. (2) respectively.

$$d_{avg} = 0.5 \times (d_{out.} + d_{in.}) \quad (1)$$

$$\rho = \frac{(d_{out.} - d_{in.})}{(d_{out.} + d_{in.})} \quad (2)$$

Where  $d_{out}$  and  $d_{in}$  represents the outer and inner diameter of the planar square antenna respectively.

In the current scenario, the expression based on approximating the sides of the spirals by symmetrical current sheets of equivalent current densities is used [8]. There are many expressions to choose from, like Wheeler's expression [14] and optimal expressions using geometric programming [15]. This particular expression was chosen owing to its simplicity and accuracy as given in (3).

$$L_{square} = \frac{N^2 d_{avg} C_1 \mu_0}{2} \left[ l_n \left( \frac{C_2}{\rho} \right) + C_3 \rho + C_4 \rho^2 \right] \quad (3)$$

Where the coefficients  $ci$  are dependent upon the layout in question. In this case it is a square for which the coefficients are given in Table 1. It has a maximum error tolerance of 8% for  $s \leq 3w$ .

As shown in Figure 3, a square planar inductor model was setup in HFSS. The model had the following dimensions:  $d_{out} = 9$  mm,  $d_{in} = 0.45$  mm,  $n = 6$ ,  $w = 0.5$ mm and  $s = 0.25$  mm. For better performance and higher efficiency, the substrate was made of Duroid material with thickness of 1 mm, and has dielectric constants with relative permittivity ( $\epsilon_r$ ) is 2.2, relative permeability ( $\mu_r$ ) is 1 and the dielectric loss tangent is 0.0009.

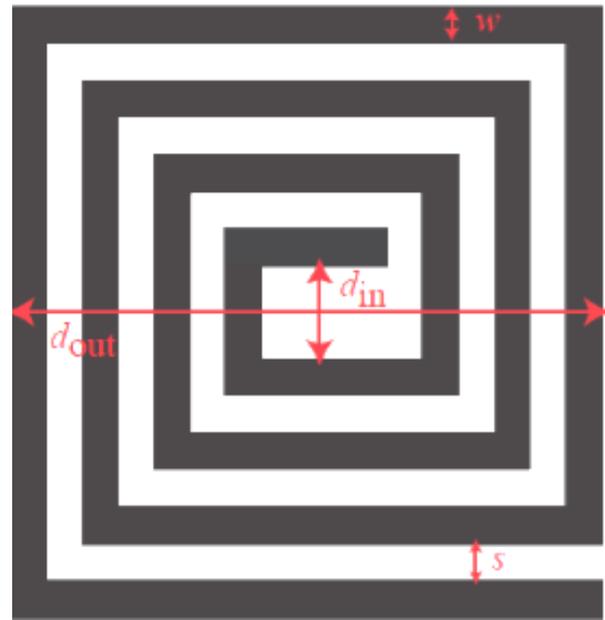


Figure 2: Layout of a simple square planar inductor

Table 1: Coefficients for Current Sheet Expansion Square Coil

Layout	$C_1$	$C_2$	$C_3$	$C_4$
Square Coil	1.27	2.07	0.18	0.13

Lumped ports were defined to act as the sources of excitation. They were defined as rectangles from the edge of the trace to the ground. The resistance was set to 50  $\Omega$ . An air box of dimensions (9:55 x 9:05 x 5) mm was defined as a radiation boundary. The electromagnetic field solution was obtained at a solution frequency of 1 MHz. Figure 4, shows a plot of the inductance of the planar square loop antenna against frequency as simulated by HFSS. The variation of the inductance is very small and lies between 0.1  $\mu$ H and 0.11  $\mu$ H. The value of the inductance was found to be 0.142  $\mu$ H by using equation (3).

The antenna gain was simulated on a sphere of radius 20 cm defined around the region of the antenna. Figures 5(a) and 5(b) show a plot of the antenna gain in the elevation and the azimuthal planes respectively. From the simulation results for the radiation patterns, it can be seen that the gain surrounded the coil is constant and conforms the omnidirectional radiation pattern associated to such loop antennas.

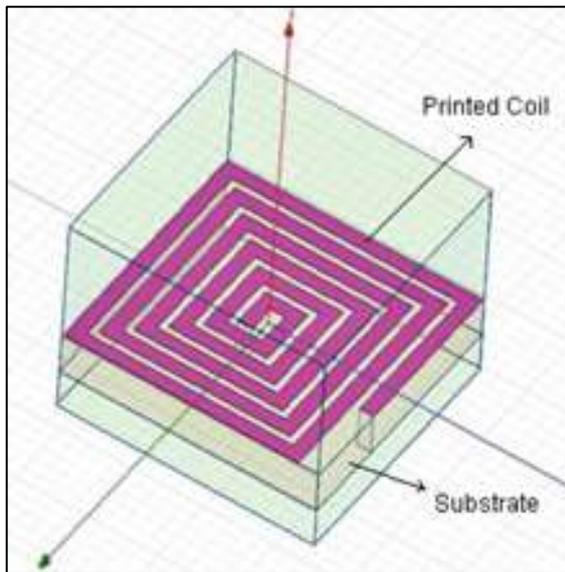


Figure 3: The design of the square planar inductor model with substrate in HFSS

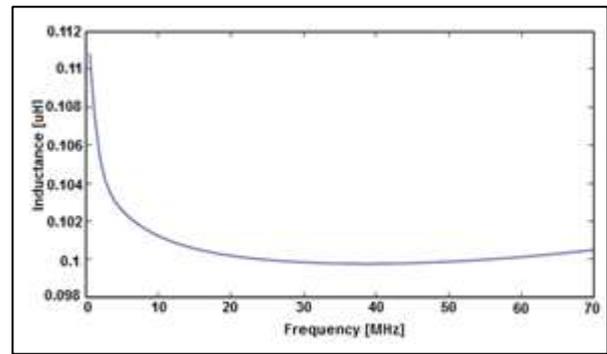


Figure 4: Simulation of the inductance of the planar square loop antenna against frequency in HFSS

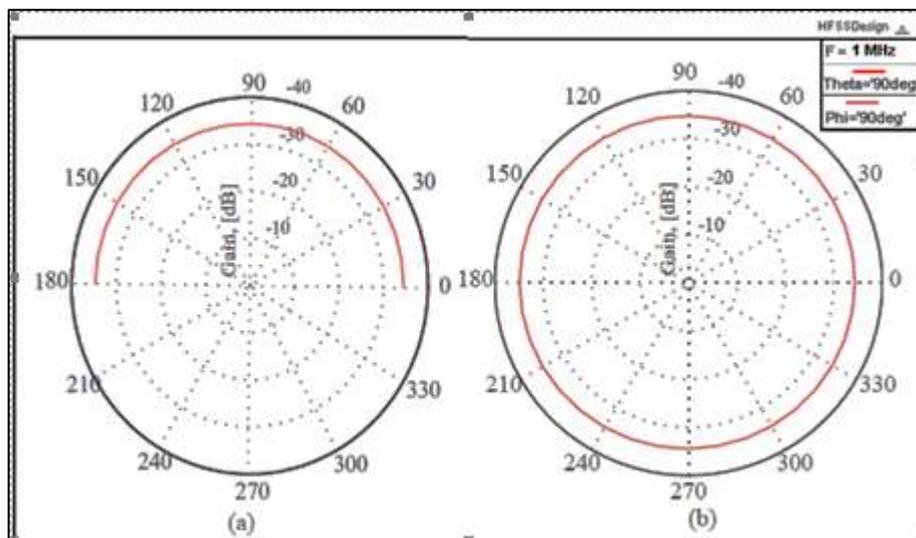


Figure 5: The simulated gain patterns of the planar square loop antenna: (a) Elevation plant ( $\Phi = 90^\circ$ ) and (b) Azimuthal plant ( $\theta = 90^\circ$ )

### 3. Solenoidal Loop Antenna

The solenoidal loop antenna is characterized by its number of turns (N), pitch (p) and the loop radius (A). Figure 6 shows the simple solenoidal loop inductor, where its inductance is calculated as given in equation (4).

$$L_{solenoid} = \frac{\mu N^2 A}{l} \quad [\text{Henrys}] \quad (4)$$

Where  $\mu$  (Henrys/meter) is constant and presents the magnetic permeability of the environment outside the conductor in free-space. Figure 7 shows the simulation model setup in HFSS. The solenoid had 9 turns, a pitch of 1 mm and a radius

of 5 mm. The wire was made of copper that had a radius of 0.355 mm.

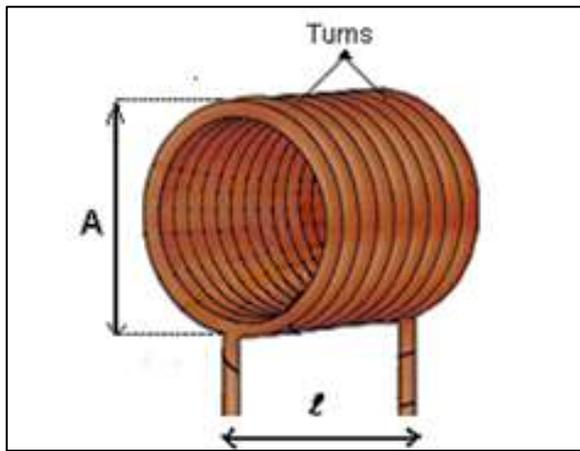


Figure 6: Simple solenoidal loop antenna

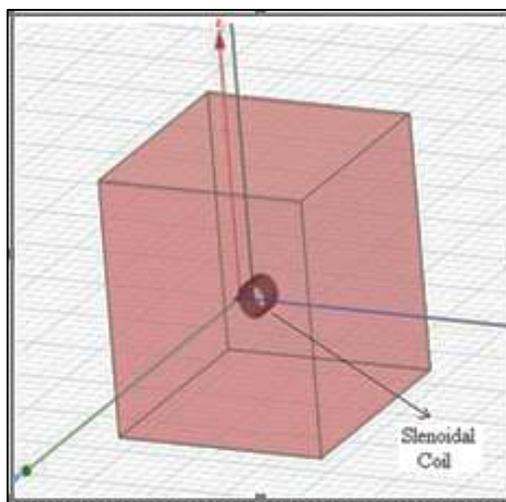


Figure 7: The design of the solenoidal loop antenna model in HFSS

A radiation box measuring (75 x 75 x 75) mm is drawn around the solenoidal loop antenna. Both the ends of the solenoid were extended uniformly to define a single lumped port. The resistance was set to 50  $\Omega$  as similar to the lumped port resistance of the planar square loop antenna and the electromagnetic field solution was obtained at a solution frequency of 1 MHz as similar to the planar square loop antenna. Figure 8 shows the variation of the inductance against frequency for the solenoidal loop antenna. From the plotted simulation in Figure 8, the value ranges between 0.525  $\mu\text{H}$  and 0.54  $\mu\text{H}$  and by using the Separation of internal inductance given by Rosa's self-inductance correction [16], the value of the inductance was found to be 0.605  $\mu\text{H}$ . A radiation sphere of radius 20 cm was inscribed around the solenoidal loop antenna and the gain plots of the solenoidal antenna were plotted in the elevation and the azimuthal planes as shown in Figures 9(a) and 9(b) respectively. The gain patterns surrounded the antenna are omnidirectional but the magnitude is not constant in every direction. A maximum change of 3-7 dB can be

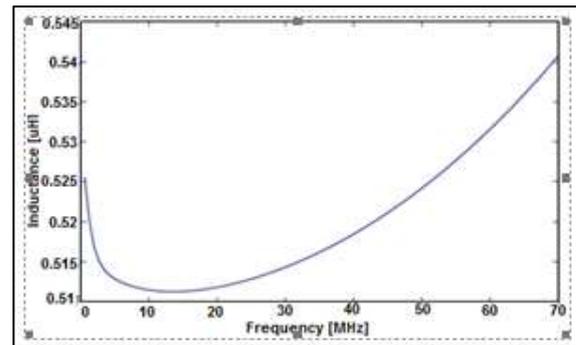


Figure 8: Simulation of the inductance of the solenoidal loop antenna against frequency in HFSS

found in the gain patterns of both the elevation and azimuthal plane patterns. The magnitude of the gain is also larger than that of the printed planar square loop antenna.

#### 4. Results and Discussions

The square loop antenna and the solenoidal loop antenna are both omnidirectional suggesting that they can be integrated with pill shaped implants such as wireless capsule endoscopy. The location of the pill will be unknown inside a human body and therefore the omni-directionality of the implant antennas is one of the salient features that have to be fulfilled. The inductive coupling links in the near-field works on the principle of coupling of magnetic fields between the transmitting and receiving antennas.

Related to Figure 5, it can be observe that the gain patterns around the printed square coil in the elevation and the azimuthal planes are mostly constant and conforms the omnidirectional radiation pattern associated to such loop antennas. Whereas, the gain patterns around the solenoidal loop coil in the

elevation and the azimuthal planes are omnidirectional but the magnitude is not constant in every direction as shown in Figure 9.

The reactive fields decay rapidly with distance; hence it becomes necessary that the radiating structure occupies a maximum volume within a confined space. It is clearly evident that the solenoidal loop antenna occupies much larger volume than a printed square loop antenna. Therefore a solenoidal loop antenna is magnetically larger than a planar square loop antenna. This claim can be supported by observing the gain of these antennas over a linear distance of 20 cm. Figures 10 and 11 shows the variation of gain with distance along the y axis for planar square and solenoidal loop antennas respectively. HFSS computes the field at a point and hence the distance has to be normalized by the number of points. For this particular case, the distance was normalized to 1000 points. It can be

observe that in either case the gain decreases with distance. But a careful observation reveals that the decay of a solenoidal loop antenna, as shown in Figure 11, is somewhat slower than the decay of a planar square loop antenna, as shown in Figure 10.

Hence the conclusion is that a solenoidal loop antenna is a better choice for use in near-field baseband communication systems. The field is measured from the centre of the solenoidal loop antenna up to a distance of 20 cm. The glitch in Figure 11 occurs as this is the boundary where the coil is positioned. Figure 12 shows the return loss  $S_{11}$  of the proposed square loop antenna which indicates that the square antenna radiates best at the working frequency 1 MHz. In additional, at 0.95 MHz the  $S_{11}$  is close to 0 dB, hence, the antenna will radiate almost nothing. Similar scenario designates for the Solenoidal Loop Antenna.

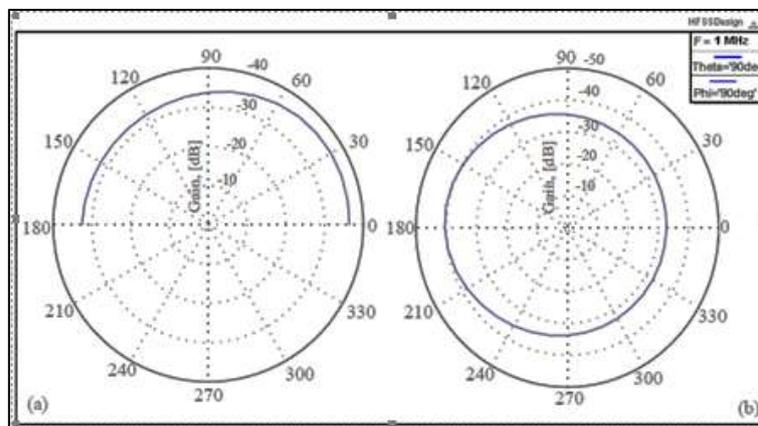


Figure 9: The simulated patterns of the solenoidal loop antenna: (a) Elevated plan ( $\Phi = 90^\circ$ ) and (b) Azimuthal plane ( $\theta = 90^\circ$ )

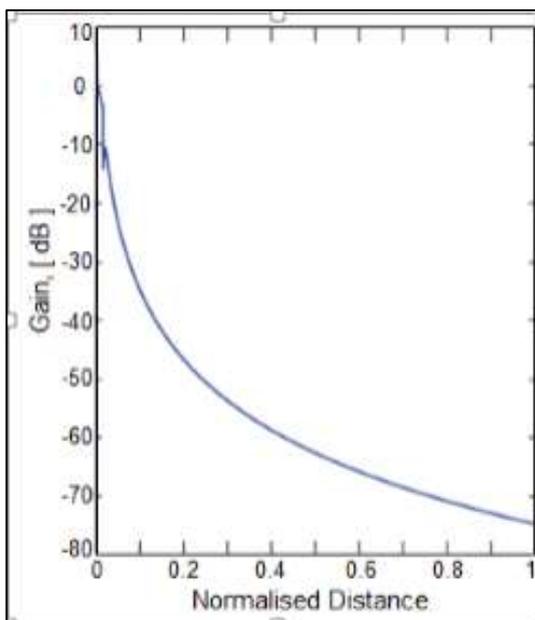


Figure 10: Gain against distance for planar square loop antennas

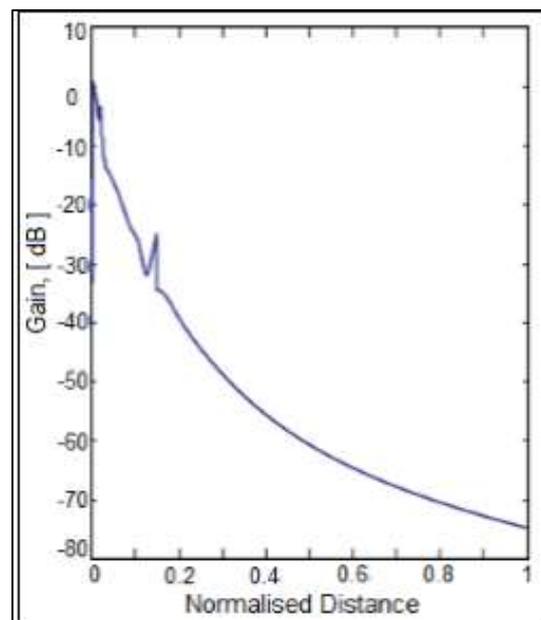


Figure 11: Gain against distance for solenoidal loop antenna

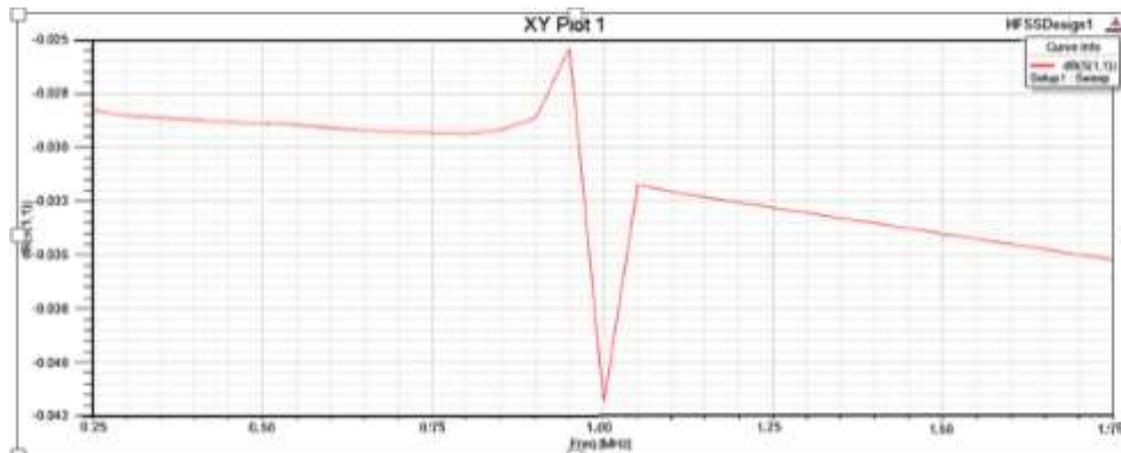


Figure 12: Return loss at 1MHz predicted by HFSS

## 5. Conclusion

This paper discussed the antenna choices, namely planar square loop and solenoidal loop antennas that are available for use to control and powering the implantable biomedical devices. HFSS, an electromagnetic field solver was used to analyze the electromagnetic fields around the antenna. It is based on the finite element method wherein geometry is divided in several tetrahedral and the field is solved on its vertices. The gain pattern of the

antennas was verified for their omnidirectionality and was found that both the antennas are omnidirectional in nature. The solenoidal loop antenna had a slightly non-uniform gain pattern but the gain was larger than the gain of a planar square loop antenna. The proposed coils may be used for bio-implantable devices based on pill shape such as wireless capsule endoscopy.

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