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Simulation of Planar Micro Coil Design for MEMS Bladder Pressure Sensor

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This paper presents a study of a copper-based planar micro inductor. The objective of this study is to investigate the performance of square planar micro coil which to be integrated with MEMS capacitive bladder pressure sensor. The micro coil structure was designed and simulated by using Computer Simulation Technology (CST) software. The investigation of the quality factor (Q-Factor), inductance and resistance of the coil was analyzed prior to the optimal geometrical dimensions. After considering the fabrication constraints, the optimal geometrical dimension of the micro coil was analyzed, and the parameters were chosen with width = 50 μm, gap = 50 μm, thickness = 3 μm, number of turns = 25 and inner diameter= 1000 μm. The Q-Factor, inductance and resistance value of micro coil were obtained at 69.2, 2.2 μH and 10 Ω, respectively at a 50 MHz operating frequency.

Keywords: square micro coil, quality factor, MEMS bladder pressure sensor

I. INTRODUCTION

In recent years, the demands for monolithic planar micromachined inductors have been greatly increased due to the rapid growth of wireless MEMS biomedical applications. The MHz range of frequency operation allows the reduction of the inductor size (Zhai et al., 2010). For in-vivo wireless measurements, the suitable and safe operating frequency is in the range of 10-100 MHz (Luo et.al, 2014). In term of size, the monolithic inductor should be designed with less than the diameter of a human intra-urethral catheter which is in the range of 7-8 mm (Alan Wein et. al, 2015). This is to make the catheterization process less painful and to provide a non-surgical option by inserting the sensor into the bladder.

In an LC resonant sensor, Q-factor is an important parameter as it measures energy transmission efficiency of the wireless system (Huang et. al, 2016).

High Q-factor is required as it will give better efficiency in energy transmission. The equation of Q-factor is given in Eq.1 where L*s* and R*s* are self-inductance and resistance of the coil, respectively.

$$f = \frac{1}{2\pi}\frac{1}{\sqrt{L_s C}} \quad (1)$$

The equation used to calculate the inductance are given by Eq. 2. (Neagu, 1998) (M Nabipoor & B Y Majlis, 2006)

$$L_S[H] = \frac{2\mu \cdot s}{\pi} N^2 \left[\ln \frac{s}{N\cdot(w+s)} + 0.2235 \frac{N\cdot(w+s)}{s} + 0.726 \right] \quad (2)$$

In which μ is the relative permeability of air, s is the distance between two wires, N is the number of turns and w is the width of the coil. The inductance value can be calculated associated with capacitance changes value of the pressure sensor. This gives changes in resonant frequency as shown in Eq.3:

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$$Q = \frac{2\pi f L_s}{R_s} \quad (3)$$

Fig.1 illustrates the circuit model of an LC pressure sensor. The sensor is modelled using an inductor, L_s, a series resistance of the inductor, R_s and a variable capacitor, C_s.

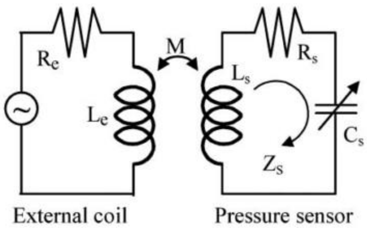

Fig. 1. Circuit model for LC pressure sensor (Huang et al., 2016)

II. MATERIALS AND METHOD

The Computer Simulation Technology (CST) software was applied to simulate the square planar micro coil. With the use of CST, the inductor parameters; Q-Factor, inductance and resistance values were analysed. The simulation setting for the finite element analysis is shown in Table 1. In this study, copper is a chosen material for the inductor due to its high conductivity. The 7740 glass substrate is used to decrease the parallel parasitic capacitance of the inductor (Zheng et al., 2016). Fig.2 shows the square micro coil design using CST software. Table 2 represents the value for the geometrical parameter of the planar coil. In this study, the geometrical parameters design (width, gap, thickness, number of turns and inner diameter) is investigated to achieve high Q-Factor for wireless bladder pressure detection application.

Table 1. The parameters setting for the finite element analysis

Parameter	Value
Resistivity, ρ	1.72 x 10 $^{-8}$ Ω.m
Young Modulus, E	120 kN/mm^2
Poisson's Ratio, v	0.33
Port Reference Impedance, Z	50 Ω

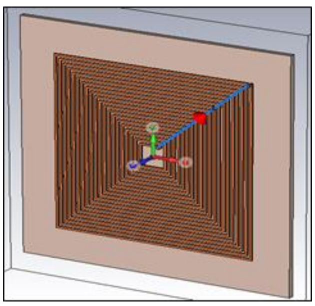

Figure 2. Square micro coil design using CST

Table 2. Parameter value of square planar micro coil

Parameter	Value
Width	50 μm
Gap	50 μm
Thickness	3 μm
Number of turns	15,20,25,30
Inner Diameter	1000 μm

III. RESULTS AND DISCUSSION

A. Geometrical Parameter Analysis of Micro Coil

The Q-Factor and the outer diameter of the micro coil were analysed due to the changes of coil geometry as shown in Table 2. The Q-Factor value was analysed prior to the changes of the number of turns as presented in Fig.3. From Fig.3, the Q-Factor was increased as the number of turns increased. This due to the increasing of inductance value which makes the increment in Q-Factor (Yunas et.al, 2010). The Q-Factor increases rapidly at low frequency region compared to the high frequency region. This is due to the skin effect phenomenon. The skin effect causes the effective resistance of the conductor to increase at higher frequencies where the skin depth is smaller, thus reducing the effective cross-section of the conductor (Akar et.al, 2001). Increasing the winding numbers would also increase the Q-Factor, however, it leads to a bigger size of the micro coil. The outer diameter of the coil should be at least 6 mm to enable it to be integrated with MEMS bladder pressure sensor application. Fig. 4 shows the plotted graph of the number of turns versus the outer diameter of the coil. From Fig. 4, the outer diameter of the coil is compensated at 25.5 number of turns and this gives the outer diameter approximately 6000 μm.

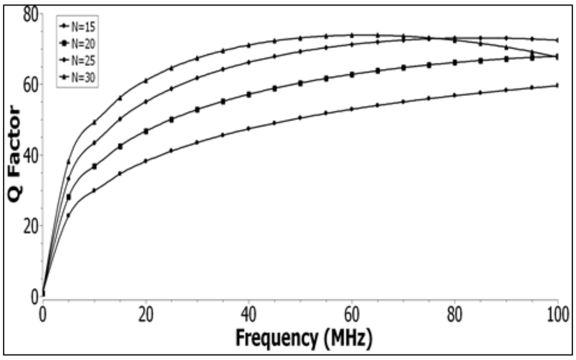

Figure 3. Q-Factor of the micro coil versus frequency with various number of turns

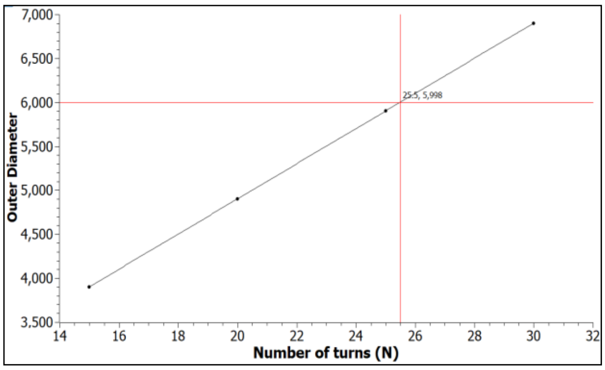

Figure 4. Number of turns versus outer diameter of the coil

B. *Optimized Parameter of the Micro coil*

From geometrical parameter analysis of the micro coil, the suggested parameters of coil width = 50 µm, coil gap=50 µm, coil height = 3 µm, number of turns = 25 and inner diameter = 1000 µm. By utilizing this combination, the output response of the Q-Factor, inductance and resistance of the coil was simulated and presented in Fig 5, 6 and 7, respectively. The value of Q-Factor, inductance and resistance value was obtained as 69.2, 2.2 µH and 10 Ω at 50 MHz, respectively.

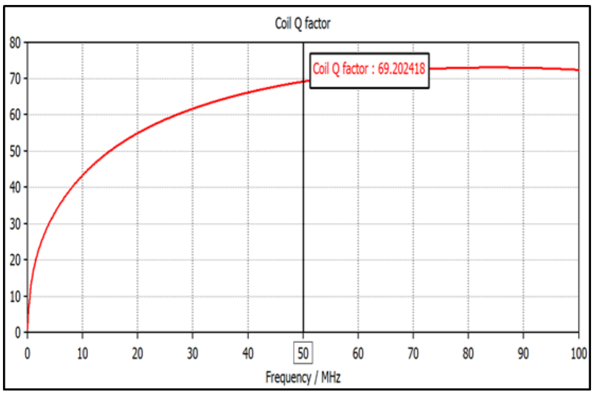

Figure 5. Q-Factor of the coil for optimized parameters

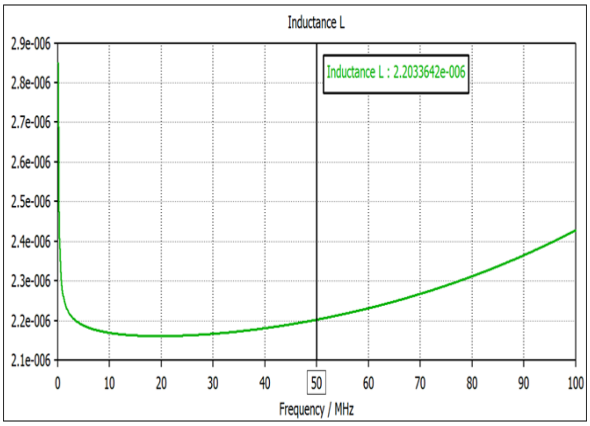

Figure 6. Inductance of the coil for optimized parameters

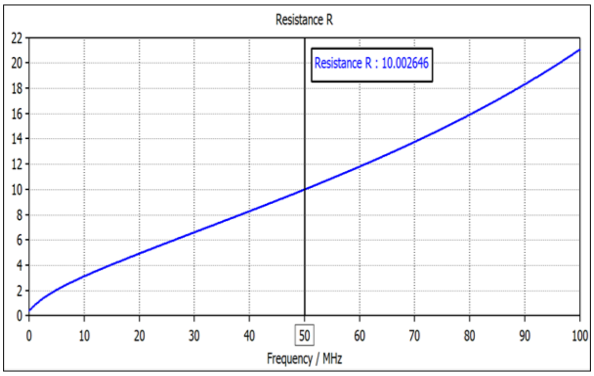

Figure 7. Resistance of the coil using optimized parameters

Based on our previous study (Yusof N et.al, 2018), the capacitance value was changed from 2.1 pF to 2.7 pF in bladder pressure range, 0-160 mmHg. By applying the inductance value, 2.2 µH and the capacitance changes in Eq. 1, the frequency changes for pressure variation can be calculated. Fig. 8 shows the changes of frequency responses for the sensor under 0–160 mmHg applied pressure. From Fig. 8, the frequency responses change linearly from 65 to 74 MHz subjected to an applied pressure with 54.4 kHz/mmHg sensor sensitivity, thus demonstrating its potential for bladder pressure monitoring.

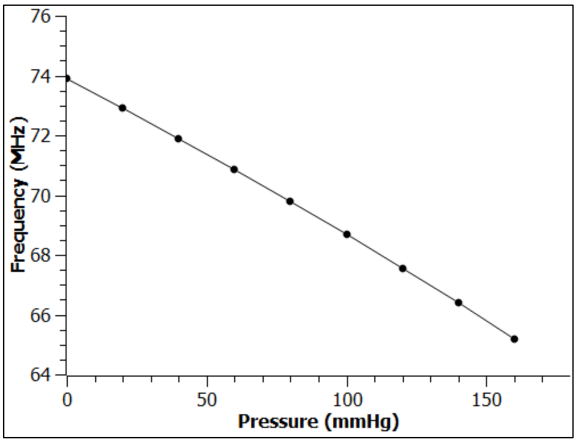

Figure 8. Frequency response versus applied pressure

IV. CONCLUSION

Analysis of a planar micro coil design was presented in this study. The coil Q-Factor, inductance and resistance were analyzed using computer simulation technology (CST) software. The optimal geometric parameters of width = 50 µm, gap = 50 µm, thickness = 3 µm, number of turns = 25 and inner diameter= 1000 µm of micro coil after considering the trade-off between the micro coil size and coil Q-Factor. From this study, it can be concluded that the geometrical parameters suggested are suitable for designing the monolithic micro coil with implantable MEMS bladder pressure sensor. Future works will focus on the fabrication of micro coil for wireless MEMS bladder implants.

V. ACKNOWLEDGEMENT

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