Cavity-backed annular slot antenna analysis for bone fracture healing stages

T. Selvaraji[1], N. B. Asan[2*]

[1]Fakulti Kejuruteraan Elektronik dan Kejuruteraan Komputer, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia
[2]Centre for Telecommunication Research and Innovation (CeTRI), Fakulti Kejuruteraan Elektronik dan Kejuruteraan Komputer, Universiti Teknikal Malaysia Melaka, Durian Tunggal 76100 Melaka, Malaysia

[*]Corresponding author's email: noorbadariah@utem.edu.my

ABSTRACT: Bone healing monitoring systems are great interest for medical applications to avoid swelling, bruising, and deformities during the healing process. In this paper, a cavity-backed annular slot antenna is proposed to assess the abnormalities in their healing progress without any additional pain. The antenna is simulated in four-layer tissues to determine its four different healing stages behavior in a human tissue environment by using the CST software. This paper deals with wearable antenna designing for the frequency range of 2.08–2.65 GHz. The simulation results indicate that three different methods for monitoring bone healing stages are possible: magnitude, frequency, and a combination of magnitude and frequency.

Keywords: *Bone healing monitoring system; Cavity-Backed Annular Slot Antenna (CBAS); Microwaves*

1. INTRODUCTION

In musculoskeletal injuries, bone fractures are the most prevalent types of trauma. X-rays are one of the most often utilized analysis methods, and visual assessment of the image determines the position and size of the fracture [1]. However, even though X-Ray may be hazardous due to significant exposure to radiation, also it is not recommended X-Ray for infants, pregnant women, or people over 50 years old [2,3]. Undoubtedly, CT scans and MRI tests produces high-quality screening, but it is not suitable for frequent use due to the expensive treatment cost and higher risk of health problem that the patient might encounter. Alternatively, this paper aims to explain about the developed non-invasive antenna system that can monitor the healing of bone fractures. This non-ionizing method may be critical for the healing process in determining if further treatment is required and reducing the number of X-rays needed to assess the bone condition. This antenna – benefits the medical applications that require a low-cost and non-invasive procedure—the cavity-backed annular slot antenna for monitoring the healing stages by looking at the changes of return loss.

2. METHODOLOGY

Humans are composed of unique and complex interconnected systems. Therefore, the structure of the four-layered tissues (skin, bone, muscle, and bone) was simplified into rectangular models using the Computer Simulation Technology (CST) Studio Suite software. Figure 1 depicts the simulation modeling setup for the ideal case of the bone healing facture, which comprises of skin, fat, muscle, and bone. To simplify the tissue structure, the tissue thicknesses was fixed to the average thickness of each tissue for an ideal case. As in the ideal case (healthy bone), the skin, fat, muscle, and bone have thickness of 2 mm, 10 mm, 20 mm, and 25 mm, respectively. To study bone healing progression as close as possible to the real situation, the tissue dimension was set to 70 mm (W) × 70 mm (L) in all cases. Additionally, the boundary conditions for all dimensions were set to be open-boundaries, except for the one on top of the skin, which was set to be an open-added boundary. The purpose of this is to mimic as close as possible the real situation in which there is air space above the skin while simulating the infinite width of the tissues. The tissue layers will also change correspondingly according to the healing stages. The healing stages have been categorized into four bone fracture healing stages: 1st stage, 2nd stage, 3rd stage, and 4th stage. Table 1 illustrates the changes in the tissue layer during the various stages of bone healing. Finally, the simplified structure is numerically simulated using the CST software to study and analyze the variation of the reflection coefficient (S_{11}).

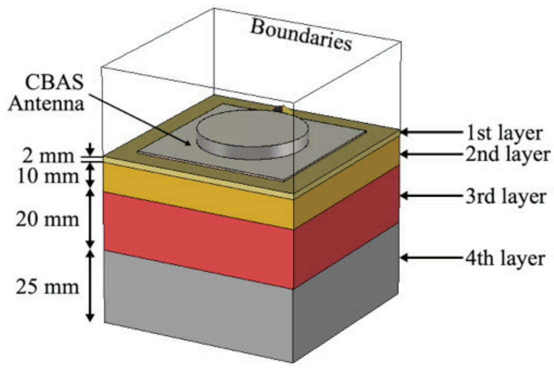


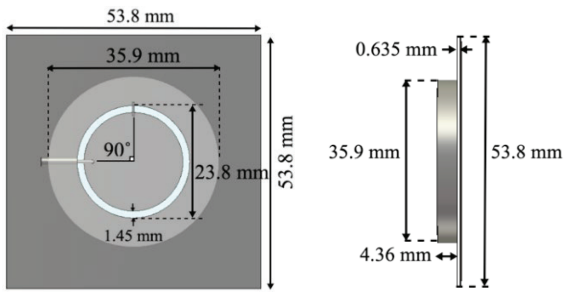
Figure 1 The simulation setup for the ideal case of bone fracture healing progress

Table 1 The tissue details of bone healing stages

Stages	1st layer	2nd layer	3rd layer	4th layer
Ideal	Skin	Fat	Muscle	Bone cortical
1st stage	Skin	Blood	Blood	Muscle
2nd stage	Skin	Muscle	Muscle	Muscle
3rd stage	Skin	Fat	Fat	Muscle
4th stage	Skin	Fat	Muscle	Bone cancellous

3. RESULTS AND DISCUSSION

The overall dimensions of the antenna design, which is integrated with Rogers TMM3, TMM6, and TMM10 substrates with dielectric constants of 3.45, 6.15, and 9.80, respectively, are shown in Figure 2. The effect of the frequency with respect to the substrate dielectric constant using the cavity-backed annular slot antenna is shown in Figure 3. The operating frequency was obtained by varying the substrate materials. The purpose of varying the dielectric constant of the substrate is to determine the antenna's sensitivity and examine the return loss changes corresponding with the healing stage of a bone fracture. The higher the dielectric constant, the resonance frequency shifts to the lower frequency.



(a) Top-view (b) Side-view

Figure 2 Cavity-backed annular slot antenna dimension optimized for skin-fat-muscle-bone structure

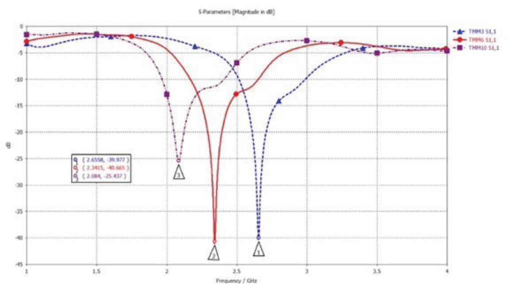


Figure 3 The effect of the frequency with respect to the substrate dielectric constant

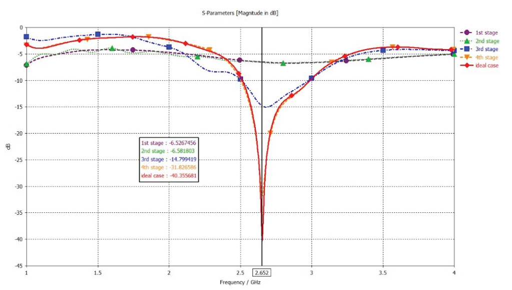


Figure 4 The return loss variations of the bone healing stages using Rogers TMM3 substrate

The changes in the return loss with respect to the bone healing stages are depicted in Figures 4–6 for the TMM3, TMM6, and TMM10 substrates. According to observations, the return loss during the first and second stages of bone healing is extremely low, typically less than –10 dB. It is due to the early healing stage of the tissue, which present high dielectric properties; blood and muscle tissue. Additionally, the variation of the return loss in the third stage (skin-fat-fat-muscle) is close to the ideal case (healthy bone). Overall, there are different trends of the return loss variations observed in Figure 4–6. Thus, it feasible to monitor the bone healing stages using a various method, including variation in the magnitude (Figure 4), a variation in the magnitude and the frequency (Figure 5), and the variation in the frequency (Figure 6).

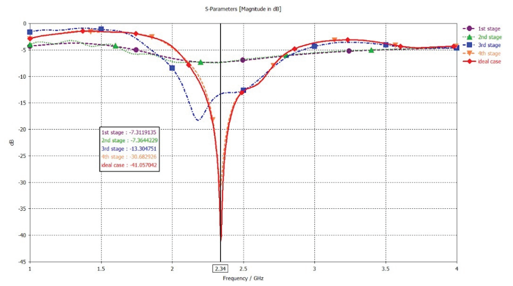


Figure 5 The return loss variations of the bone healing stages using Rogers TMM6 substrate

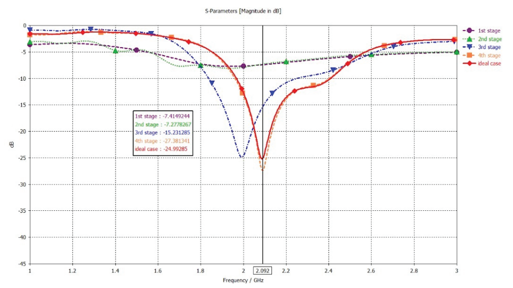


Figure 6 The return loss variations of the bone healing stages using Rogers TMM10 substrate

4. CONCLUSION

This paper presents a cavity-backed annular slot antenna to monitor the bone healing fractures for medical applications. The antenna was designed and optimized in a simplified four-layered structure. In conclusion, based on the results obtained, the magnitude, frequency as well as combinational of magnitude and frequency methods can be used to monitor the healing stages of bone fracture.

ACKNOWLEDGEMENT

The authors are grateful to Universiti Teknikal Malaysia Melaka for the financial support.

REFERENCES

[1] D. R. Kumar, G. V. Babu, and N. Raju, Intelligent Antenna System for Medical Applications. SN COMPUT. SCI. 1, 176 (2020).

[2] S. Redzwan et al., "Frequency domain analysis of hip fracture using microwave Split Ring Resonator sensor on phantom model," *in Proceedings of 2016 IEEE Asia-Pacific Conference on Applied Electromagnetics (APACE)*, Langkawi, 2016, pp. 244–247.

[3] D. Lee, J. Velander, T. J. Blokhuis, K. Kim and R. Augustine, "Preliminary study on monitoring the progression of osteoporosis using UWB radar technique in distal femur model," *in Electronics Letters*, vol. 52, no. 8, pp. 589–590, 2016.