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Development of Microwave Antenna for Cancer Treatment

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Abstract. For cancer treatment, microwave thermotherapy method is widely used especially for liver cancer treatment by using a coaxial biomedical applicator device. This device is used to transfer heat from microwave generator to liver tissue in order to kill cancerous tissue. Neglecting the impedance matching between the applicator and the liver tissue can lead power reflection to the power supply or loss into the surrounding healthy tissue. The impedance of the applicator is hugely dependent on the structure and dielectric material used as the insulator for the biomedical applicator. In this work, we aim to study the best structure of the applicator, which can minimize the impedance mismatch. There are two phases required in order to achieve the aim. In first phase, parameter of the applicator has been estimated using the characteristic of impedance for coaxial structure. In phase two, the biomedical coaxial applicator is designed using the electromagnetic simulator software and the results were analyzed to identify the best parameter used for the design. The result of return loss obtained at 2.45 GHz is −25.42 dB with impedance of 21.23 Ω. From the value of return loss, 0.29% of power will be reflected to the generator or surrounding tissue while another 99.71% of power will be transmitted into the cancer cell. Based on the finding, most power is transmitted efficiently to the liver and less power is reflected to the surrounding which means it is harmless to the surrounding tissue.

Keywords: Ablation · Thermotherapy · Cancer treatment · Impedance matching

1 Introduction

Cancer begins when healthy cell transforms and develops out of control, forming a mass called a tumor. A cancerous tumor is malignant, which means it can grow and spread to other body parts. Cancer that begins in the liver usually called as primary liver cancer. There are three types of primary liver cancer happen in adults. The first one is hepatocellular carcinoma (HCC). HCC is the most common type of primary liver cancer in adults that is the most common cause of death in people. Roughly, 75% of liver cancer are HCC. The second one is Cholangiocarcinoma. Cholangiocarcinoma is a type of cancer that forms in the bile ducts. Approximately around 10% to 20% of liver

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cancer develop in the bile duct of the liver [1]. The last type of primary liver cancer are Angiosarcomas. Angiosarcomas is a cancer of the blood vessel's inner lining and it can occur in any part of the body. The disease occurs mostly in the skin, breast, liver, and deep tissue. Around 1% of liver cancer begins in the blood vessels of the liver and it can grow very quickly. Besides types of primary liver, there are four main stages in liver cancer [1]. The stages are determined by the size of the cancer (tumors) and how the cancer spread into the body. On the first stage of liver cancer, a single tumor grows around 2 cm or less than 2 cm and the cancer has grown or has not grown into the blood vessels. As the liver cancer reach the second stage, the single tumor reach 2 cm and has spread into the liver's blood vessels or there are numbers of tumor in the liver but all of them is less than 5 cm. There are several tumors in the liver but one of them must be larger than 5 cm in third stage of liver cancer. Onto the final stage of liver cancer, the cancer already grown into the blood vessel or has spread to organs around the liver. Besides that, the cancer also grown through the lining that wrap around the abdomen's internal organs.

Traditionally to treat cancer treatment, majority choose to use a major surgical operation and this technique is widely used in medical institutions especially in Malaysia. In this modern technology, minor surgery techniques have been proposed to kill the cancer cells by heating them within temperature range of 42 °C until 45 °C. This is because this range of temperature, which is 42 °C until 45 °C, is good enough to kill the cancer cells. Currently, this technology has been explored using a Magnetic Nano Particle (MNP) [2, 6, 7]. This MNP induces into human body and cancer cell is killed by using heat from magnetic field vibration. This process is called self-regulating. However, there are several problems that need to be solved when using this technique. One of them is to control the temperature so that it can maintain in suitable range during operation. Another problem is to maintain the focus point for the heating process when using magnetic particles. Therefore, to overcome these problems the thermotherapy technique is one of the best options since the heating can be transferred using an antenna applicator. In this technique, a needle-shaped antenna is used to kill the cancer tissue [3, 8].

In conventional design, the design neglects impedance matching between antenna and cancer cell [3, 11, 12]. The return loss, S_{11} drop at frequency of 2.45 GHz for conventional design is −9.82 dB. This situation can conclude that 90% power will transmit into the cancer tissue but there will be another 10% of power will loss. This can be harmful if the power loss is lost to the surrounding of the liver tissue, which can harm normal tissue [10]. This situation happens because the impedance of the applicator mismatch with the impedance of the liver as in theory of impedance matching. The impedance between applicator and liver should be similar to minimize the mismatch between the applicator and the liver. Thus, adjusting the impedance of the applicator is the only option to match the impedance, since the impedance of the liver is unchangeable. In this work, a new design of biomedical applicator is proposed by using microwave coaxial antenna in order to treat liver cancer by minimizing the impedance mismatch so that more power will be supplied to the cancer liver. The coaxial structure is used because of the needle-shaped structure which will ease the surgical procedure in addition to the simplicity in derivation of its impedance based on impedance-line microwave theory.

2 Design of Antenna

2.1 Impedance Theory and Dimension Determination for the Applicator

The difference between the impedance of the biomedical applicator and liver tissue can lead power reflection to the power supply or loss to the surrounding healthy tissue. Thus, the impedance matching is very crucial in this work. In this work, the coaxial biomedical applicator used is shown in Fig. 1. When using structure of coaxial cable, there is a specific formula on how to calculate the impedance. The equation of the impedance of coaxial structure is:

$$Z_o = \frac{138\, log_{10}\left(\frac{2\times R_2}{2\times R_1}\right)}{\sqrt{\varepsilon r}} \tag{1}$$

From the equation, the factor that affects impedance, Z_o are the value of inner, R_1 and outer radius, R_2 and, the value of dielectric property, ε_r. Teflon with permittivity (dielectric property) of 2.08 and tan $\delta = 0.00048$ is chosen in this work because this material has very low loss properties. Figure 2 shows the cross-section of coaxial cable where, D_i is the diameter of inner conductor while D_o is the diameter from inner conductor. The value of radii is one of the main factor that should be considered before choosing the suitable dimension for the applicator, in order to have an appropriate size of needle especially for minor surgery. From Fig. 3, the value of impedance is chosen as nearly equal to impedance of liver, which is 21.23 Ω at 2.45 GHz. The impedance of liver was estimated from the simulation based on conventional design of coaxial cable with phantom liver. When the return loss is low the impedance of the coaxial cable can be considered same as the liver. After the impedance value is known, the ratio of R_2/R_1 can be obtained in order to calculate the specific size of the parameter used. From the graph the value of R_2/R_1 is 1.67. The different of R_1 and R_2 is represent the thickness of dielectric material, so the appropriate thickness for fabrication need to be considered during the selection of R_1 and R_2. Thus, value of R_1 is chosen as 0.48 mm and the value for R_2 is 0.8 mm.

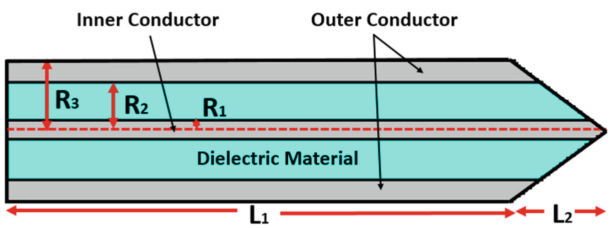

Fig. 1. Structure of needle-shaped antenna.

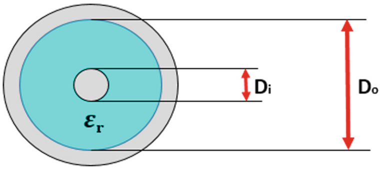

Fig. 2. Coaxial cable cross-section.

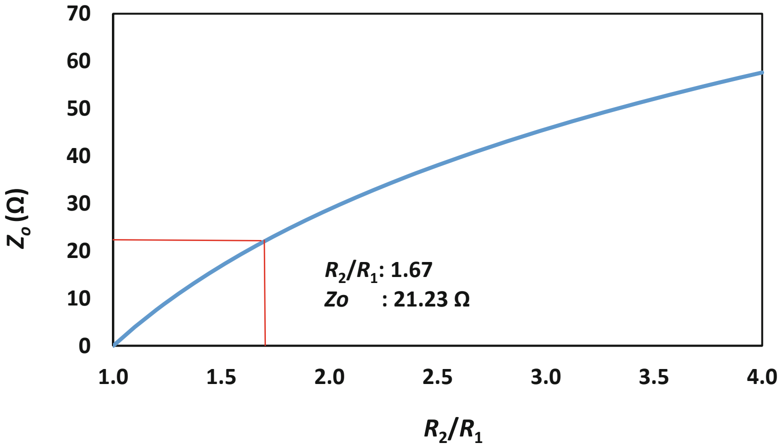

Fig. 3. Impedance characteristic towards ration of R_2 and R_1.

2.2 Phantom of Liver

Liver which affected with cancer cell is considered having the same electrical properties as the healthy liver [5]. Thus, the properties of liver is imported from voxel data of human biological models that having permittivity of 46.83. Since the size of cancer cell for stage one to three is around 10 to 50 mm, a 40 × 40 × 31 mm liver phantom model is modelled as a cuboid in simulation software as shown in Fig. 4. It is necessary in order to monitor the specific absorption rate, SAR.

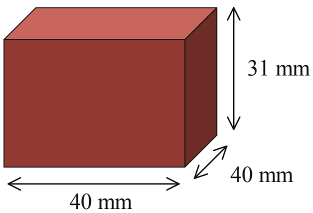

Fig. 4. Model of liver phantom for microwave ablation.

3 Result and Discussion

In this work, the design of the applicator is designed based on design in Fig. 1 but with different parameters. This way is important in order to analyze the effect of different parameters, which are the radius of R_1, R_2, R_3, and the length of L_1, L_2. The analysis of the parameter is needed in order to estimate the impact towards body tissue if the fabrication is imperfect. The parameters of return loss, S_{11} and specific absorption rate, SAR have been simulated. S_{11} is simulated in order to getting the performance of the antenna where S_{11} should lower than -10 dB, while SAR will indicate the energy absorb by human body when exposing to electromagnetic field. In this work, the value for S_{11} and SAR are simulated at frequency of 2.45 GHz which is the common frequency for microwave ablation in liver cancer treatment using CST Studio Suite.

3.1 Parametric Analysis Towards Return Loss

Effect of R_1 Toward Return Loss. From the S_{11} values in Fig. 5, the deepest S_{11} is obtained when $R_1 = 0.48$ mm which indicated the loss is at minimum level. Other than that, the S_{11} does not met the requirement as a good antenna at 2.45 GHz, for example, when $R_1 = 0.25$ mm the value of S_{11} is -7.79 dB which is greater than -10 dB. This value of S_{11} can lead to almost 17% of power reflected back to the surrounding and only 83% power will be transmitted compare to our chosen R_1 which is $R_1 = 0.48$ mm. This R_1 has value of $S_{11} = -25.42$ dB. When value of S_{11} is -25.42 dB, only 0.29% of power will be reflected back while the remaining power will transmit into the cancer tissue.

Effect of R_2 Toward Return Loss. From Fig. 6, the $S11$ values did not suit as the good antenna's condition while using $R2 = 0.75$ mm, 0.83 mm and 0.88 mm. Even though the value of $S11$ for these $R2$ are good and have a good depth which is -18.36 dB, $-$ 27.49 dB and -19.46 dB but the $S11$ do not drop at frequency of 2.45 GHz which cannot be accepted. Meanwhile, $R2 = 0.80$ mm was accepted as the good parameter value of $R2$ because the value of $S11$ drop exactly at 2.45 GHz with the value of -25.42 dB.

Effect of R_3 Toward Return Loss. From Fig. 7, almost all five parameters of R_3 has the value of S_{11} that drop at the required frequency. So, the best value for R_3 is at 0.90 mm (red line) which has the depth of $S_{11} = -25.42$ dB. Besides that, at $R_3 = 0.82$ mm and $R_3 = 0.87$ mm, the value of S_{11} at both R_3 have more depth compared to the value of S_{11} at $R_3 = 0.90$ mm. However, those R_3 is not good enough to be selected because the values were too close to the R_2 value which will affect the thickness of the outer conductor. Thus, this design is not practical and difficult for fabrication process. For $R_3 = 1.00$ mm and 1.50 mm the value of S_{11} recorded too close to -10 dB which will degrade during real fabrication.

Effect of L_1 Toward Return Loss. From Fig. 8, all S_{11} are below -10 dB, which indicates that L_1 has less effect on the return loss value. Therefore, L_1 is chosen as 73.00 mm to avoid a bulky design but at the same time the performance is preserved.

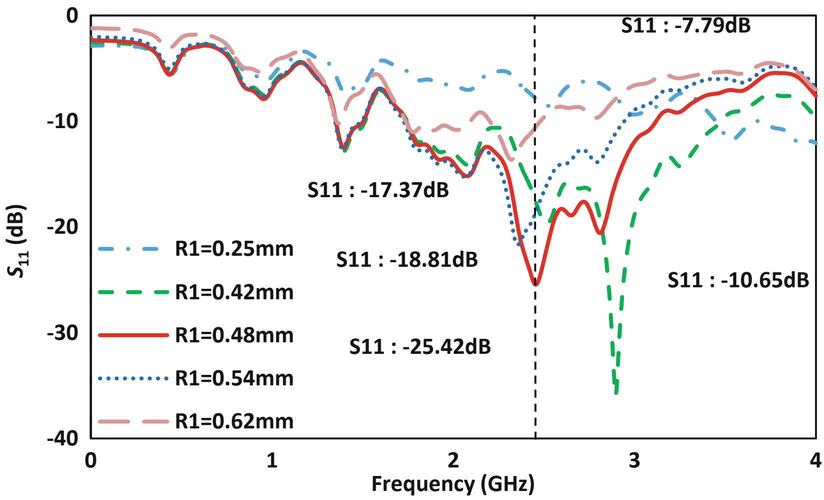

Fig. 5. Effect of inner radius towards return loss.

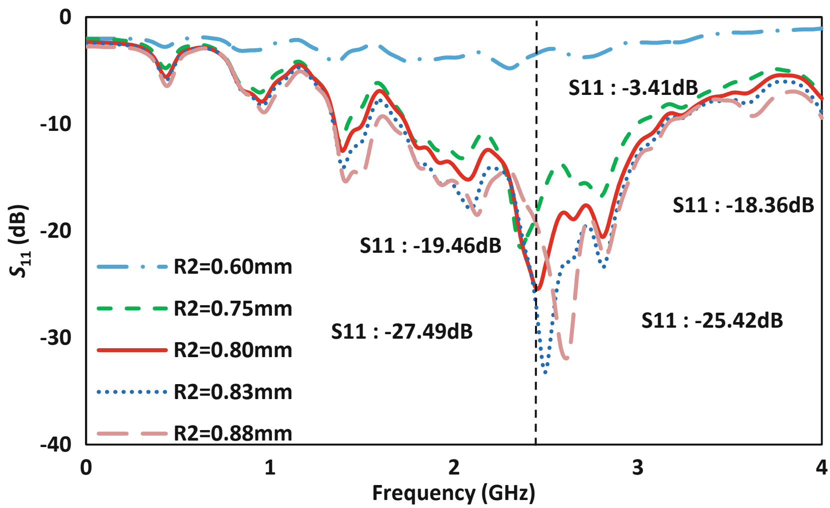

Fig. 6. Effect of dielectric radius towards return loss.

Effect of L_2 Toward Return Loss. From Fig. 9, the value of S_{11} for $L_2 = 4.5$ mm, $L_2 = 5.0$ mm, $L_2 = 8.0$ mm and $L_2 = 10.0$ mm were -7.37 dB, -10.43 dB, -15.79 dB and -8.62 dB, respectively. These parameters cannot be selected because the value of S_{11} are either close to or less than -10 dB. Therefore, the red line is the only line lies at 2.45 GHz and has S_{11} of -25.42 dB.

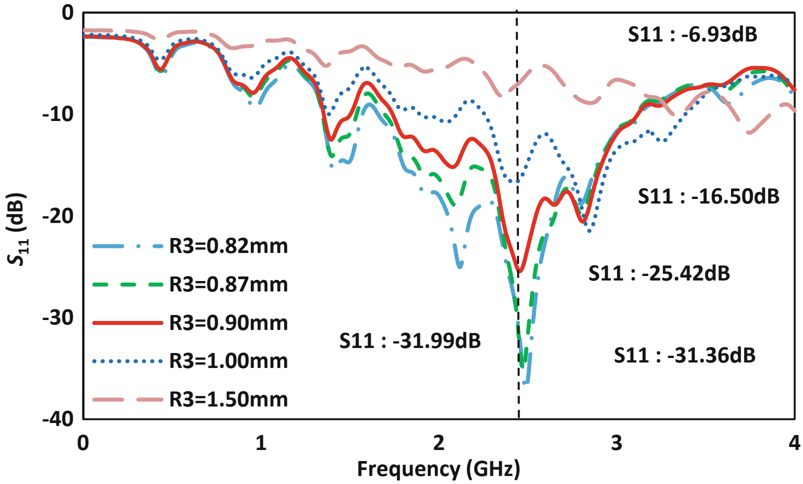

Fig. 7. Effect of outer radius towards return loss.

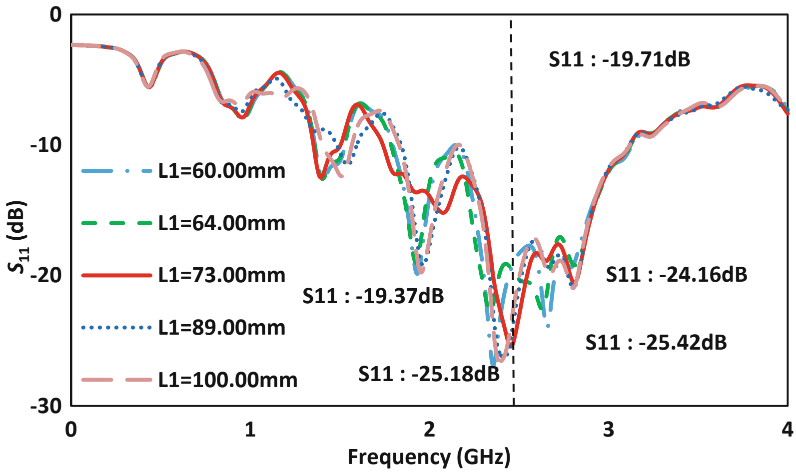

Fig. 8. Effect of L_1 towards return loss.

3.2 Simulation of Return Loss and SAR for the Final Design

From the analysis above, the final parameter for final design are $R_1 = 0.48$ mm, $R_2 = 0.80$ mm, $R_3 = 0.90$ mm, $L_1 = 73.00$ mm and $L_2 = 6.69$ mm. From the parameter value, the impedance for the applicator can be calculated using formula (1) and the value of impedance obtained is $Z_o = 21.23\ \Omega$. By using concept of impedance matching, when the impedance of the applicator match with the impedance of the liver, the reflected heat power will decrease and more heat power will transmit into the liver.

Figure 10 shows the return loss for the final design of the applicator. It is clearly shown that the design can afford a depth of return loss at 2.45 GHz. When 100% power

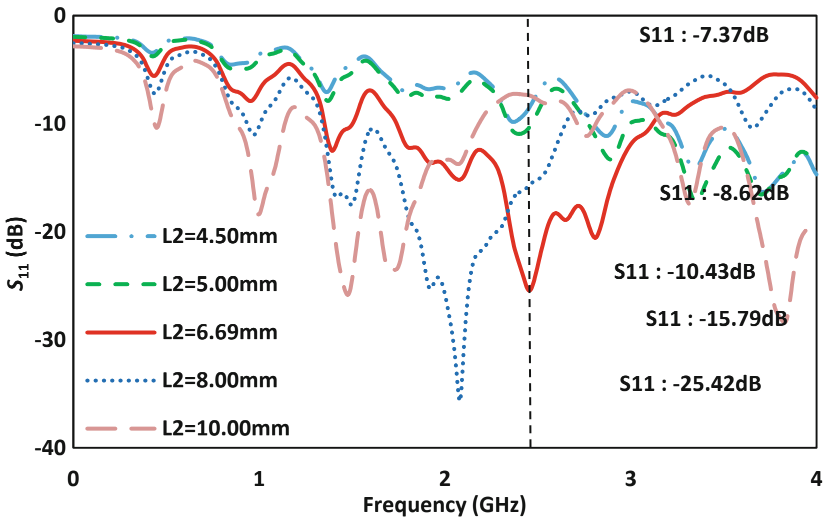

Fig. 9. Effect of L_2 towards return loss.

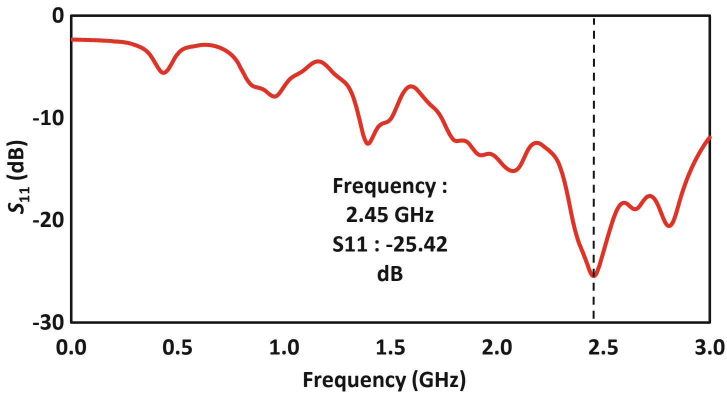

Fig. 10. Return loss characteristics of final design.

is assuming incident the applicator, 0.29% power will be reflected back to the generator or to the surrounding tissue and the remaining power that is 99.71% power will be transmitted into the liver cancer and heat the cancer cell.

Figure 11 shows the simulated SAR at 2.45 GHz. The peak SAR is 104.54 W/kg, which is sufficient for microwave ablation method. In this figure, the heating has a target because the heating region is around the tip of the applicator. The heating is in red zone which maximum heat is apply at the tip of the applicator and along the length of the applicator, the zone is in light blue and almost too dark blue region that has less heat or no heat around the applicator which can reduce the potential to harm normal tissue. From this, we can conclude that, if the applicator match with the targeted tissue, the reflected power that can harm the normal tissue can be minimized and more heating power that can be used to kill the cancer cell.

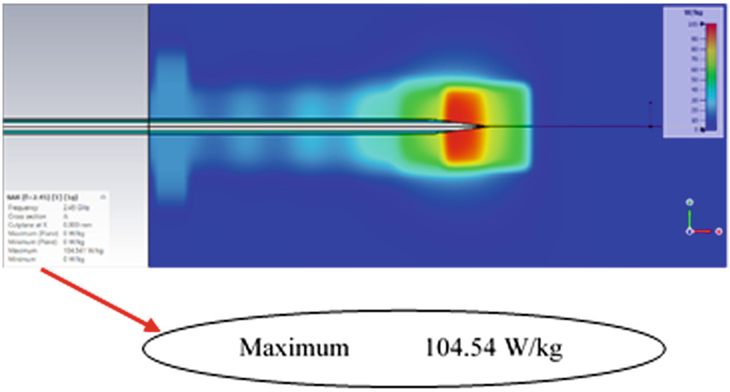

Fig. 11. Simulated SAR distribution at 2.45 GHz.

4 Conclusion

In this paper, a new coaxial biomedical applicator consist of three layer was designed by using microwave thermotherapy procedure. A method that leads to accurately S_{11} value at 2.45 GHz is needed for microwave thermotherapy method in order to guarantee destruction of the cancer tissue and minimizing damage to surrounding healthy tissue. This research was carried out to observe the effects of S_{11} on the destruction/death of cancer cell and input microwave power on the SAR during microwave thermotherapy. The result obtained for S_{11} is less than -10 dB, which indicates the proposed design is applicable to use for microwave thermotherapy. This reduction of S_{11}, makes it possible to supply more power into the cancer cell and reflect less power without heating and harmful towards normal tissue.

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