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Design and Investigation on Wideband Antenna based on Polydimethylsiloxane (PDMS) for Medical Imaging Application

***Abstract**. This paper presents an antenna for the medical imaging application which can detect unusual tissues on any part of the body. A compact design of wideband antenna with wearable properties is proposed for the medical imaging application. The wideband antenna is designed with introducing notches to the patch and a t-shaped slot at the partial ground. Polydimethylsiloxane (PDMS) is introduced to the antenna for the implementation of the wearable antenna. The proposed antenna operated in a frequency range of 3GHz to 6GHz. The antenna that embedded with PDMS shows a good agreement to the antenna without PDMS. An experimental proposed structure shows a good agreement with the simulated results. The overall dimension of the antenna is 24mm(W) x 38mm(L) which consider is a miniature antenna. This proposed design give an alternative solution for the antenna which cannot be wear on the body and protect the antenna. The introduction of PDMS will reduce the signal reflection cause by the high coupling of the human body.*

Streszczenie.** W artykule opisano antenę umożliwiającą wykrywanie zmian w tkance w ciele człowieka. Antena została zaprojektowana do celw obrazowania medycznego. Antena pracuje w zakresie częstotliwości 3 – 6 GHz. Rozmiary anteny wynoszą 24 x 38 mm. Konstrukcja anteny umożlwia ciągła pracę w różnych warunkach i wykorzystuje polydimethylsiloxane PDMS. **Projekt i badanie szerokopasmowej anteny przeznaczonej do zastosowań medycznych bazującej na materiale polydimethylsiloxane

Keywords: Medical imaging application; Wideband; wearable antenna; Polydimethylsiloxane (PDMS).
Słowa kluczowe: antena szerokopasmowa, badania medyczne, Polydimethylsiloxane (PDMS).

Introduction

Microwave imaging is one of the types of medical imaging. Microwave imaging worked by transmitting microwave impulse signal to the interested region, then receive the scattered signal to generate maps of electrical property distribution [1]–[3] . Microwave imaging for medical application has been widely use for the research over the past decade as it is low cost, fast and save to use [4]. The microwave imaging can detect the unusual tissue, for example brain tumor, breast cancer, stroke and internal bleeding.

The wideband frequency range is demanded by the medical field with the bandwidth at least 2GHz or more. The wideband antenna is preferable because of the large bandwidth and low power consumption [1], [5]–[8]. The wideband antenna is produced as a microstrip antenna. The microstrip antenna having characteristics of low profile, light and easy to be brought over which suitable for medical application [9], [10]. While there are many types of the substrate which can produced microstrip antenna.

The recent research of the antenna for the microwave imaging having a frequency range of wideband and ultra-wideband (UWB) with the omnidirectional pattern [11]. The frequency within the UWB range is widely been used in the research. The lower spectrum of the UWB frequency provide a better penetration and the higher spectrum of frequency provides better resolution [1], [12], [13]. The antenna with lower frequency spectrum is practiced by the researchers which include head, breast and small intestine. Different designs have been proposed to realize a wider bandwidth antenna . A spiral antenna is proposed by for the breast cancer detection. The antenna operated in 2 GHz to 4 GHz and having a miniature size with 20mm x 20mm[3]. However, the size of the antenna is too small and the design is complicated. A rectangular-shaped slotted patch with two circles at the end of the slot is proposed by [13]. The antenna operated at 3.18 GHz to 5.52 GHz and the researcher using plastic to cover the antenna when patched to the human body. The antenna is protected by the plastic but the antenna need to be covered by plastic each time the antenna is used. There are many antenna is designed for the medical imaging application that operated in the wideband frequency range which using the Co-planar Waveguide (CPW) structure, partial ground structure and many types of slots and notches are introduced [9], [11]. However, the antenna is designed to have a direct contact to the human body which will cause the inconsistencies in the performance of antenna.

While most of the antenna is not wearable for human, the wearable antenna is proposed with the application of polydimethylsiloxane (PDMS) [14]–[17]. The wearable antenna is designed by embedded PDMS on the antenna. The characteristics of the PDMS are the water-resistance, flexible, easy realization, robust, thermal and chemical stability [16-18]. PDMS is polymer gel that sticky on top on the antenna which acts as the spacer between the antenna and the human body [18]. By using the dielectric spacer with low loss and permittivity matching the human skin, more energy can be release into the human body and reduce the sensitivity of the antenna. PDMS is used for the protection of the antenna and reduce the signal loss through the human body [15].

In this paper, a novel approach to design a wearable wideband antenna embedded with PDMS is presented. The antenna is designed with the rectangular shaped patch antenna with the partial ground. The antenna is designed to operate in the range of 3GHz to 6GHz. The patch of the antenna is modified and the ground is also been introduce a t-shape slot as the modification. These modifications are used in increasing the bandwidth of the antenna. The PDMS is then embedded to the antenna. The analysis focuses on the frequency response based on S-parameter and bandwidth.

Antenna design

Antenna is designed based on the rectangular patch antenna with partial ground. Figure 1 shows the design of the antenna with the dimension in Table 1. The patch of the antenna is modified by adding notches in order to increase the bandwidth. The slots operated in high frequency and introduced a ripples. For the partial ground, a t-shaped notch is introduced in order to increase the bandwidth of the antenna. The t-shaped slot is also operated in a high frequency. The substrate for the antenna is Roger Duroid 4350B with the thickness of 0.168mm which having the permittivity of 3.48 and the loss tangent is 0.0037. The substrate is chosen because it having a low loss, available in the market and it is very thin in term of thickness. The overall size of the antenna is 38 mm (L) x 24 mm (W) x 0.168 mm (H) which is a miniature size antenna. Figure 2 shows the fabricated antenna.

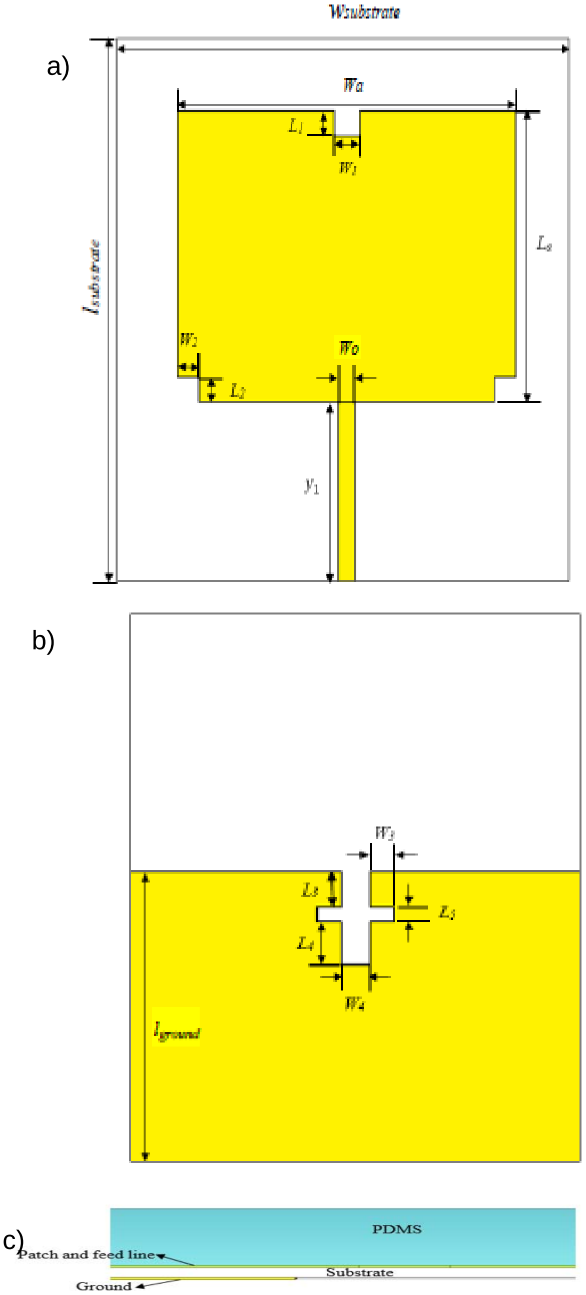

Fig.1. a) Front view of the designed antenna, b) Back view of the antenna, c) Side view.

Table 1 Dimension of the antenna

Symbol	Value (mm)	Symbol	Value (mm)
$l_{substrate}$	38	L_1	1
$w_{substrate}$	24	W_2	1
W_a	16	L_2	1
L_a	11.5	W_3	0.65
y_1	20.7	L_3	0.95
l_{ground}	20	W_4	0.8
W_o	0.8	L_4	1.2
W_1	1.2	L_5	0.4

The design antenna is then embedded with PDMS which the PDMS is stick on top of the antenna. Figure 3 the layers of the antenna including PDMS. The PDMS is in liquid form and it need several steps to be prepared and left for dry. The dimension of the required PDMS is determined first for the preparation of the volume of PDMS and the moulid. The mould is prepared for PDMS because PDMS is in liquid form and it need the mould for shaping and drying process. After the mould is prepared, the PDMS can be pour on the antenna into the prepared mould. The PDMS is left for several day for fully dried. The antenna is embedded with half PDMS and full PDMS. The half PDMS antenna is the PDMS is covered only the top half on the patch of the antenna while the antenna with full PDMS is the front side of the antenna is fully covered with PDMS. The dimension of the half PDMS is 24 mm (W) x 19 mm (L) x 1 mm (H). For the full PDMS, the dimension is 24 mm (W) x 38 mm (L) x 1 mm (H) while the overall thickness of the antenna including PDMS is 1.168 mm. Figure 4 shows the antenna that embedded with half and full PDMS.

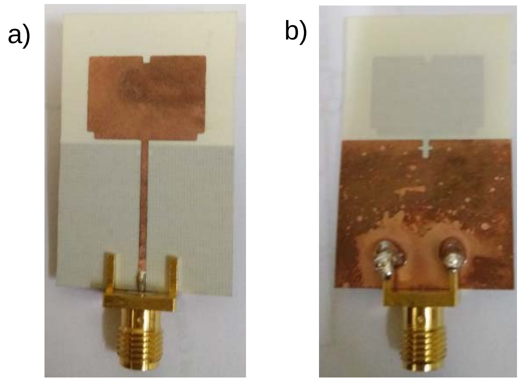

Fig.2. a) Front view of the fabricated antenna, b) Back view of the fabricated antenna.

Fig.3. a) Antenna with half PDMS, b) antenna with full PDMS.

Results, Analysis and Discussion

The antenna is designed and simulated in the Computer Simulation Technology (CST) Software. The parameters of the antenna that taken in concern is the return loss and radiation pattern. Figure 5 shows the comparison on the simulation of antennas with and without PDMS. The antenna without PDMS operated in the frequency range of 2.6 GHz to 6.3 GHz. The antenna with half PDMS having the frequency range of 2.8 GHz to 6 GHz while the full PDMS antenna operated in 2.7 GHz to 5.8 GHz. The antenna without PDMS showing a better result compared to the antenna with PDMS which having a wider bandwidth and a better return loss. Figure 5 shows the comparison on the measurement result for the antennas with and without PDMS. The antenna without PDMS operated in 3.5 GHz to 5.1 GHz and the antenna with half PDMS operated in 4.3 GHz to 5 GHz. While the antenna with full PDMS operated in 4.5 GHz to 5.2 GHz.

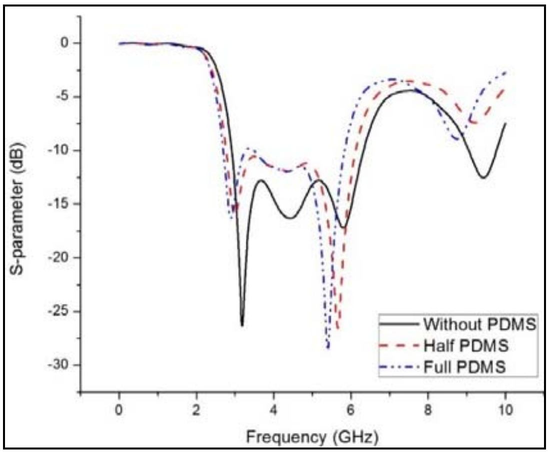

Fig.4. Comparison on the simulation result for the antenna with and without PDMS.

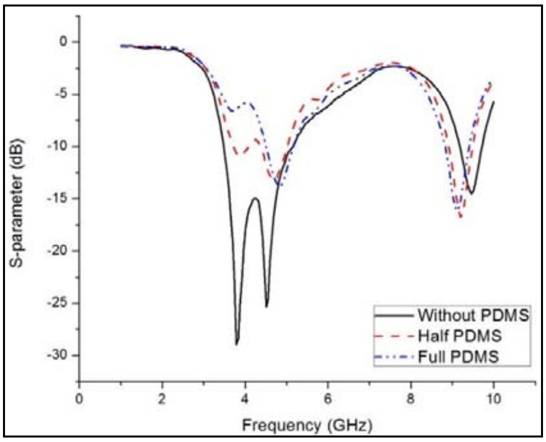

Fig.5. Comparison on the measurement result for the antenna with and without PDMS.

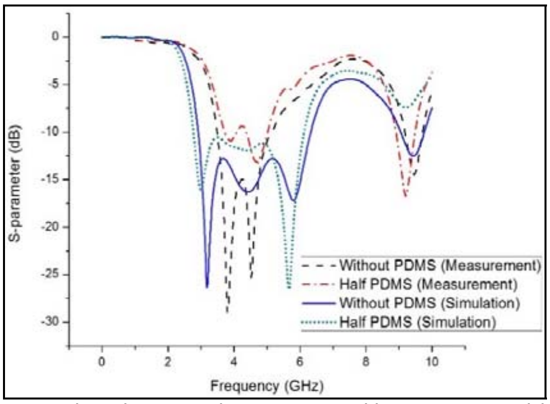

Fig.6. Comparison between the antennas without PDMS and half PDMS.

Table 2 Summary on the simulated and measured results.

Antenna Stage	Achieved Result	Frequency Range (GHz)
Antenna without PDMS	Simulation	2.6-6.3
	Measurement	3.5-5.1
Antenna with half PDMS	Simulation	2.8-6
	Measurement	4.3-5
Antenna with full PDMS	Simulation	2.7-5.8
	Measurement	4.5-5.2

The antenna with PDMS showing the waveform shifted upward and the return loss not as good as the antenna without PDMS. The antenna with PDMS showing the shrinkage of the bandwidth. Table 2 shows the summary of the result on simulation and measurement.

Figure 6 shows the antenna with half PDMS is compared with the antenna without PDMS. The antenna with half PDMS shows the decreasing in bandwidth compared to the antenna without PDMS in simulated and measured results. Among all the result curves in Figure 6, the measured curves go well with simulated curves, while a slight bandwidth shrinking for measured curves and a little discrepancies between the simulated and measured curves are observed in Figure 6 which may caused by fabrication tolerance and connector welding.The overall return loss for the antenna without PDMS is better compared to the return loss for the antenna with half PDMS.

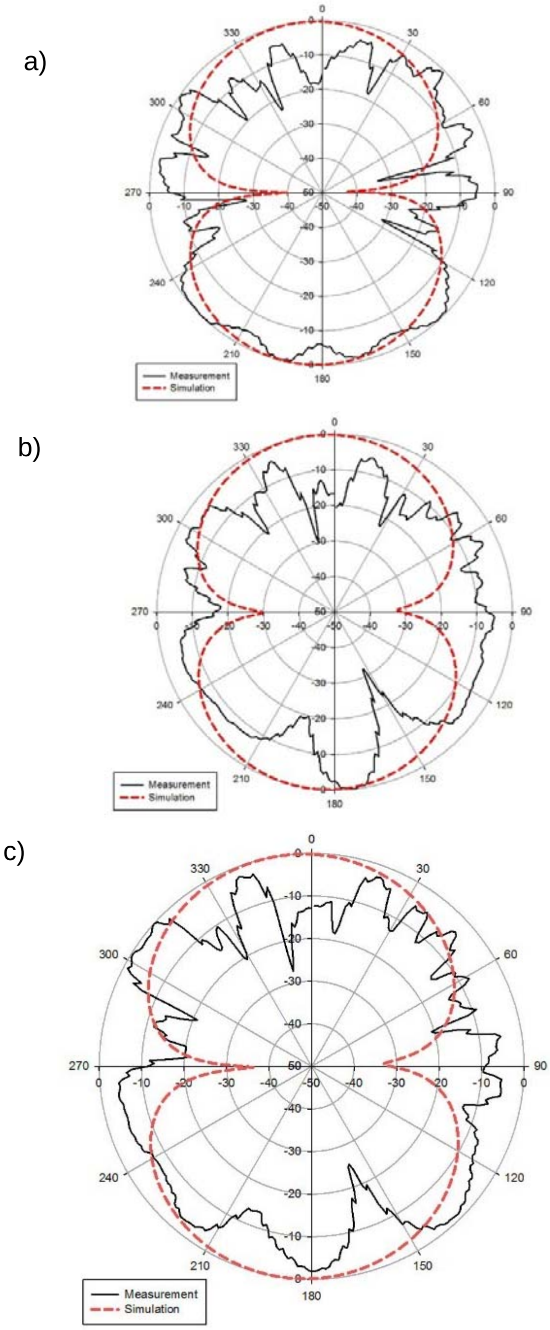

Fig.7. a) Radiation pattern of antenna without PDMS at 4.5GHz, b) Radiation pattern of antenna with half PDMS at 4.5GHz, b) Radiation pattern of antenna with full PDMS at 4.5GHz.

The radiation patterns for the antenna with and without PDMS is shows in the Figure 8. The radiation pattern of the antenna is measured in E-plane at the frequency of 4.5GHz which is the center frequency of the antenna. The radiation patterns show that the antenna with and without PDMS has omnidirectional radiation property. Due to the limitation of testing environment, a slight difference and tilted between the simulated and measured radiation patterns are shown in Figure 7, The simulated gain that obtained at 4.5GHz is 3.1 dBi for the antenna without PDMS. The gain for the antenna with half PDMS is 2.7dBi while the antenna with full PDMS is 2.6dBi. The measured gain that obtained by the antenna without PDMS is -6.5dBi at 4.5GHz. While the measured gain for the antenna with half PDMS is -12.19dBi and the gain for the antenna with full PDMS is -16.41dBi. The proposed antenna able to maintain omnidirectional radiation pattern along the x-z plane.

Conclusion

A wearable wideband antenna has been successfully designed, simulated and manufactured. The antenna is designed with the introduction of a t-shaped slot at the partial ground and notches on the patch for the wideband frequency range. The wearable properties of the antenna is realized by embedding the PDMS to the antenna. The antenna is designed without PDMS at first to achieve a wideband frequency range of 2.6GHz to 6.3GHz in simulation. The antenna that included the half PDMS showing the result of 2.8GHz to 6GHz while antenna with full PDMS shows a frequency range of 2.7GHz to 5.8GHz in simulation. The measurement result for the antenna without PDMS is 3.5GHz to 5.1GHz and the antenna with half PDMS is 4.3GHz to 5GHz. For the antenna with full PDMS shows the result of 4.5GHz to 5.2GHz. The overall measurement result shows the reduction of bandwidth compared to the simulated result. The antennas having a omnidirectional pattern for both measurement and simulation. The antennas had achieved the requirement for the medical application. The novel design of the antenna with PDMS is useful for the reduction of the signal reflected cause by the human body.

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