

Prototyping UWB Fetal Imaging and Monitoring System

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Abstract — An UWB microwave imaging technology particularly designed for fetal monitoring has been continuously studied. A single element of printed microwave medical transducer operated on extra large interval of the resonant frequencies was numerically computed using the HFSS software and experimentally tested. The main functions of UWB transducer are to sense the RF-energies reflected back from the surface of artificial abdomen and fetal tissues and to feed all collected signals to the signals processing unit for the imaging visualization purpose. Both UWB transducer and the abdomen of the pregnant mother together with its fetal inside were modeled in such manner to allow the reflection constant S_{11} enable to be recorded during the computation and optimization phases. The simulation result shows that the medical transducer is able to work on a frequency range of 3.6 - 4.8 GHz. On the experimental testing an homogeneous abdomen phantom (assumed of half spherical model) of the physical size 240 mm (diameter) x 40 mm (depth) and the growth fetal inside (assumed of cylindrical model) with the physical size varied according to the pregnant ages were built. The 2D medical images of the abdomen and fetal tissues were visualized based on the variability of the recorded S_{11} .

Keywords — UWB microwave imaging, UWB medical transducer, fetal monitoring, homogeneous phantoms, and microwave imaging.

I. INTRODUCTION

Advances of communication technology is believed to be increasing from year to year. One of the most common technologies applied is the microwave technology commonly used for radar communication systems or microwave sensing. The use of such technology requires considerable bandwidth.

An ultrawideband (UWB) technology provides several excellent properties such as enable to deliver data at high-radio frequency channel, extra large bandwidth, fast data transfer, and low power consumption. Other word, this UWB technology offers solutions for bandwidth, price, power consumption, and relatively small physical size required on implementing the communication devices. These advantages are very useful to apply while constructing the detector (sensor) unit. High frequency imaging system provides the better resolution on the object scanning and its image mapping.

Medical detection method using UWB technology has been studied and continuously developed in [1-8]. Previous research activity in [2] allowed the lighter, smaller, cheaper,

and high usage mobility characteristics of the designed prototype of fetal monitoring and detection system.

In reference [2], a portable fetal detection and monitoring system was constructed with simple and low cost design using the UWB microwave imaging technique. The technology is expected very useful to help the pregnant women to monitor and to maintain the fetus growth inside the mother abdomen without visiting the hospital or another healthcare center. A large amount of money and energy could be saved considerably. It may also reduce the potential health risks due to the frequent mobility during the pregnant period. This paper is an extended study in [2] regarding the development of fetal detection and monitoring system. Previous studies used microwave sensor with physical dimension 50 mm x 50mm connected directly to VNA as the transceiver unit to illuminate 1 mWatt RF power to certain abdomen area and to receive the reflected energy. In addition, the visualization technique applied to plot all collected power was still using smaller number of pixels, i.e. 48 pixels, using a grayscale filter and focus only on the midpoint of abdomen surface area. Several numbers of modified UWB transducer, considering the proposed sensor model published in [8], were numerically computed and experimentally evaluated. Some optimization results and a number of new innovations in terms of the increasing pixels numbers of the reflected power classification in order to display medical imaging are discussed; and the sliding measurement apparatus attached to install the single element of UWB transducer was also built. In overall, fetal monitoring and detection installed with a compact transducer and has precise results, i.e. under no fetal condition, 2 months of fetal age, 3 months of fetal age and 4 months fetal age, are evaluated in this paper.

II. ULTRAWIDEBAND TRANSDUCER AND FETAL MONITORING

A. Fetal Monitoring

One effort to reduce the risk of maternal and fetal death, among others, by monitoring the welfare of the fetus in the womb. Fetal monitoring is a method of examining the condition of the baby in utero during pregnancy to ensure the condition of the baby in a normal and healthy condition. Some indicators in self-monitoring fetal are temperature, heart rate, mass, blood pressure, respiration, movement, and fetal growth [1]. One method of fetal monitoring is the use of ultrasonography (ultrasound) technology. The image generated from ultrasound is to utilize the reflected (echo)

results of ultrasonic waves when transmitted to a particular tissue or organ. The echo of the wave is then detected by a transducer that converts ultrasonic waves to electronic signals to be processed and reconstructed into an image.

B. Ultrawideband Medical Transducer

Ultra-Wide Band technology (UWB) is widely used for applications such as military communications, radar, and sensing. Until now, UWB technology utilization has evolved extensively and applied in many medical fields [1]. This technology has been used for early detection of breast cancer, fetal monitoring, head hemorrhagic stroke and other medical applications [2] [3].

UWB communication system is a type of wireless communication system operated at 3.1 GHz-10.6 GHz with minimum bandwidth of 500 MHz as regulated by U.S. Federal Communications Commission (FCC) and ITU-R (International Telecommunication Union-Radio Communication sector) [1] [4].

UWB transducer produces a very large bandwidth compared to the common microwave electronic transducer in general. There are two criteria to identify a transducer whether it belongs to an ultrawideband transducer. The definition provided by the Defense Advanced Research Project Agency (DARPA) [5] specifies that ultrawideband transducer have a bandwidth percentage (BW) greater than 0.25, and alternatively, Federal Communications Commission (FCC) of the USA defines an ultrawideband transducer having the limit bandwidth percentage of 0.2. This can be written as follows:

$$B_w = 2 \frac{(f_H - f_L)}{(f_H + f_L)} \geq \begin{matrix} 0.25 & \text{DARPA} \\ 0.20 & \text{FCC} \end{matrix} \dots\dots\dots (1)$$

In addition, FCC defines an ultra wideband transducer/antenna that is a transducer that has bandwidth greater than 500 MHz.

To illustrate the performance of a transducer, it is important to understand the transducer parameters. Some parameters are interrelated and not all need to be determined for the overall picture of transducer performance. Types of transducer parameters according to IEEE Standard Definition of Terms for Antennas/transducers, ie reflection coefficient (S_{11}), Voltage Standing Wave Ratio (VSWR), bandwidth, radiation pattern, gain and input impedance [6]. However, the parameters that become the focus in this research are S_{11} (reflection coefficient) parameter.

A circuit can contain various electronic components such as resistors, capacitors, inductors and transistors. To define the S parameter, it should be emphasized that the whole network is linear with a small signal input. This applies to components in telecommunication systems such as attenuators, filters, couplers and equalizer on condition that they operate in linear conditions. At low frequencies, the commonly used parameters are the Y or Z parameters using current and voltage values measured on open circuit or short circuit. At high frequencies, these parameters (Y, H, and Z) are very difficult to measure because the use of open load / short

circuit can cause the active components used to be unstable (oscillating).

In addition, it is difficult to obtain an open load / short circuit with a wide frequency field at high frequencies. Therefore, at high frequencies the parameter measured is the S (scattering) parameter which uses the magnitude and phase concepts of the current wave (forward wave and reflected wave). S parameter is an important concept in microwave design because it is easily measured and works well at high frequencies. The advantage of using the S parameter departs from the fact that the wave runs unlike voltage and current, does not experience any magnitude variations along the lossless transmission line. This means that the S parameter can be measured at a certain distance assuming the transmission line has small losses [6].

S Parameter illustrated in 2 port network (4 poles) can be seen in Fig.1.

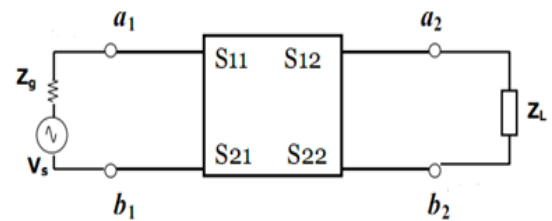


Figure 1. S Parameter specified in a four-pole network

where :

- a_1 : the total current of the AC current source
- a_2 : current that has passed through the load
- b_1 : current returning to the AC current source
- b_2 : current leading to the load

Reflection coefficient of voltage at the input port is Γ_{in} equivalent to S_{11} . VSWR on a port corresponds to the magnitude of the reflection coefficient, with the relationship:

$$\Gamma_{in} = \frac{1 + |S_{11}|}{1 - |S_{11}|} \dots\dots\dots (3)$$

The reflection coefficient S_{11} can be plotted in the smith chart, converted to impedance and can easily be manipulated to determine impedance matching circuit for circuit design optimization.

VSWR value has correlation with reflection coefficient value (S_{11}). To see the relationship we can note the following equation:

$$S_{11} = 20 \log \left[\frac{|1 - \text{VSWR}|}{|1 + \text{VSWR}|} \right] \dots\dots\dots (4)$$

C. Microwave Imaging

The image generated from the data processing will be a representation of the shape or the measurements of the observed object. There are three basic principles of imaging process that are to transmit the electromagnetic energy in the

target object, to receive the reflected power from object and to further process the reflected power to obtain the information. Electromagnetic waves are transmitted toward the target to be observed and across each layer of the composit tissue/material. The tissue characteristics affect the reflected signal generated from the observed object.

A particular microwave imaging system for sensing the human body is depicted in Fig.2. In practice, the UWB transducer is a kind of printed directional antenna to illuminate RF-signals to the target and to receive the amount of energy contained in the reflected signals. As clearly shown in Fig.2 the RF transceiver has two different tasks during the object scanning. The UWB pulse is periodically generated and fed to Tx front-end unit to be modulated and boosted. The UWB microwave signals outputted is then delivered to cross the UWB medical transducer to be emitted approaching the targeted human body. Meanwhile, the Rx front-end part which connected to another UWB medical transducer will detect the reflected RF-signals from human object. These are then demodulated and filtered-out before the acquisition and signal processing unit (so-called controlling subsystem) extracted the required medical information to be plotted later on inside the image displaying unit. Controlling subsystem contains various electronic parts such as microwave sensor devices, acquisition controllers, data storage and communication interfaces with PCs. The PC is installed with the imaging software for displaying the targeted image (medical data visualization).

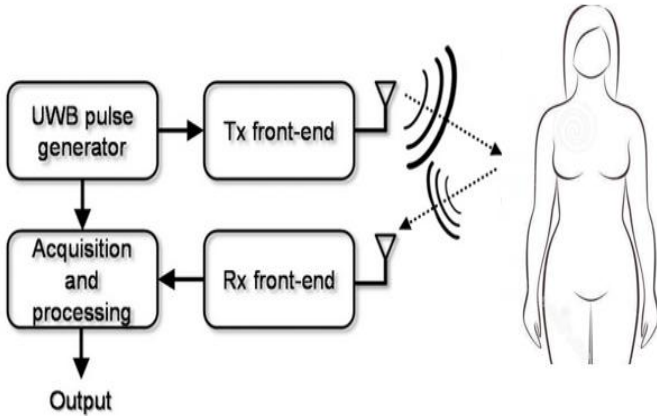


Figure 2. A particular microwave imaging system for monitoring human body.

III. IMPLEMENTATION

A. UWB Transducer

The design of printed UWB microwave transducer was performed by calculating several physical parameter using the following equations:

- The width (W) of the printed UWB microwave transducer is given by the following equation [6],

$$W = \frac{c}{2f_0 \sqrt{\frac{\epsilon_r + 1}{2}}} \dots \dots \dots (5)$$

- The effective dielectric constant (ϵ_{reff}), from the above equation gives the effective dielectric constant as follows [6],

$$\epsilon_{reff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \left[1 + 12 \frac{h}{W} \right]^{-\frac{1}{2}} \dots \dots \dots (6)$$

- Length of printed UWB microwave transducer (L) is given as follows [6],

$$L_{eff} = L + 2\Delta L \dots \dots \dots (7)$$

With effective length (L_{eff})

$$L_{eff} = \frac{c}{2f_0 \sqrt{\epsilon_{reff}}} \dots \dots \dots (8)$$

and the following additional length (ΔL) [6],

$$\Delta L = 0.412h \frac{(\epsilon_{reff} + 0.3) \left(\frac{W}{h} + 0.264 \right)}{(\epsilon_{reff} - 0.258) \left(\frac{W}{h} + 0.8 \right)} \dots \dots \dots (9)$$

- where,
- $c = 3.10^8$ m/s
 - f_0 = resonance frequency (Hz)
 - ϵ_r = relative permittivity
 - ϵ_{reff} = Effective dielectric constant
 - W = wide of patch(mm)
 - h = thick of patch (mm)
 - L = length of patch (mm)
 - L_{eff} = effective length of patch (mm)
 - ΔL = additional length of patch (mm)

The results of whole mathematical calculations as the basic guideline to be considered for modification of the printed UWB transducer dimensions is tabulated in Table 1. The transducer lay-out constructed considering the dimension shown in Table 1. Through several optimization steps the final design was generated. The interesting result of the ground plane optimization is depicted in Fig.5. The optimization was performed for three different sizes, i.e. 10 mm x 18 mm, 12 mm x 18 mm and 14 mm x 18 mm, respectively. The fabricated one is visualized in Fig. 4, respectively.

Table 1. Printed UWB Microwave Transducer Dimensions

Structure	Material	Relative Permittivity	Transducer Dimensions (mm)			
			Thickness	Width	Length	
Dielectric	FR-4 Epoxy	4.4	1.6	22	24	
Patch	Patch 1	PEC	1	0.05	3	12
	Patch 2			0.05	1	5
	Patch 3			0.05	3.5	7
Ground	Whole Patch (WP)		0.05	22	24	
Plane	Blank Part (BP)			12	18	
Boundary	Air	1.0006	5	55	56	

The prototype of UWB transducer was manufactured from a dual layer printed circuit board with edge feeding technique as shown in Figs.3 and 4.

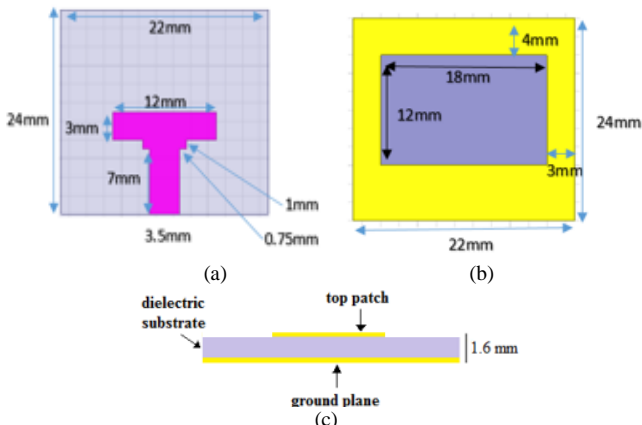


Figure 3. UWB transducer numerical model
(a) Top conducting layer view (b) Bottom layer view (c) Side view



Figure 4. Fabricated transducer (a) top conducting layer (b) ground plane

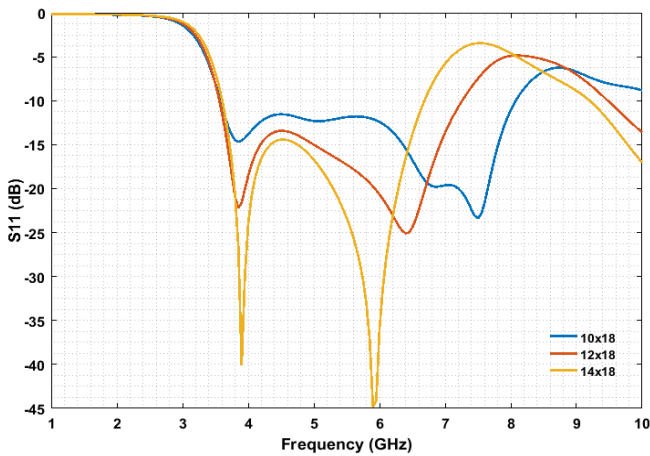


Figure 5. S_{11} parameter of UWB transducer through the optimization

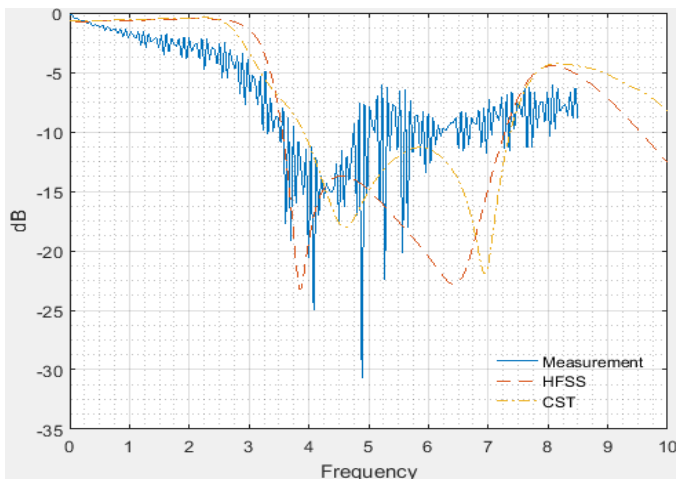


Figure 6. S_{11} parameter comparison of UWB transducer

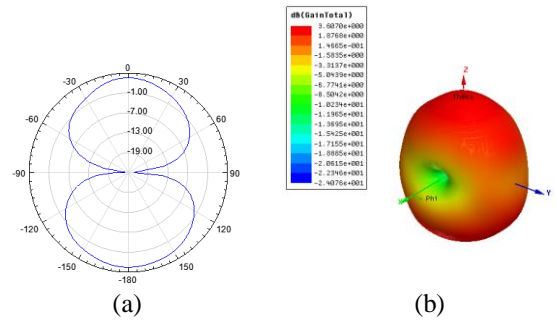


Figure 7. (a) 2D Radiation Pattern (b) 3D Radiation Pattern

The electrical properties of UWB transducer has an excellent performance in terms of the available operation bandwidth that varied from 3 to 4 GHz. The bandwidth was verified through HFSS and CST computations. However due to the technical difficulties existed during the experimental evaluation the available bandwidth to allow the microwave imaging system working precisely is more or less 1.2 GHz. All those bandwidth values are portrayed in Figs. 5 and 6, respectively. Experimentally, UWB transducer well operates at frequencies from 3.6 GHz up to 4.8 GHz. In this case, bandwidths percentage is 28% (or 0.28).

B. Phantom Modeling

Abdomen phantom (phantom stomach) is made with a certain size following the pregnant woman's stomach where the characteristics of each layer are arranged with different characteristics for relative permittivity (ϵ_r), conductivity (σ) and relative permeability (μ_r) according to the layer composing it. The designed phantom is a homogeneous phantom consisting of three layers of skin, fat and fetal with characteristics as shown in Table 2 below.

Table2. Abdomen phantom characteristics[2][7][8].

Layer	Permittivitas (ϵ_r)	Konduktivitas (σ)	Permeabilitas (S/m)
Skin	36.587	2.3404	1
Fat	4.8393	0.26229	1
Fetal	62.078	2.2546	1

Phantom designs were made with assumptions ranging from no fetal state, 2 month old fetal with a length of 40 mm, a 3 month old fetal with a length of 60 mm and a 4 month old fetal with a 120 mm long dimension. Each of these designs is shown in Figure 8.

The design is made with the length of phantom diameter of pregnant women by 30 cm. Each fetal is placed right in the middle of the phantom stomach. The simulation was performed by dividing the phantom stomach area by 256 points consisting of 16 rows and 16 columns. The result is data to be analyzed about the difference of reflection coefficient response of each phantom part.

From the results of the four simulation conditions then focuses on the point of simulation of the fetal area. It aims to assess whether there is influence of reflection coefficient

value to fetal size. The comparison of reflection coefficients (S_{11}) of the simulation results in the fetal area is shown in Fig. 10.

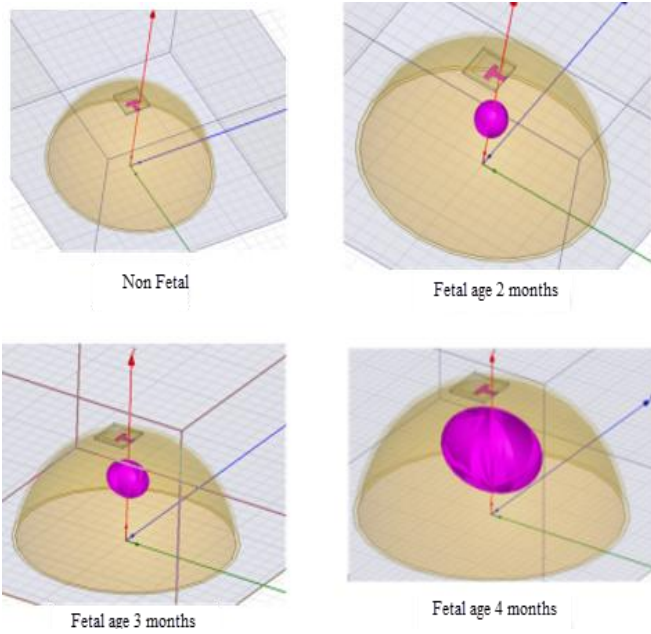


Figure 8. Fetal grow-up inside abdomen phantom through numerical model.

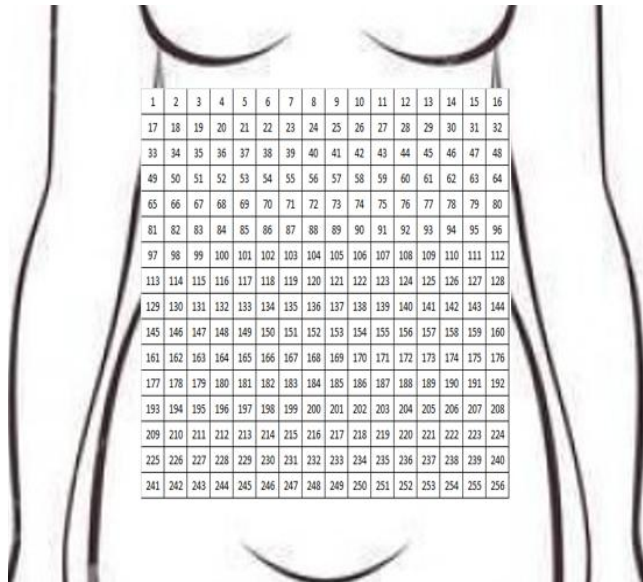


Figure 9. Power Level Classification for Abdomen and Fetal Imaging Plot

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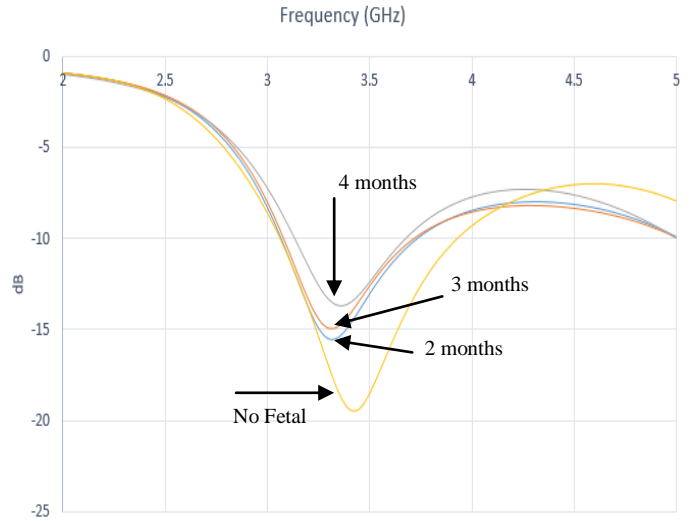


Figure 10. Reflection coefficient (S_{11}) responses of UWB transducer at various fetal ages.

Considering the numerical computations as shown in Fig.8 it is clearly seen that different fetal sizes (resemble the fetal different fetal ages) are really affecting the impedance matching (or S_{11}) produced during the operation of UWB microwave imaging system. It is found that the larger the fetal size the reflection coefficient value will be smaller (degrading significantly). S_{11} variations might occur about 3 to 5dB while the fetal ages altered from 2 months age to 4 months age. Significant differences occurred between nonfetal phantom inside abdomen and phantom with fetal existed. This occurs because the abdominal characteristics of phantom (i.e. relative permittivity ϵ_r and conductivity σ) between fat tissue and fetal structure are also different [2] [7] [8].

A larger fetal dimension existed inside abdomen causes the transmitted power to be largely absorbed by the fetal so that the power received back by UWB transducer becomes smaller. In other words, the value of S_{11} which is the reflection coefficient level of this value will show the difference based on the layer it passes. The reflection coefficient data is then processed to produce the image based on the reflection coefficient level.

IV. TEST AND RESULT

The data collections to record the variability of reflection coefficient S_{11} due to the interaction between UWB transducer and various tissue layers of both abdomen and fetal were performed through four main experiments conditions. These include the following:

- Abdomen phantom without fetal.
- Abdomen phantom of 2 months age with fetal size 40 mm x 25 mm.
- Abdomen phantom of 3 months age with fetal size 65 mm x 65 mm.

- Abdomen phantom of 4 months age with fetal size 130 mm x 70 mm

Phantom prototype design of 300 mm x 300 mm size used is composed from NaCl 0.9%, Agar 5% and 3% Sukrosa. All ingredients are mixed-up together in water container then heated to 900 C until all the ingredients converge. The process is then poured into a hemispherical container. Fetal production was maintained using the same way. However, fetal materials used are composed from 3% NaCl, 5% agar and 3% Sukrosa. The final fetal structure built will then be placed inside the available constructed abdomen phantom.

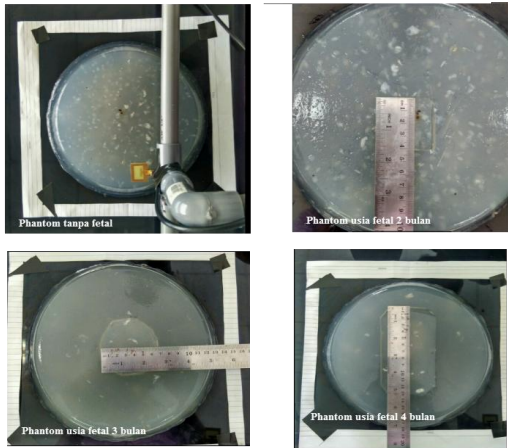


Figure 11. Measurement scenario of phantom with fetal

Each state takes the measurement data of the reflection coefficient S_{11} . Scanning size is performed horizontally and vertically 16x16 pixels (see Fig.9). Each measurement point uses a frequency domain sweeping range of 100 KHz - 8 GHz. The working frequency of the UWB transducer was set-up to 3.9 GHz. The result of the reflection coefficient response data S_{11} each point then processed using Matlab which represents pixel on image image generated

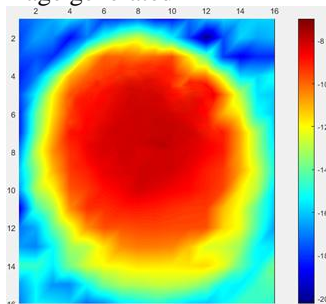


Figure 12. Non-fetal phantom imagery.

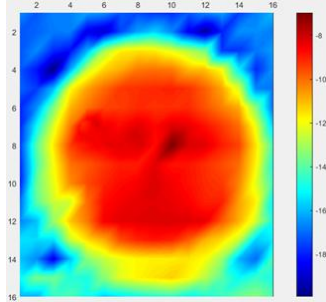


Figure 13. Phantom image of fetal age of 2 months

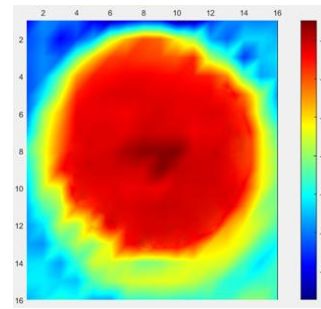


Figure 14. Phantom image of fetal age of 3 months

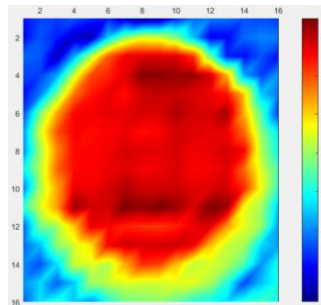


Figure 15. Phantom image of fetal age of 4 months

The measurement results of UWB transducer test show that the larger fetal area produces a S_{11} response smaller value than the nonphantom area. While the largest S_{11} value occurred in non-phantom areas. The larger the fetal size, then the return loss generated is also smaller. The presence of fetal causes the power transmitted from transducer partially absorbed by fetal, so that power is reflected back to UWB microwave system becomes smaller. The element of tissue layers are also very influential because each constituent to the very specific electrical properties of each material. It has its own characteristics and different responses to electromagnetic waves.

V. CONCLUSION

Based on the simulation results, the measurement and data analysis that has been performed in this study, it is concluded that the results of the scanner tests show us the proposed ultrawideband imaging works well to detect and identify fetal phantom for the application of fetal monitoring of pregnant women. In S_{11} measurements during the imaging process, the ultrawideband transducer can work precisely in accordance with the various conditions and fetal sizes. Therefore, from a preliminary study conducted that shows the fetal scanner and monitoring system intended for helping pregnant women to enable for self detection and monitoring the fetal grow-up inside abdomen phantom.

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