Improvement of UWB Patch Transducer Properties Applicable for Fetal Monitoring System

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Abstract — The great potential application of wireless body network (WBN) to improve the quality of healthcare service to people was evaluated to incorporate the ultra wide band (UWB) technology to obtain the better performance of WBN stuff functionality. One of the very challenging WBN device developed is specifically applied for fetal monitoring. The designed fetal monitoring was intended for specifically applied to suitable utilized by the risk pregnant woman who has the difficult access to the hospital. Despite the many risk factors existed during the pregnancy the constructed UWB fetal monitoring system is designed to capable for sensing the fetus heart rate variability, the fetus growth and its contraction. The numerical evaluation performed was mainly focused to assess the electrical properties of the designed UWB transducer to meet the technical specification required. In practice, the transducer is in the form of the designed UWB transducer to meet the technical specification required. In practice, the transducer is in the form of patch antenna structure. The antenna was designed using the basic structure of dielectric/substrate which consists of FR4-Epoxy material, top conducting radiator and ground. This antenna is connected by edge feeding technique that set SMA connector on the side of the dielectric material. A number of significant electrical properties improvements of the designed UWB patch transducer were found during the numerical computing stage including the radiator/transducer pattern, the $S_{11}$, VSWR, and the gain. Through the numerical assessment it is clearly shown that the return loss ($S_{11}$) is very excellent to reach the value of approximately -35 dB. Considering the $S_{11}$ boundary of -10 dB value the constructed RF-waves radiating transducer is working well at the frequency range from 1.3 GHz up to 4.1 GHz (equal to the bandwidth 2.8 GHz). The best VSWR value obtained during the RF transducer numerical design is approximately 1.12. The gain achieved is 2.61 dB. The advanced fetal monitoring development will also utilizes the incorporation of the robust image processing technique to plot the woman pregnancy indicators on the display unit.

Keywords—Fetal monitoring, UWB technology, Microwave imaging, and Pregnancy risk factors (PRF)

I. INTRODUCTION

The intensive study on the development of UWB medical monitoring systems for specifically applied in the diagnostic and treatment purposes of prenatal and neonatal cares has shown the positive growth trend since the last five years [1-3]. More consistent and serious attempts should be performed for helping to minimize the risks factors during the pregnancy and after the baby was successfully delivered-out. Various medical indicators could be collected from the mother and the baby to be further analyzed to provide the better healthcare for both fetal and maternal health issues. These indicators include fetal heart rate, fetal heart rate variability, fetal respiration, fetal gross body movement, maternal contractions, maternal heart rate, maternal respiration and many others physiological and medical parameters [1-3].

Some related papers have intensively discussed about the implementation of UWB technology in medical field. One of them described future possibilities that could take advantage of UWB technology for medical applications including fetal monitoring [4-6]. Fetal monitoring is a periodical checking method provided for the pregnant women during pregnancy to determine the condition of the fetus. The health of pregnant women and the fetus are critically need more serious attention and the prompt healthcares, because due to existing data, Perinatal Mortality Rate (PMR) appeared to be high in some countries including the developing countries like Indonesia. Therefore, the continuous research activities related to this issue must be seriously supported and performed in any research centers and universities. The final product design of the fetal monitoring system must be a simple design, low cost and portable using UWB technology. This allows the better access of the poor people living in the remote location to enable getting the better health services.

The research results are presented in the current scientific paper is the advanced studies of the previous one reported in [1]. Several optimization steps on the last fetal monitoring system prototype were performed including the UWB microstrip antenna and the RF processing configuration [1]. The main goal of the optimization performed is to improve the patch antenna performance. To achieve this goal some antenna physical parameters and the related ones were consistently adjust to meet the required antenna output. The optimization was executed by adjusting the dimension of antenna design and appropriately generating the woman abdomen phantom for later testing in order to better accurately assessing the constructed RF wave radiating transducer and to study more the abdomen environment and its interaction characteristics to the UWB microwave monitoring and imaging instrument.
During the numerical investigation, several important RF-electronic transducer parameters such as the impedance matching, the bandwidth, the radiation pattern and the gain was carefully recorded and further analyzed.

II. THE CONFIGURATION OF FETAL MONITORING SYSTEM

The fundamental importance of the fetal monitoring system incorporated with the UWB (Ultra Wide Band) technology that it has now become very attractive study area and has many potential applications includes in the medical field. There are several advantages of exploiting this technology, i.e. no ionization, low power, and low cost. Thus, it can be easily implemented to create an inexpensive device with a simple design. These make UWB technology suitable to be developed for medical application. InfoComm Development Authority (IDA), a spectrum regulatory department of Singapore sets UWB frequency at 2.2-10.6 GHz. On the other hand, UWB communication system operates in the (3.1-10.6) GHz with a bandwidth of at least 500 MHz according to other international standards such as US Federal Communications Commission (FCC) and ITU-R (International Telecommunication Union - Radio communication sector) [4-6].

The system of fetal monitoring transmits the signal towards the human body that is stomach area (abdomen) from a RF transducer that is connected with transmitter device then reflected signal transmitted and received by a receiver device. The information about fetal growth, as for instance, obtained while the RF-processing as illustrated in Figure 1 completed and image processing results will be plotted immediately after the whole data recorded to cover all the abdomen surface area. The final image processing may be drawn later on in the display unit.

A. The Antenna Numerical Design

The structure of the antenna for fetal monitoring system is shown in Fig 2. This antenna was designed by using FR4-Epoxy materials. The layers consist of a piece of metal that serves as a layer radiator/receiver RF energy, called a patch top layer, which is typically made of thin copper material that is printed on the base of a grounded dielectric [6]. Top patch layer as a plate that radiate the power from a dielectric. Ground patch layer and the top patch are connected by edge feeding or SMA connector. The design looks like a stair as

![Fig. 2. Structure of microstrip antenna](image)

(a) top view  (b) bottom view  (c) side view

B. Human Body Modelling and Microwave Imaging

Human body can be modelled in first approximation as a multi-layer structure which each layer corresponds to a particular tissue [5-6]. Different parts of the human body can
be modelled through different multi-layer structures. Each layer is characterized by its relative permittivity ($\varepsilon_r$), conductivity ($\sigma$), density and relative permeability ($\mu_r$). The abdomen model (phantom) consists of two layers, skin and fat which has the electrical characteristic that shown in Table I below.

<table>
<thead>
<tr>
<th></th>
<th>($\varepsilon_r$)</th>
<th>($\sigma$)</th>
<th>$\mu_r$ (S/m)</th>
<th>Mass Density (kg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skin</td>
<td>36.587</td>
<td>2.3404</td>
<td>1</td>
<td>1109</td>
</tr>
<tr>
<td>Fat</td>
<td>4.8393</td>
<td>0.26229</td>
<td>1</td>
<td>911</td>
</tr>
</tbody>
</table>

The simulation of abdomen phantom is configured by considering the age pregnancy to be about five months. The common dimension of the pregnant woman abdomen is about 28.25 cm of height and 89 cm of abdominal circle. The model is shown in Fig. 3. The antenna will be placed on the surface of the phantom and shifted following the antenna size to cover the entire surface of the phantom to obtain the required data which will be processed by utilizing the most common available of image processing technique. One of the simple image processing techniques applied was reported in [8].

The principle of imaging system that is used will show the different information for each abdomen surface condition based on the differences of the material illuminated from the RF microwave transducer. Each abdomen tissue has the different dielectric property. This will contribute the different power reflected-back from a particular abdomen surface. The captured data via RF microwave transducer need to be further processed with the image processing software and plot the result onto the display electronic part based on the color code assigned for each data plot pixel. The more sophisticated and advanced design of the fetal monitoring RF transducer is in the form of array configuration [1]. This is drawn in Figure 4.

![Fig. 4. The UWB fetal monitoring transducers configured in an array [1]](image-url)

![Fig. 5. Graph of $S_{11}$](image-url)

![Fig. 6. Graph of VSWR](image-url)

III. NUMERICAL RESULTS AND DISCUSSIONS

The RF microwave patch transducer developed to be suitable for fetal monitoring and imaging purposes has been designed according standardization of UWB technology and
design has a standard value of VSWR seen in Fig. 6. The simulation result shows that the antenna performance of the antenna is a VSWR value that can be used in the UWB fetal monitoring system.

This could be clearly seen in Fig. 5. The last RF transducer model has the bandwidth improvement of approximately 47.4% comparing to the available bandwidth using the previous patch antenna (bandwidth only 1.9 GHz at the frequency range from 2.54 to 4.45 GHz) employed in the UWB fetal monitoring system.

Other parameter which is used in the process of verifying the performance of the antenna is a VSWR value that can be seen in Fig. 6. The simulation result shows that the antenna design has a standard value of VSWR ≤ 2 that is 1.12.

Radiation pattern of the antenna represents the antenna transmit power level through a palette of colors range from blue to red that the transmit power level getting better to the red color. This microstrip RF transducer design has highest gain value of 2.61 dBi. This is the most significant research achievement on designing the required RF patch transducer. The theoretical gain obtained is illustrated in Fig. 7.

More advanced studies should be performed later on to improve the research outcomes which had been presented in the paper. Several critical works are desired to be soon executed including the numerical testing to assess the potential capability of the proposed imaging technique to visualize the fetal grew-up inside the abdomen; to assess the constructed antenna array of stairs-like patch model both in the numerical and experimental evaluation stages; and how complicated the proposed fetal monitoring system to be improved to allow the new insertion of medical sensors such as pulse sensor to monitor both the baby and the mother heart rate.

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The optimization steps were performed by reconfiguring the physical dimension of all antenna parts, i.e. the radiating layer size, the ground plane dimension and the substrate dimension, without altering the shape model of each patch layer. In average, all the current dimension to be adjusted to double comparing with the previous design dimension. Simulation results exhibit that the S11 parameter of the designed transducer can operate in the frequency range from 1.3 GHz up to 4.1 GHz with a bandwidth of approximately 2.8 GHz. This could be clearly seen in Fig. 5. The last RF transducer model has the bandwidth improvement of approximately 47.4% comparing to the available bandwidth using the previous patch antenna (bandwidth only 1.9 GHz at the frequency range from 2.54 to 4.45 GHz) employed in the UWB fetal monitoring system.

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The improvement of the antenna simulation to evaluate the performance of the designed RF microwave transducer suitable for fetal monitoring system has been discussed. Based on the assessment to some electrical properties produced during the computation phase and considering the standard requirements in terms of the reflected coefficient, VSWR, bandwidth, radiation pattern and gain, the current transducer design were perfectly achieved. The antenna works well at the operating frequency from 1.3 GHz-4.1 GHz with bandwidth 2.8 GHz, VSWR value is 1.12 and has the gain about 2.61 dB. The abdomen phantom simulation also designed to complete the testing later.

IV. CONCLUSION

The improvement of the antenna simulation to evaluate the performance of the designed RF microwave transducer suitable for fetal monitoring system has been discussed. Based on the assessment to some electrical properties produced during the computation phase and considering the standard requirements in terms of the reflected coefficient, VSWR, bandwidth, radiation pattern and gain, the current transducer design were perfectly achieved. The antenna works well at the operating frequency from 1.3 GHz-4.1 GHz with bandwidth 2.8 GHz, VSWR value is 1.12 and has the gain about 2.61 dB. The abdomen phantom simulation also designed to complete the testing later.

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REFERENCES


