Low Cost Design of Precision Medical Ultrasound Power Measurement System

Imamul Muttakin, Yeap S.Yu, Muhammad M. Mansor, Mohd H. M. Fathil, Izzeldin Ibrahim, Ismail Ariffin, Camallil Omar, and Eko Supriyanto

***Abstract*—** Ultrasound power measurement system is widely used in health care institutions especially to measure the power generated by ultrasound therapeutic machines. The existing ultrasound power meter, however is high cost, heavy and only for specific machine. Besides, most of them have limitation of resolution, are not considering temperature disturbance and no graphical interface for further analysis. Since piezoelectric polyvinylidene fluoride (PVDF) has been explored to be a potential candidate for ultrasound sensor, this work has observed this polymer film behavior in medical ultrasound power measurement application. Effects of distance, frequency, voltage and temperature on the received signal (voltage) were analyzed. In order to enable PVDF sensor for low cost ultrasound power meter, a robust low-cost casing has been built. The casing has been designed to enable optimum capturing ultrasound power from therapeutic and diagnostic ultrasound machine, minimize interference effect and noise as well as stabilize mechanical construction of sensor. Test result shows acceptable correlation between ultrasound intensity and sensor's generated voltage. For signal processing unit, a Field-Programmable Gate Array (FPGA) based ultrasound processing platform has been proposed. This platform is able to process data from two PVDF sensors and a temperature sensor with high precision. It was prepared to measure ultrasound frequency from 500 kHz to 10 MHz with temperature range from 10 °C to 50 °C and power range from 1 mW/cm^2 up to 10 W/cm^2 (with resolution 0.87 mW/cm^2). In addition, a graphical user interface (GUI) has been utilized for further analysis. Test result shows that the platform is able to process 10 µs ultrasound data with 20 ns time-domain resolution and 0.12 mV magnitude resolutions then display these waveform and calculation result in the GUI.

***Keywords*—**Ultrasound power, low cost, precision, PVDF, temperature effect, robust casing, FPGA, GUI.

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I. Introduction

ULTRASOUND is one of the most popular and productive non-invasive therapeutic and diagnostic modality. The major frequencies used for the diagnostic and therapeutic purposes are about 1-10 MHz. Higher frequency of the ultrasound will give good resolution of image. However, high frequency and high power ultrasound may cause harmful impacts to human soft tissues [1].

Ultrasound power meter measures and calibrates output power and intensity of the ultrasound machine. It is useful to ensure the ultrasound wave is under safety condition according to International Electrotechnical Commission (IEC). Currently, there are several ultrasound power meters in market but high in cost, big and heavy (less portability). Using radiation force balance method [2-3] and another method with single polymer sensor [4], they are also do not concern about temperature changing at the medium which was used. Most of them have power resolution between 10 and 100 mW/cm^2.

The polymeric material adopted in sensor design becomes aggressively emerges nowadays with introducing new sensor classes. These classes known as polymer sensor are widely used in different applications. It is available in market with differently fabricated shapes and several of it in research and development stage. One among methods applied to implement ultrasound power meter is hydrophone with polyvinylidene fluoride (PVDF) sensor.

PVDF is one of the widely used polymer sensors in various applications and conventionally used as sensing element in pressure sensing, tactile sensor and infrared sensor. Due to technology improvement, PVDF become crucial sensor in medical applications in respect to its properties advantages especially its wide frequency range [5-6]. PVDF has been employed as ferroelectric material that exhibit strong piezoelectricity and pyroelectricity effect. PVDF takes advantage of its low acoustic impedance with 2.7 Mrayl [7] and closely to water and organic tissues. It also has moderate coupling coefficients and flexibility texture.

The unique features of PVDF enabled the initial development and utilization of low frequency transducers and, subsequently, the development of high performance high frequency transducers. PVDF has been used in several investigations for applications in different areas such as medical imaging transducers, ultrasound biomicroscopy [8], hydrophones, non-destructive testing (NDT) transducers, ultrasonic transducers calibration [9], surface acoustic waves (SAW) devices, measurement of shock waves [10-11], energy storage [12], and industrial acoustic and vibration sensors. An overview of PVDF application in biomedical exposimetry, diagnostic and therapeutic ultrasound was explained in [13].

The main disadvantages of PVDF is it has low relative permittivity, which means that small sensing elements will have low capacitance and suffer from signal loss through electrical loading. Most of the characteristic studies are focused on pressure sensing element and temperature dependant. While, for ultrasound field especially ultrasound imaging and ultrasound exposure, it requires more investigation.

Owing to limited numbers of characteristic study, it is demanding to observe the behavior of PVDF sensor for power measurement system. Furthermore, equivalent electrical model for PVDF in pressure sensing application has already discovered and very useful in research and development stage. This model is different in medical implementation due to operating frequency and propagation medium. That is unlikely to adopt the characterization into ultrasound application without properly adjusted in ultrasound field.

At the beginning, this work constructed simple transmit-receive material with 1 centimeter square using 110 micron thickness with gold-plated PVDF on both sides. Effects of distance, frequency, voltage and temperature variables to obtain the performance of PVDF were evaluated. The relationship for those variables also has been derived based on experiment result. The understanding would be helpful for PVDF transducer development.

Afterwards, in order to enable the utilization of PVDF sensor for ultrasound power measurement, a robust casing has been designed and implemented using low-cost material. The casing is built from plastic material. There are two PVDF film attached inside the tank-type casing. The size of the casing can be varied and depends on the size of therapeutic or diagnostic ultrasound probe. The work was also to investigate a low-cost appropriate material that can absorb ultrasound wave. This material or absorber is important to reduce the reflection of ultrasound wave inside the receiver. In order to reduce the current leakage and protect the signal from external noise, a special connector between sensor and electronic circuit was also implemented.

For testing purpose, 1 MHz frequency from ultrasound therapy machine was used in this project. The ultrasound probe area is 5 cm^2. De-gassed water was used as ultrasound wave propagation medium.

In the meanwhile, Field-Programmable Gate Array (FPGA) has been rapidly used for high-speed and reliable solution for electronic devices. It provides a versatile and cost-effective platform in designing system [14]. FPGAs are used to providing hardware platform on which the physical implementation of new algorithms is verified [15]. A recent trend proves that FPGA is also applicable for digital signal processing. The use of high-speed and configurable FPGA will provide faster, cheaper, and better quality of medical instrumentation. Several publications report that there is a possibility to process the signal from the ultrasonic probe by using FPGA [16]. FPGA is chosen due to its high frequency feature and high program memory over the product that easy available in the market. Another programmable devices, the DSP (Digital Signal Processor), has a high sampling rate but lack of the input-output (I/O) ports, while for the microcontroller (μC), it has a low sampling rate and also has very limited I/O ports.

Based on those facts, an ultrasound processing unit using FPGA has also been developed. This design comes out with a platform which satisfies the ultrasound power meter requirement. Moreover, it can be characterized to be used for temperature dependent ultrasound power intensity measurement.

A whole integrated system resulting in implementation of new method of ultrasound power measurement for both therapeutic and diagnostic machines.

II. PVDF CHARACTERIZATION

This part explains study of attenuation signal between two PVDF films conducted by suitable experiments.

A. Characterization Method

In the case, PVDF film acts as transmitter and receiver with proposed distance. To overcome the acoustic impedance that similar to human tissue, both transmitter and receiver were immersed in the water. Distances between both films are 2 cm long.

The film is 1 cm x 1 cm PVDF sensor with 110 micrometer thickness with poled and gold plated on its both surfaces from Precision Acoustic. Another study [17] has a solution in wire or connection selection by using shielded coaxial cable and is adopted in this work by using RG58 C/U coaxial cable and at the end of the cable is male BNC connector. Fig. 1 shows the transmitter-receiver with specific distance between them had been developed for experiment in water.

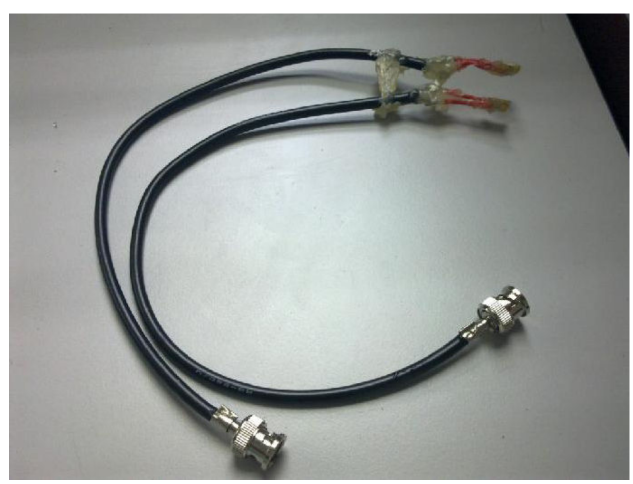


Fig. 1 PVDF transmitter-receiver design

The transmitter part of PVDF transducers is connected to function-generator which is supplying sinusoidal signal with different voltage level and frequency depending on each experiment. Whereas, receiver parts of PVDF transducer is connected to digital oscilloscope analyzing the shape of signal, voltage level and frequency which is received. The distance between transmitter and receiver is maintained 2 cm in water medium. Fig. 2 shows the block diagram for experimental setup to observe the attenuation signal.

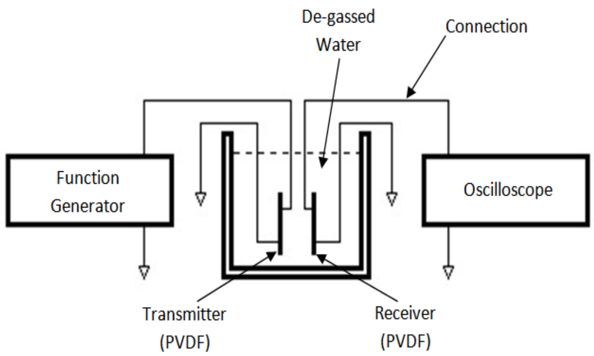


Fig. 2 Diagram of PVDF experiment setup

For an experiment to observe the effect of frequency changes, function generator was supplying sinusoidal signal with 1 Vpeak and frequency between 10 KHz and 10 MHz to the transmitter film. While, another experiments were varying the voltage between 120 mVpeak and 1 Vpeak by keeping the frequency at 1 MHz. Experiment to study the effect of temperature was conducted by varying the water temperature between 10 ^{O}C and 50 ^{O}C and fixing the voltage at 1 Vpeak and frequency at 1 MHz.

B. Effect of Distance in Water

Since the measurement would be immersed in water-tank with diameter not exceeds 10 cm, transmit-receive distance was varied at about 0 cm, 2 cm and 9 cm fixed respectively. For each distance, voltage source was emitted 1 Vpeak sine wave and frequency increased up to 10 MHz.

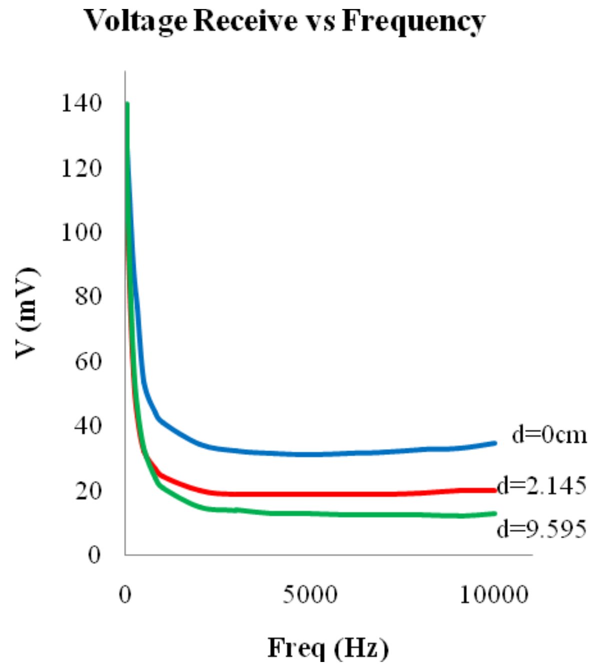


Fig. 3 Voltage vs frequency with varying distance

Fig. 3 shows plot voltage receives versus frequency. It can be seen that non-zero distance does not have major effect on received voltage amplitude. The same behavior pattern with increasing frequency looks obvious. Thus, 2 cm distance has been chosen.

C. Effect of Frequency

Experiment was conducted by supplying 1 Vpeak voltage and frequency was varied from 20 KHz until 10 MHz. The result is shown in Fig. 4.

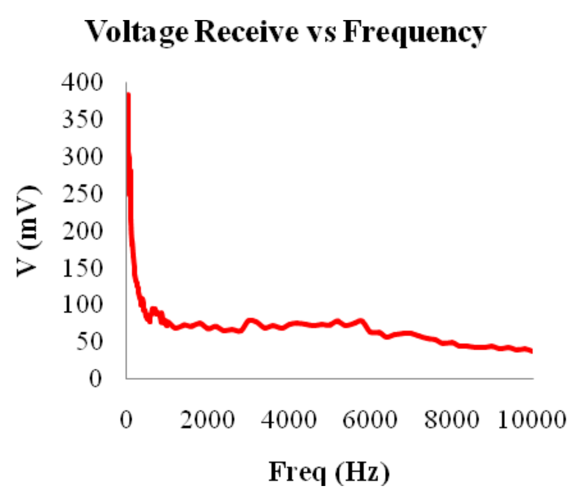


Fig. 4 Voltage receive vs frequency

From Fig. 4 above, voltage that has been sensed at receiver part is inversely proportional to the transmitted frequency. The received voltage was decreased upon the increasing of the frequency. Only 40 percents from transmitted voltage were received at receiver and this value was decreased slowly until 10 percents of amount at 600 KHz.

Non-linear trend is unintended. However, since frequency of interest shall be taken at medical ultrasound area, so linearity is possible. Between 1 MHz up to 6 MHz the curve shows an acceptable constant. Hence, effect of frequency can be neglected. This circumstance gives an advantage for reducing complexity in further implementation.

D. Voltage Transfer Characteristic

The observation was conducted by supplying 1 MHz frequency and voltage were varies between 120 mVpeak and 1 Vpeak.

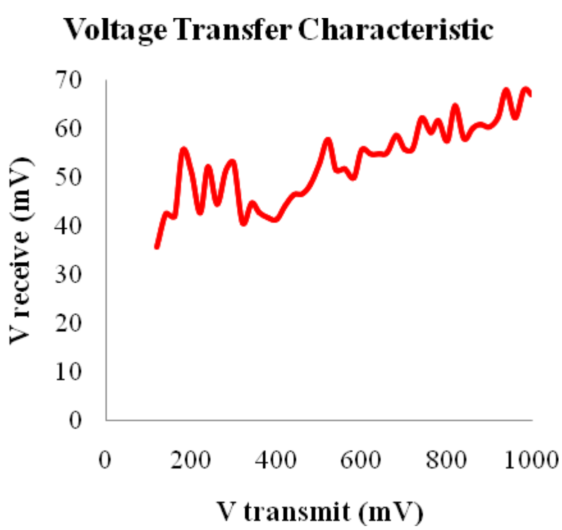


Fig. 5 Voltage transfer characteristic

Fig. 5 shows that the received voltage has a linear relationship with transmitted voltage. However, result shows its gradient is increasing between 30 mV and 60 mV.

From the curve fitting process, the relationship between received voltage V_R (mV) and transmitted voltage V_T (mV) are obtained as shown in following (1) with coefficient 95% confidence bounds.

$$V_R = 0.5361\,V_T + 40.86 \quad (1)$$

E. Effect of Temperature

A testing was carried to study the effect of signal propagation based on temperature changes in water. This was conducted by changing temperature between 10 ^{O}C and 50 ^{O}C by maintaining voltage and frequency at 1 Vpeak and 1 MHz respectively.

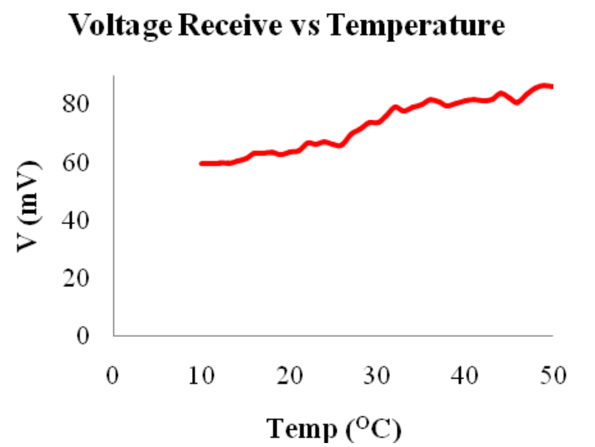


Fig. 6 Voltage vs temperature

Based on Fig .6, the received voltage is slightly increased with the increase of water temperature. Meanwhile, the signal received is also influenced by temperature where low temperature caused much distortion compared to high temperature.

With the curve fitting process, the relationship between received voltage V (mV) and temperature T (^{O}C) are obtained as show in following (2) with coefficient 95% confidence bounds.

$$V = 0.7473T + 57.29 \quad (2)$$

III. PVDF Sensor Casing

A. Design Method

Casing design plays important role in ultrasound power meter development. The casing should be able to protect the sensors from the water leakage that can cause short circuit to the electrical part. Besides that, the receiver should have a good absorber that can prevent the ultrasound wave from being reflected inside the receiver and increase the chance for the sensor to capture good signal from the ultrasound transducer [18].

This project used ultrasound transducer to give ultrasound wave to the designed receiver. It also used oscilloscope to detect and measure the signal from the receiver. Meanwhile, data analysis was done with the help of computer software.

General setup for the receiver system is described as in Fig. 7.

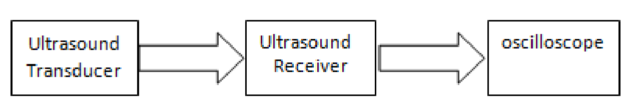


Fig. 7 General view of receiver system

The system is being used to receive the signal from the ultrasound transducer/transmitter (therapeutic or diagnostic probe) and display it at the oscilloscope in terms of voltage by varying the intensity of the power emitted by the transmitter.

B. Fabrication of Water-Tank

The fabrication of the water-tank is based on the power meter available in the market. The difference is the sensor used to measures the ultrasound signal from the ultrasound transducer. For the available power meter in the market, they are using radiation force based position sensor as the main sensor to detect the ultrasound signal. This project uses PVDF sensor to detect the ultrasound signal. The actual illustration of this water-tank can be seen in Fig. 8. Two holes at the bottom of the tank are for the PVDF sensors.

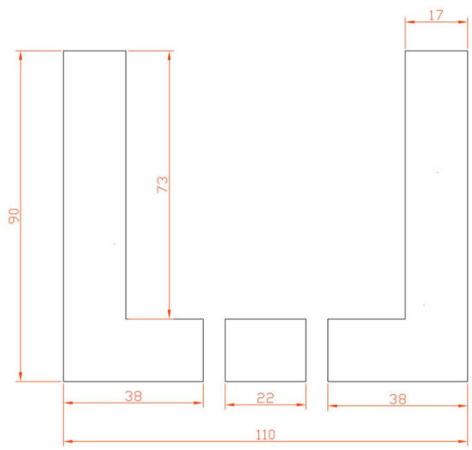
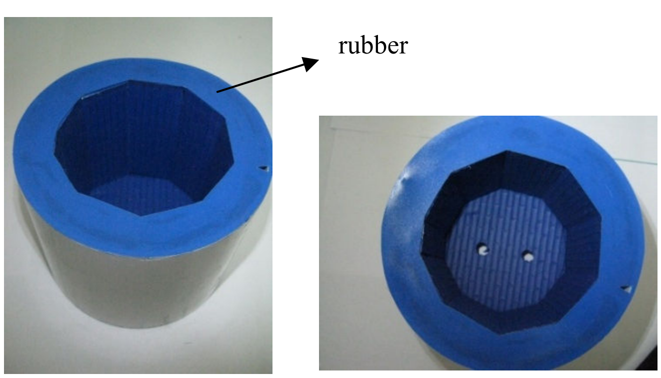


Fig. 8 Schematic of water-tank

Outer casing is made of polyvinyl chloride (PVC). The height of the PVC pipe used is about 90 mm with 110 mm diameter and 2 mm thickness. There are some reason using this type of casing, i.e. because it light in weight, low-cost, easy to cut and can avoid from any current leakage to the environment.

The cutting must be perfect to avoid any water leakage during the experiment. The bottom of this pipe is closed by hard plastic with two holes for the PVDF sensor. PVC glue is being used to glue those two parts together.

Rubber is a material that has a good attenuation characteristic which is used to absorb the access ultrasound wave inside the tank as shown in Fig. 9. The blue material is rubber that already sticks inside the inner wall of the PVC pipe. The thickness of the rubber is 15 mm. At the bottom of this casing, there are 2 holes for the PVDF sensors.



(a) (b)

Fig. 9 Rubber inside the casing: top view (a), side view (b)

C. PVDF Sensor Housing

SubMiniature version A (SMA) connector is a high frequency component that is used as the base of the PVDF sensor as shown in Fig. 10. Top section of the SMA connector is connected with brass casing to hold the PVDF films. Conductive Epoxy is inserted inside the brass casing that act as backing material and as the adhesive between the PVDF and the conductive part. Top of the PVDF also have a layer of nonconductive epoxy that used to secure the PVDF from the water. This sensor is directly connected to the coaxial cable (RG-58). There are two sensors needed for the tank type and this is one of them [19]. This sensor then will be put at bottom of the tank.

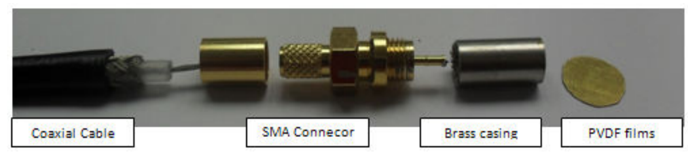


Fig. 10 PVDF sensor with SMA connector

Backing material is used to ensure the effective operation of the sensor as well as adjusting certain bandwidth. It must be sufficiently attenuating to absorb the ultrasound wave incident. For this sensor, EPOTEK EE129-4 was used also as the material to make an electrical connection. It comes with part A and Part B, this part should be mixing together with ratio of weight is 1:1. It takes almost 8 hours to become hard and can conduct electricity.

The backing material used under the PVDF film for wave attenuation is mixing of aluminum powder with the epoxy resin. This material will reduce the signal by absorbing the ultrasound wave which may cause some echo and noise to the signal. Aluminum is being used because it is a soft metal so easier to make a smooth surface. It also has relatively low acoustic impedance among other metal [20].

This sensor is totally immersed in the water. Therefore, after it is plugged at the bottom of its casing, plastic glue was used to protect the sensor from water leakage. At top side of the PVDF sensor also must be protected by using epoxy resin hardener. This hardener should not have bubble inside it because it can disturb the ultrasound wave and it should be a very thin layer to avoid it becomes attenuation to the wave.

D. Integrated Receiver Casing

After the fabrication of PVDF sensor is completed, the last step is to insert the sensor at the bottom of the casing. Plastic glue is being used to stick the sensor and the base of the tank together. Fig. 11 shows the complete design of the water-tank for power meter. The gold color inside the tank is the PVDF layer that has already covered by the epoxy resin to prevent it from water leakage. This PVDF sensor is connected to the BNC cable that will connect this receiver to the oscilloscope.

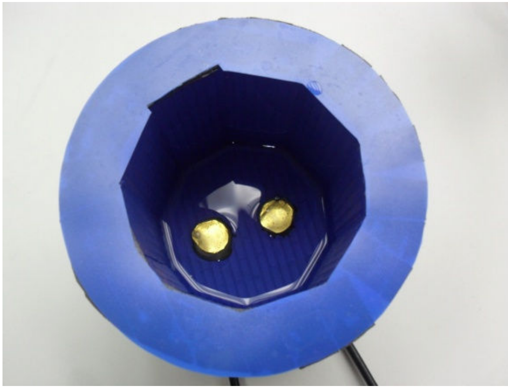


Fig. 11 Complete design of PVDF sensor water-tank casing

E. *Water-Tank Implementation*

This receiver has been tested using the therapeutic ultrasound probe. For better visualization, we can see the diagram on the Fig. 12. The transducer head is approximately 5 cm from the sensor and the head surface is immersed inside water in tank. For this project, only one transducer head is used that is 5 cm2 with frequency 1 MHz (as capability of available ultrasound therapy machine).

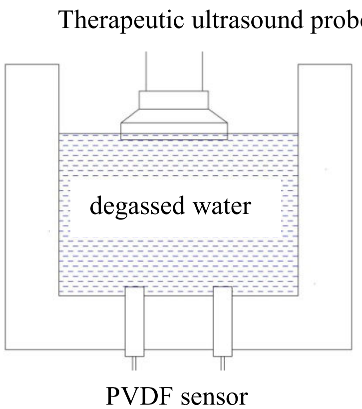


Fig. 12 Water-tank implementation setup

Water used inside the tank, as a measurement medium, is degassed water. This is to minimize the micro bubbles effect during measurement. The ultrasonic attenuation in the water can be taken as a lower limit on the attenuation which will be encountered in the human body. Large areas in the body can consist of low attenuating material such as urine and amniotic fluid. The use of water prevents measurements in a more highly attenuating material such as liver equivalent gels from representing the highest possible intensities which might be encountered in the body [21].

The procedure to make degassed water is: boil distilled water on 20 minutes, then pour into a suitable container, seal tightly and place in the refrigerator. This process will give the required quality. The container should be heat resistance glass or thick plastic may be used after the water has been cooled. Before testing, pour water into tilted test tank to minimize the turbulence. The test tank water surface will absorb the oxygen and a change of degassed water is recommended before each experiment [21].

The experiment was conducted by varying the power emitted by the transducer head from 0.1 W/cm^2 to 1.9 W/cm^2. The output voltage peak-to-peak produced was recorded at the oscilloscope. The temperature level being used is at room temperature.

From the result as can be seen in Table I, the output voltage shows some pattern while the intensities of the transducer head are higher. If the output voltages become increase as the intensities of the transducer head increase somehow we can say that the voltage output is proportional to the intensities of the transducer head.

TABLE I
VOLTAGE VERSUS ULTRASOUND INTENSITY

Intensity (W/cm^2)	**Voltage (V)**	**Intensity (W/cm^2)**	**Voltage (V)**
0.1	10.6	1.1	12.3
0.2	10.8	1.2	12.3
0.3	11.3	1.3	12.4
0.4	11.5	1.4	12.1
0.5	11.7	1.5	12.2
0.6	11.9	1.6	12.4
0.7	12	1.7	12.5
0.8	11.9	1.8	12.3
0.9	12	1.9	12.9
1	11.9		

The following Fig. 13 shows graph of voltage versus intensity.

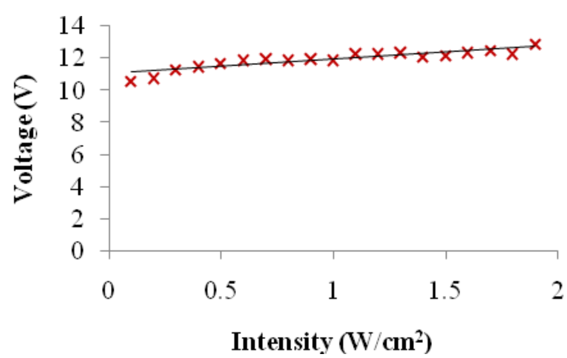


Fig. 13 Graph voltage versus intensity

The non linear result is likely because of the noise from surrounding and also noise from the reflection of the ultrasound wave inside the tank itself. The noises cause the input signal become worst to be captured by the sensor. Still, linear correlation between voltage (V) and non-zero intensity (I) is approached in (3).

$$V = 0.914I + 11.03 \quad (3)$$

IV. Ultrasound Power Calculation

According to guidance issued by U.S. Food and Drug Administration [22], ultrasonic power (Watt) is a quantity describing the rate at which acoustic energy travels per unit time in the direction of propagation. Ultrasound intensity is the ultrasonic power transmitted in the direction of acoustic wave propagation, per unit area normal to this direction, at the point considered. For measurement purposes, this point is restricted to points where it is reasonable to assume that the acoustic pressure and particle velocity are in phase, viz., in the far field or the area near the focal surface.

The instantaneous ultrasonic power transmitted in the direction of acoustic wave propagation, per unit area normal to this direction, at the point considered is given in the far-field by:

$$i = {p^2}/{\rho c} \ (W cm^{-2}) \tag{4}$$

where
p is the instantaneous acoustic pressure (Pa);
ρ is the density of the medium (kg/m^3);
c is the speed of sound in the medium (m/s).

Ultrasound intensity spatial-peak temporal-average (I_{SPTA}) is the value of the temporal-average intensity at the point in the acoustic field where the temporal-average intensity is a maximum, or is a local maximum within a specified region. This I_{SPTA} is usually taken into account for acoustic output measurement labeling.

The relationship between PVDF hydrophone output voltage and acoustic pressure as been documented by Precision Acoustics [23] is:

$$p = \frac{V}{M(f)} \ (Pa) \tag{5}$$

where
p is the acoustic pressure (Pa);
V is the measured voltage output (V);
M(f) is the sensitivity of the hydrophone as a function of frequency (V/Pa).

At 1 MHz, M(f) is 100 mV/MPa; while at 2 MHz, M(f) is 88 mV/MPa. Maximum temporal average power can be calculated as follows:

$$P_{TAmax} = \left(\sum_{Beam\ Area} I_{SPTA} \right) x (Beam\ Area) \tag{6}$$

Frequency domain analysis is one of method for calculating ultrasound acoustic intensity. By this way, signal in time domain are observed and then converted into frequency spectrum. The magnitude of respective frequency of interest is captured to be calculated in term of power spectral. Ultrasound intensity then can be obtained by implementing particular formulas.

V. Signal Processing Device Development

Basically, ultrasound power meter is a device that sense, process, and display result of signal characteristic and/or parameter. Transducer is handling sensing job while the result would be mentioned in displaying unit. Processing unit is a core segment that deals with conditioning, calculating, and transmitting ultrasound data.

The project published in [24] built ultrasound processing unit using FPGA as core processor device. It also employed Analog-to-Digital Converter (ADC) and microcontroller (with Programmable Interface Controller – PIC) for supporting the system. GUI was added as interface in personal computer (PC).

A. System Specification

The ultrasound processing system should be able to measure ultrasound frequency range between 500 kHz and 10 MHz while temperatures range from 10 °C to 50 °C. Table II shows the detail specification.

Table II
Specification of the System

Input ports	- 12-bit hydrophone signal - temperature signal (analog)
Output ports	- LCD - USB
Intensity range (resolution)	1 mW/cm^2 – 10 W/cm^2 (0.87 mW/cm^{2})
Temperature range (resolution)	10 °C - 50 °C (1.95 °C)
Frequency range	500kHz – 10MHz

Ultrasound processing unit is dealing with modules inside boundary in Fig. 14. The function for each component is to process the data input from the PVDF sensor and send the data to PIC and PC, while for the PIC, it used to provide analog-to-digital converter (ADC) for temperature and as a level converter for the FPGA to LCD. The LCD function is to display the result in graphical and text mode.

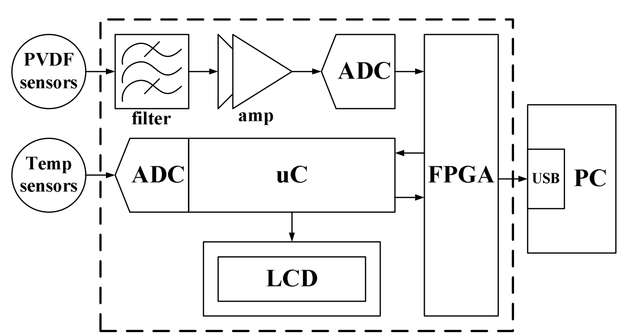


Fig. 14 Block diagram of ultrasound power meter

Meanwhile in PC, a graphical user interface has been developed. The GUI receives the data from the ultrasound processing unit through serial communication and display the result in the graph format.

B. System Architecture

Referring to the Fig. 15, the system captures sensors' output which is converted into digital by ADC. After buffering the data, it will perform the ISPTA calculation and transform voltage to ultrasound intensity value. Next, it will send the intensity result to LCD and the whole set of buffered data to PC for the further analysis about the waveform of the ultrasound.

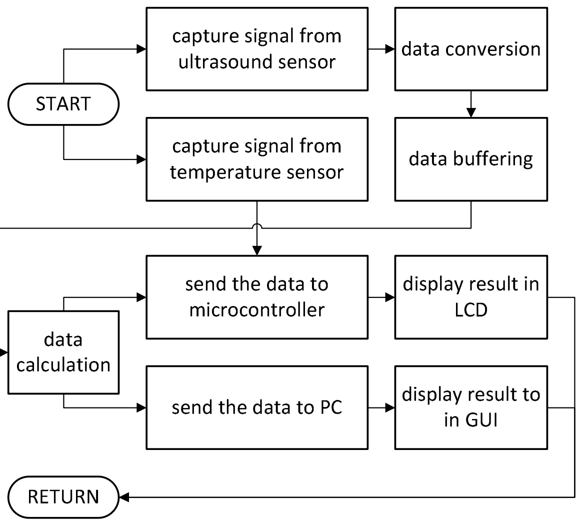


Fig. 15 System design of the ultrasound processing unit

As described in previous chapter, ultrasound intensity calculation requires a translation from time domain into frequency domain. Some constant values are involved. Arithmetic operations for linear equation such as addition, multiplication, division, and power are applied. Communication procedure for data transfer between hardware is also needed. The process is explained in Fig. 16.

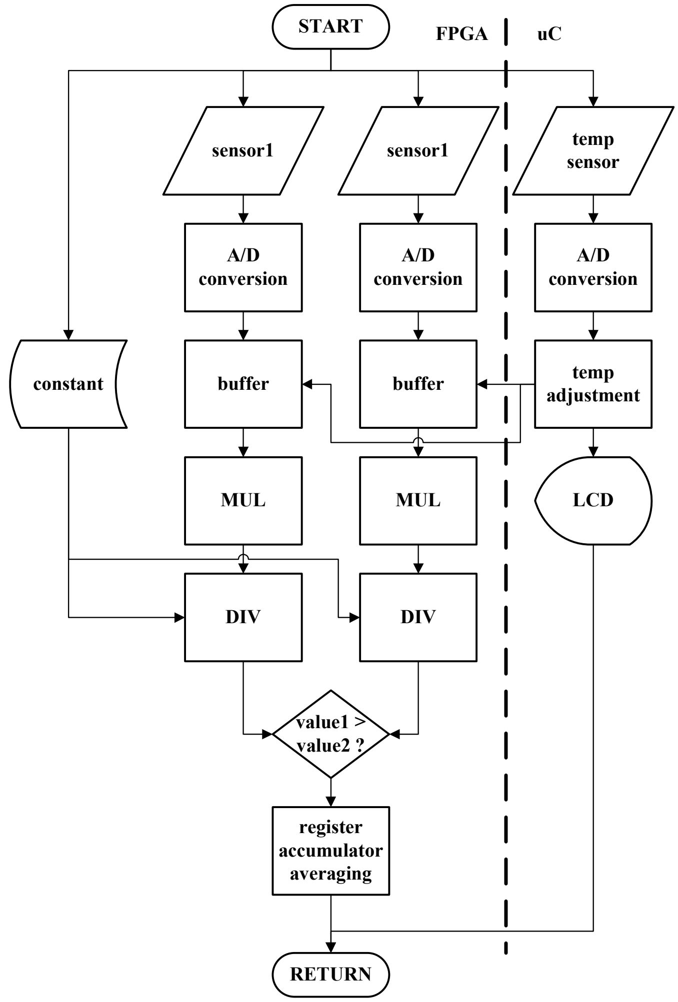


Fig. 16 Algorithm of ultrasound intensity calculation

Digital processing and data management works are done in FPGA. An example of FPGA implementation for Universal Asynchronous Receiver Transmitter (UART) was described in [14]. Some works in implementing Fast Fourier Transform into FPGA platform was explained in [25]. The need of multiplier can be fulfilled by Booth Multiplier circuit. High-speed 8-bit Booth multiplier was proposed in [26]. FPGA capability to handle linear equation systems with single and double precision floating-point data was proved by [27]. A low-power and good Electro-Magnetic Compatibility (EMC) may be obtained with asynchronous design [28].

Fig. 17 shows architecture diagram of ultrasound processing unit. FPGA should covering elements such as memory unit, arithmetic, and transmit register for datapath along with control unit.

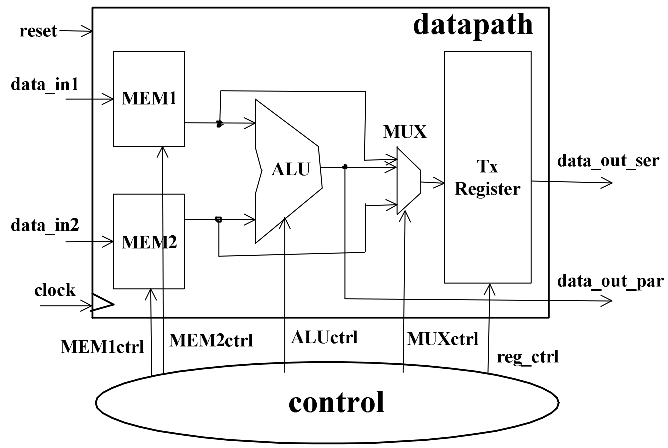


Fig. 17 RTL block diagram of ultrasound processing unit

In addition, the platform which is designed also need additional data acquisition module. In this case, the microcontroller (i.e. PIC18F452) is used. The need of data acquisition module occurs as a result of LCD display and temperature sensing requirements.

VI. Simulation and Testing

Based on [24], simulation was done with Altera Quartus II 8.1 Web Edition in order to examine the function and timing characteristic of the developed module for implementation in Altera Cyclone II FPGA device (EP2C20F484C7N).

A. Hardware Requirement

The FPGA clock should be able to capture at maximum 10 MHz full-form of ultrasound signal and its certain voltage magnitude given by transducer output. Therefore, FPGA clock must reach 50 MHz (20 ns time-domain resolution) in order to make good sampling of ultrasound signal. Voltage work level is chosen 5 Vpeak.

Storage capability also considered to catch full-cycle of ultrasound waveform. Hence, logic element of FPGA has to be sufficient at least for registering 100 kHz (10 µs at time domain) ultrasound data so that the processing would deals with complete form of signal. The use of external memory such as 512 KB available Static Random Access Memory (SRAM), Dynamic Random Access Memory (DRAM), or flash memory could be helpful. Table III is derived from the simulator's summary report.

Table III
Hardware Requirement

Digital logic / registers	16.273 K
Memory	1.311 KB
FPGA clock	50 MHz
ADC sampling rate	53 MSPS

Another important matter is connection and timing between FPGA-PIC, and FPGA-PC. FPGA and PIC were set at condition that both devices could drive each other. In other case, FPGA should have UART module to send and/or receive data to/from PC.

B. Simulation Result

Fig. 18 shows the simulation results of the data buffering from Quartus II software. From the graph, pulses are used as the inputs for the ultrasound processing unit. There are two outputs from FPGA that are output to PIC (dataout_par) and PC (dataout_ser).

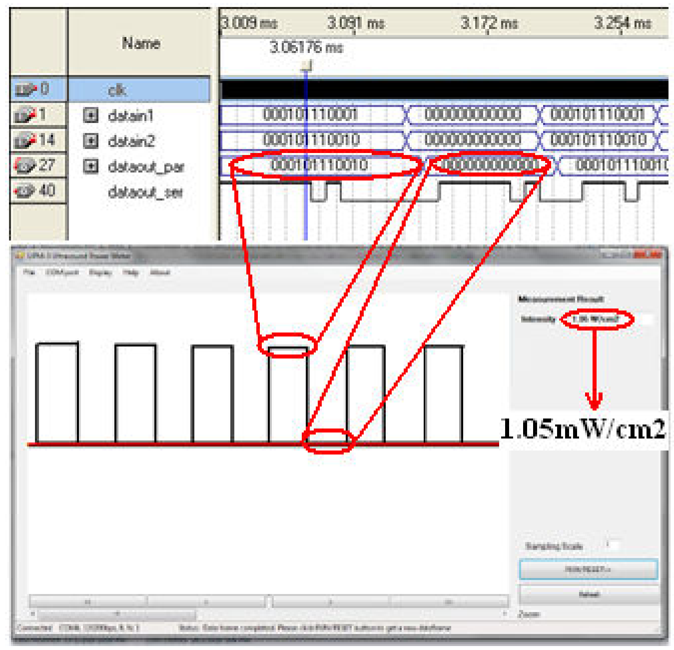


Fig. 18 Simulation result from Quartus and GUI

From the figure, a square wave graph is drawn by GUI. This result is match to the input given by FPGA. At about 3ms, data are being sent. This is taken as an example of displaying ultrasound signal on PC via GUI.

Ultrasound intensity is digitized by ADC. 12-bit version ultrasound intensity is sampled from 1 mW/cm^2 up to 10 W/cm^2. Correlation between amplitude (voltage) and intensity of ultrasound signal is obtained from modified PVDF formula as mentioned in [29] and [30].

$$I = \frac{V^2}{{g_{33}}^2 t^2 \rho c} \tag{7}$$

g_{33} = Piezo stress constant (VmN^{-1})
t = PVDF sensor thickness (m)
ρ = Water density (kgm^{-3})
c = Ultrasound speed in water (ms^{-1})
V = PVDF sensor output voltage (V)
I = Intensity (Wm^{-2})

Test result for input 1 W/cm^2 ultrasound therapy signal's intensity with 1 MHz frequency at 22 ^{o}C temperature is shown in Fig. 19.

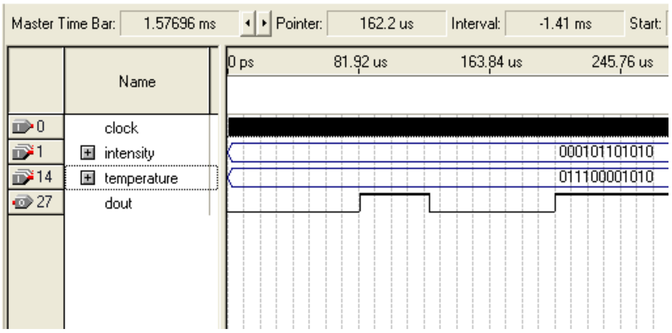


Fig. 19 Test result 1 W/cm^2 1 MHz 22 ^{o}C

It is shown that the platform could response ultrasound signal (then convert into its power value) and temperature. Thereafter, data (labeled 'dout') would be captured 10.9 µs per-cycle.

VII. Conclusion

This work proves that the frequency, voltage and temperature do have effects in performance of the ultrasound power measurement using PVDF film. Each equation can be further adjusted to theoretical parameters for practical custom. Furthermore, the relationship between variables is beneficial for designing transducer especially in medical ultrasound exposimetry.

A low-cost robust PVDF sensor casing has been successfully developed. Receiver housing is fabricated with inexpensive material and producing a good functionality. The unique design has been obtained while the test result shows a possibility to use it for ultrasound intensity measurement purpose. The derived formula then can be further implemented along with data acquisition and signal processing platform for low-cost ultrasound power measurement system.

An algorithm to create an ultrasound processing unit and its implementation has been described. With this system, there is a possibility to develop a FPGA based ultrasound power meter. In future, further modification on ultrasound processing unit can be done in order to improve the performance. Various works might be in area of real-time processing, optimizing hardware area (e.g. reducing logic element), embedding system, etc.

To sum up, the whole system represents a novel design of low cost ultrasound power measurement system with high precision capability for medical application. This may improve the existing power meter which has power resolution limitation, no mechanism to handle the temperature disturbance and no possibility for further data analysis.

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References

[1] N. J. Hangiandreou, "Physics Tutorial for Residents: Topics in US: B-mode US: Basic Concepts and New Technology ," *Radiographics* vol. 23, no. 4, pp. 1019-1033, July 2003.

[2] M. A. Lim, R. A. Dove, and P. J. Bones "Diagnostic Ultrasound Power Meter," in *22nd Annual International Conference of the IEEE Engineering in Medicine and Biology Society,* USA, vol. 4. pp. 2644-2655, 2000.

[3] Whittingham et al., "Ultrasonic Radiation Balance," U. S. Patent 4,104,923, August 8, 1978.

[4] Bajram, "Apparatus for Measuring Ultrasonic Power," U. S. Patent 6,978,677 B2, December 27, 2005.

[5] C. O. Gonzalez-Moran, R. Gonzalez-Ballesteros, and E. Suaste-Gomez, "Polivinylidene Difluoride (PVDF) Pressure Sensor for Biomedical Applications," *1st International Conference on Electrical and Electronics Engineering*, pp. 473-475, 2004.

[6] S. Foster, K. A. Harasiewicz, and M. D. Sherar, "A History of Medical and Biological Imaging with Polyvinylidene Fluoride (PVDF) Transducers," *IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control*, vol. 47, no. 6, pp. 1363-1371, November 2000.

[7] M.-H. Jung, M. G. Kim, and J.-H. Lee, "Micromachined ultrasonic transducer using piezoelectric PVDF film to measure the mechanical properties of bio cells," *Sensors, 2009 IEEE*, pp.1225-1228, 25-28 Oct. 2009.

[8] F. S. Foster, K. A. Harasiewiez, and C. J. Pavlin. "Advances in ultrasound Biomicroscopy." *Journal of Ultrasound Med. Biol.*, vol. 26, pp. 1-27, 2000.

[9] W. Galbraith and G. Hayward, "Development of a PVDF Membrane Hydrophone for use in Air-Coupled Ultrasonic Transducer Calibration," *IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control*, vol. 45, no. 6, pp. 1549 – 1558, 1988.

[10] B. Granz, "PVDF Hydrophone for the Measurement of Shock Waves," *IEEE Transactions on Electrical Insulation*, vol. 24, no. 3, pp. 400-403, 1989.

[11] D. Cathignol, "PVDF Hydrophone with Liquid Electrodes for Shock Wave Measurements," in *Proceedings of the 2009 IEEE Ultrasonics Symposium*, Honolulu, USA, December 4-10, 1990, pp. 341-344.

[12] J.P. Zheng, "Dielectric Properties of PVDF Films and Polymer Laminates with PVDF for Energy Storage Applications," *6th International Conference on Properties and Applications of Dielectric Materials*, Xi'an Jiaotong University, Xi'an, China, 2000.

[13] G. R. Harris, "Piezoelectric polyvinylidene fluoride (PVDF) in biomedical ultrasound exposimetry," in *Biomedical Applications of Electroactive Polymer Actuators*, F. Carpi and E. Smela, Eds. Chicester: John Wiley & Sons, 2009, Chapter 19, pp. 369-383.

[14] R. S. J. Reyes, C. M. Oppus, J. C. S. Monje, N. S. Patron, R. A. Gonzales, O. Idano, and M. G. Retirado. "Field programmable gate array implementation of a motherboard for data communications and networking protocols". *International Journal of Circuits, Systems and Signal Processing*. NAUN Press, Vol. 5, Issue 4, 2011, pp. 391-398.

[15] H. Ouarda. "FPGA and Field Programmable Devices architecture: A tutorial". *International Journal of Circuits, Systems and Signal Processing*. NAUN Press, Vol. 5, Issue 5, 2011, pp. 529-536.

[16] P. Zurek, "Implementing FPGA Technology in Ultrasound Diagnostic Device," in *Proceedings of the 5th International Conference on Information Technology and Application in Biomedicine*, pp. 179-182, May 2008.

[17] A. Selfridge and P. A. Lewin, "Wideband Spherically Focused PVDF Acoustic Sources for Calibration of Ultrasound Hydrophone," *IEEE Transaction on Ultrasonic, Ferroelectrics and Frequency Control*, vol. 47, no. 6, pp. 1372-1376, 2000.

[18] E. Supriyanto, I. Muttakin, M. H. M. Fathil, and C. Omar, "Low-cost PVDF sensor casing for ultrasound power measurement," in *Proceedings of the 15th WSEAS International Conference on Circuits*, Corfu Island, Greece, July 14-16, 2011, pp. 144-147.

[19] G. R. lockwood, D. H. Turnbull, and F. S. Foster, "Fabrication of High Frequency Spherically Shaped Ceramics Transducer," *IEEE transactions on Ultrasonic, Ferroelectric and frequency Control,* vol. 41, no. 2, pp. 231-235, 1994.

[20] H. S. Cheng and C. L. Yung, "Fabrication of Poly(Vinylidene Fluoride-Trifluoroethylene) Ultrasound Focusing Transducer and Measurements of Elastic Constants of Thin Plates," *NDT&E International*, vol. 43, pp. 96-105, 2010.

[21] Ohmic Instruments Co. *Ultrasound Power Meter Manual*. 1996.

[22] USA. US Department of Health and Human Services, Food and Drug Administration Center for Devices and Radiological Health, *Information for Manufacturers Seeking Marketing Clearance of Diagnostic Ultrasound Systems and Transducers*. September 1997.

[23] Precision Acoustics. *Simple Guidelines on Conducting Ultrasonic Intensity Measurements*. June 2007.

[24] E. Supriyanto, K. J. Yeo, I. Muttakin, I. Ariffin, S. Y. Yeap, "A novel FPGA based platform for ultrasound power measurement," *in Proceedings of the 3rd International Conference on Biomedical Engineering and Informatics (BMEI)*, vol.4, no., pp. 1405-1408, 16-18 Oct. 2010.

[25] A. Saeed, M. Elbably, G. Abdelfadeel, and M. I. Eladawy. "Efficient FPGA implementation of FFT/IFFT Processor". *International Journal of Circuits, Systems and Signal Processing*. NAUN Press, Vol. 3, Issue 3, 2009, pp. 103-110.

[26] H.-C. Chow, I.-C. Wey and H.-C. Liang. "High speed pipelined booth multiplier". *WSEAS Transactions on Circuits and Systems*, Vol. 4, Issue 5, 2005, pp. 495-505.

[27] R. Martinez, D. Torres, M. Madrigal and S. Maximov. "Parallel architecture for the solution of linear equations systems based on Division Free Gaussian Elimination Method implemented in FPGA". *WSEAS Transactions on Circuits and Systems*, Vol. 8, Issue 10, 2009, pp. 832-842.

[28] S.-Y. Tan and W.-T. Huang. "A VHDL-based design methodology for asynchronous circuits". *WSEAS Transactions on Circuits and Systems*, Vol. 9, Issue 5, 2010, pp. 315-324.

[29] D. Damjanovic, "Ferroelectric, Dielectric and Piezoelectric Properties of Ferroelectric thin Films and Ceramics", in *Rep. Prog. Phys. 61*, pp. 1267–1324, 1998.

[30] H. Mulyadi, I. H. Hii, M. N. M. Nordin and E. Supriyanto, "Characterization of Polyvinylidene Fluoride for Temperature Dependent Ultrasound Intensity Measurement", *Proceeding of 2008 Student Conference on Research and Development (SCOReD)*, Malaysia, pp. 61.1-61.4.

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