ULTRASOUND POWER MEASUREMENT SYSTEM DESIGN USING PVDF SENSOR AND FPGA TECHNOLOGY

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ULTRASOUND POWER MEASUREMENT SYSTEM DESIGN USING PVDF SENSOR AND FPGA TECHNOLOGY

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"in The Name of Allah The Most Gracious The Most Merciful
seeking forgiveness from Rabb All-Hearer All-Sufficient"

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ABSTRACT

Ultrasound machine is widely used in industrial and medical institutions. With the purpose of avoiding the unwanted power exposed on human, ultrasound power meter is employed to measure output power of ultrasound machine for diagnostic, therapeutic and non-destructive testing purposes. The existing ultrasound power meter, however, is high-cost, low-resolution and only for specific machine. Radiation balance method consists of calculation and calibration complexity while the calorimetric produces inaccurate result compared to the standard. On the other hand, application of piezoelectric sensor in hydrophone-based measurement requires advancement on processing device and technique. This work deals with the development of ultrasound power measurement system on Field Programmable Gate Array (FPGA) platform. Polyvinylidene Fluoride (PVDF) was employed to sense medical ultrasonic signal. PVDF film's behavior and its electro-acoustic model were observed. Signal conditioner circuit was then described. Next, a robust low-cost casing for PVDF sensor was built, followed by the proposal of the use of digital-system ultrasound processing algorithm. The simulated sensor provided 2.5 MHz to 8.5 MHz response with output amplitude of around 4 V_{pp}. Ultrasound analog circuits, after filtering and amplifying, provided frequency range from 1 MHz until 10 MHz with -5 V to +5 V voltage head-rooms to offer a wideband medical ultrasonic acceptance. Frequency from 500 kHz to 10 MHz with temperature span from 10 ^{o}C to 50 ^{o}C and power range from 1 mW/cm^2 up to 10 W/cm^2 (with resolution 0.05 mW/cm^2) had been expected by using the established hardware. The test result shows that the platform is able to process 10 μs ultrasound data with 20 ns time-domain resolution and 0.4884 mV_{pp} magnitude resolutions. This waveform was then displayed in the personal computer's (PCs) graphical user interface (GUI) and the calculation result was displayed on liquid crystal display (LCD) via microcontroller. 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 meters which have intensity resolution limitation (at best combination, of all products, utilize: 0.25 MHz - 10 MHz frequency coverage; 10 ^{o}C to 30 ^{o}C working temperature; 0 W/cm^2 - 30 W/cm^2 power range; 20 mW/cm^2 resolution), neither having mechanism to handle the temperature disturbance nor possibility for further data analysis.

ABSTRAK

Mesin ultrabunyi digunakan secara meluas dalam bidang perubatan dan industri berat. Bagi mengelakkan para pengguna mesin ultrabunyi daripada terdedah kepada kuasa elektrik yang tidak diingini, meter kuasa ultrabunyi digunakan untuk mengukur kuasa keluaran mesin ultrabunyi diagnostik, terapi, dan ujian tanpa musnah. Walaubagaimanapun, meter kuasa ultrabunyi yang sedia ada mempunyai kos yang tinggi, beresolusi rendah dan digunakan secara khusus untuk jenis-jenis mesin tertentu. Pengukur kuasa ultrabunyi sedia ada terdiri daripada beberapa jenis termasuk *radiation balance*, *calorimetric* dan *hydrophone*. Kaedah pengukuran kuasa berdasarkan teknik *radiation balance* adalah amat rumit manakala teknik *calorimetric* pula tidak memenuhi piawaian pengukuran yang ditetapkan. Selain itu, teknik pengukuran menggunakan *hydrophone* dengan penggera piezoelektrik pula memerlukan peranti dan teknik pemprosesan yang kompleks. Oleh yang demikian, kajian ini memberi fokus kepada pembangunan sistem pengukuran kuasa ultrabunyi berteraskan *Field Programmable Gate Array (FPGA)* yang lebih tepat, mudah dan murah. Di dalam kajian ini, *polyvinylidene Fluorida (PVDF)* digunakan untuk mengesan isyarat ultrabunyi perubatan. Karakter filem PVDF dan model elektro-akustiknya telah dikaji diikuti oleh pembinaan litar *conditioning*. Kemudian, pelindung penggera PVDF berkos rendah yang teguh pula dibina. Kajian ini turut mencadangkan penggunaan algoritma sistem digital untuk pemprosesan ultrabunyi. Simulasi penggera telah menunjukkan respon pengukuran 2.5 MHz hingga 8.5 MHz dengan amplitud keluaran sekitar 4 V_{pp}. Litar analog ultrabunyi, selepas penapisan dan penguatan, telah memberikan julat frekuensi 1 MHz hingga 10 MHz dengan -5 V hingga +5 V ruang voltan mampu menawarkan penerimaan ultrabunyi perubatan jalur lebar. Frekuensi dari 500 kHz hingga 10 MHz dengan rentang suhu daripada 10 ^{o}C hingga 50 ^{o}C dan nilai kuasa daripada 1 mW/cm^2 hingga 10 W/cm^2 (dengan resolusi 0.05 mW/cm^2) telah dijangka oleh perkakasan yang ditubuhkan. Hasil ujian menunjukkan bahawa platform baru ini mampu memproses 10 μs data ultrabunyi dengan resolusi domain masa 20 ns dan resolusi magnitud 0.4884 mV_{pp} serta berkeupayaan untuk memaparkan bentuk gelombang tersebut pada komputer melalui grafik antara muka pengguna (GUI). Hasil pengukuran pula dipaparkan dalam paparan kristal cecair (LCD) melalui litar mikropengawal. Keseluruhan sistem yang dibina di dalam kajian ini merupakan sebuah rekabentuk baharu untuk sistem pengukuran kuasa ultrabunyi berkos rendah dan berketepatan tinggi untuk digunakan di dalam bidang perubatan. Kaedah baharu ini mampu meningkatkan meter kuasa sedia ada yang mempunyai kelemahan resolusi kekuatan dan tidak mempunyai mekanisme untuk menangani gangguan suhu mahupun ruang untuk data analisis lanjutan.

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LIST OF ABBREVIATIONS

AC - Alternating Current
ADC - Analog-to-Digital Converter
AIUM - American Institute of Ultrasound in Medicine
ALU - Arithmetic Logic Unit
ASM - Algorithm State Machine
ASCII - American Standard Code for Information Interchange
A/D - Analog-Digital
BNC - Bayonet Neill-Concelman
CAD - Computer Aided Design
CCCS - Current-Controlled Current Source
CFA - Current-Feedback Amplifier
CFOA - Current-Feedback Operational Amplifier
CM - Common Mode
CMT - Circuit Modeling of Transducer
CPU - Central Processing Unit
CRT - Cathode Ray Tube
CU - Control Unit
CW - Continuous Wave
DAC - Digital-to-Analog Converter
DC - Direct Current
DSP - Digital Signal Processor
DU - Datapath Unit
EEPROM - Electrically Erasable Programmable Read Only Memory
EDA - Electronic Design Automation
EMC - Electro-Magnetic Compatibility
FF - Flip-Flop

FFT	-	Fast Fourier Transform
FDA	-	Food and Drug Administration
FP	-	Fabry Perot
FPGA	-	Field-Programmable Gate Array
FSM	-	Finite State Machine
FSR	-	Full Scale Range
GPIO	-	General Purpose Input Output
GUI	-	Graphical User Interfaces
HDL	-	Hardware Description Language
HDTV	-	High Definition Television
IEC	-	International Electro-technical Commission
I/O	-	Input-Output
JTAG	-	Joint Test Action Group
KLM	-	Krimholtz-Leedom-Matthaei
LCD	-	Liquid Crystal Display
LE	-	Logic Element
LVDS	-	Low Voltage Differential Signaling
MI	-	Mechanical Index
NDT	-	Non-Destructive Testing
NEMA	-	National Electrical Manufacturers Association
NIST	-	National Institute of Standards and Technology
OSC	-	Oscillator
PC	-	Personal Computer
PCB	-	Printed Circuit Board
PIC	-	Programmable Interface Controller
PLL	-	Phase Locked Loop
PRF	-	Pulse Repetition Frequency
PSPICE	-	PC Simulation Program with Integrated Circuit Emphasis
PSU	-	Power Supply Unit
PTG	-	Programmer-to-Go
PVC	-	Polyvinyl Chloride
PVF_2	-	Polyvinylidene Fluoride

PVDF - Polyvinylidene Fluoride
PZT - Lead Zirconate Titanate
RAM - Random Access Memory
RF - Radio Frequency
RTL - Register Transfer Level
SATA - Spatial-Average Temporal-Average
SCE - Sister Chromatide Exchange
SMA - Sub-Miniature version A
SPICE - Simulation Program with Integrated Circuit Emphasis
SPTA - Spatial-Peak Temporal-Average
SPPA - Spatial-Peak Pulse-Average
S/N - Signal-to-Noise
TGC - Time-Gain Compensation
TI - Thermal Index
TTL - Transistor Transistor Logic
UART - Universal Asynchronous Receiver-Transmitter
UPM - Ultrasound Power Meter
US - Ultrasound
USB - Universal Serial Bus
VB - Visual Basic
VCVS - Voltage-Controlled Voltage Source
VHDL - Very High Speed Integrated Circuit Hardware Description Language

LIST OF SYMBOLS

A - Area

C - Capacitance

c - Wave Velocity

D - Charge Density

d - Piezoelectric Transmission Coefficient

E - Energy

F - Force

f - Frequency

G - Conductance

g - Piezoelectric Reception Coefficient

h - Piezoelectric Coefficient

I - Intensity

k - Electromechanical Coupling Coefficient

L - Inductance

l - Length

M - Sensitivity

m - Mass

P - Power

p - Pressure

Q - Quality Factor

Q_m - Piezoelectric Mechanical Coeffcient

R - Resistance

s - Elastic Compliance

T - Period

t - Thickness

U - Displacement

V - Voltage

W - Weight

X - Reactant

Y - Young Modulus

Z - Acoustic Impedance

α - Acoustic Propagation Loss Coefficient

δ - Dielectric Loss Factor

ϵ - Dielectric Constant

ε - Permittivity

λ - Wavelength

μ - Amplitude Attenuation Coefficient

ρ - Density

τ - Time Constant

ω - Angle Frequency

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CHAPTER 1

INTRODUCTION

The thesis is introduced with background, statement of problem, objectives, scope, importance of the research, and the writing structure respectively.

1.1 Background

Ultrasound machine are widely used in medical technology. For the past decade, it has been reported that there are about quarter of million diagnostic ultrasound instruments spread over the world with an estimated quarter of billion exams per year. Significant share of those are managing fetal exposures [1]. Ultrasound is managed at 1 MHz up to 10 MHz frequency for diagnostic use. While, increasing between 1.5 MHz to 3.5 MHz of frequency comes in therapeutic application with safety emission of 3 W/cm^2. Signal to noise ratio of the image are improved by increasing the ultrasound power. Absorption power in the body causes heating effect which may harmful in excess. Therefore, best sufficient overall power is desired to avoid any unintended outcomes. The ultrasound's output power produced by medical ultrasonic device represents safety boundaries [2]. In the beginning of 1960, there was proposal for measuring the physiotherapy ultrasound machines and came a specification and standard for those purposes by the International Electro-technical Commission (IEC) [3]. Accuracy power values are needed to ensure the equipment is complies with IEC standards. Medical devices are regulated under IEC61161-2 safety standard [4].

Therapeutic modality using ultrasound was starting to emerge almost five decades ago. The ability to heating a tissue up to some centimeters under the skin was demonstrated back then [5]. Frequency from 0.7 to 3.3 MHz were used in common therapy. Depending on the purpose of treatment, reversible or irreversible change is desired by therapeutic with continuous wave or tone burst exposures. For diagnostic, images with good spatial and temporal resolution are desired using sufficient amplitude of short repetition pulses to obtain acceptable signal to noise ratio. In contrast to therapeutic, diagnostic application avoids biological effects [6].

The total energy produced by ultrasound beam is expressed with power in term of watt. It has dependency upon frequency, amplitude, wave focusing, and its uniformity. The medium through which ultrasound travels, such as tissue, is also as of influential factor. The dosage can be varied by wave amplitude intensity that is different for each machine's setting [7]. That ability comes with undoubtedly requirement for ensuring the correct treatment level and site. Furthermore, the accurate methods to predict the ultrasound's dose and monitor its performance are needed. Most importantly, reliable measurement and characterization methods should be clearly defined [3]. Consequently, ultrasound power meter is a device used to measure and calibrate the output power and intensity of the ultrasound machine. The main objective of inventing power meter is related to the safety awareness. At the same time, the relationship between intensity and output power are able to be analyzed.

The difficulty to measure an output acoustic field of medical device was quoted at more than twenty years ago. This paper [8] expressed, "The measurement of the absolute output acoustic field intensity parameters of diagnostic and therapeutic medical devices has always been difficult. In order to measure effectively, precise mechanical positioning, sound field sensing, data acquisition and elaborate data analysis are required. Additionally, a sophisticated, user friendly interface is important if less experienced technical staff will be operating the instrument." Therefore, to eliminate uncertainties in converting acoustic pressure values, and to provide a direct measurement of intensity for underpinning ultrasound safety standards, an intensity measurement device is highly desired [9].

As improvements in performance of ultrasound system extended its power and reliability, it has been shown that those situation is associated with arguably safety concern. Heating due to absorption of energy is the most widely reported impact on tissue. Another phenomenon such as cavitation in the presence of gas bubbles is considered as non-thermal effect. The elevation of temperature in transducer because of dissipation of electrical energy can also warm the adjacent tissues. The increase of 1.5^{o} C within the normal human diurnal of 37^{o} C is non-hazardous. But, exposures that is rising embryonic or fetal temperature above 41^{o} C for about more than or equal to five minutes of diagnostic time are regarded as a very potential hazard [10]. One standard dictates the parameter to be displayed. Another limits the value of excess; while surface transducer's temperature is restricted in European standard [11].

On the other hand, in addition to piezoelectric ceramic material, piezoelectric polymers also have potential for ultrasonic applications [12]. They are capable of high ultrasound frequencies, broadband, and also short ring-down periods. Those characteristics give advantage so that the sensor is possibly placed close to the observed region in pulse-echo mode to produce high spatial resolution. Since the observation of piezoelectric effect in polyvinylidene fluoride (PVF_2 or PVDF), it found certain usage in actuation works. Among others are pressure transducer, ultrasonic transducer, pyroelectric transducer, and also audio transducer [13].

PVDF film is a flexible, light weight material that is available in variety of thickness and large area. Also, it works in wide frequency range between 0.001 Hz and 10 GHz. Low acoustic impedance that closely matches to the human tissue, water and other organic materials are one among advantages of PVDF. Other properties of PVDF are producing high output voltage and dielectric strength compare with other piezo materials. Further, PVDF are moist resisting and can be fabricated into unusual designs [14].

PVDF film has a natural capability to convert mechanical energy produced by ultrasonic signal into electric energy. Hence, it is useful in detecting ultrasound field for measurement purposes. To reduce the time required in analyzing result, resolution should be enhanced. Necessity also lies in computational and modeling mechanism which are can be much of contributions to evaluate the intensity of hydrophone measurements more accurately [3].

As the medical use of ultrasound has developed, so has the need to quantify acoustic field variable defining the extent of exposure [15] [16]. It was even said in [17], "The availability of a precise technique for the measurement of ultrasonic power is important in the calibration of transducers for medical use or for other measurement applications." An accurate measurement of relevant ultrasound field quantity is a prime importance to assess an exposure, increase treatment effectiveness, and improve image quality [18].

1.2 Research Motivation

Having widely been used in medical diagnostic purposes, therapy, surgery and cosmetology, ultrasound (US) methods introduced predicaments as well. In an attempt of ultrasound equipment developers to increase the intensity of ultrasound radiation on the one hand provides image visualization improvements, on the other hand can lead to undesirable consequences, resulting from thermal and mechanical action of ultrasound vibration (intense acoustic and radiation pressure, vibration acceleration, cavitation and flow effects). Hence, radiation intensity is the main characteristic of ultrasound medical equipment and requires verification to provide safety of diagnostic and treatment [19].

There are two types of biophysical effects of the ultrasound: thermal effect caused by absorption and non-thermal effect from scattering. The absorption of ultrasonic energy causes tissue heating [20]. Absorption rate is proportional to ultrasound frequency [6]. At 1 MHz and 3 MHz with both continuous and pulse mode, studies proved time and dose dependency of ultrasound; the greater the frequency, the faster the temperature increasing rate in tissue [21]. Continuous ultrasound has a greater thermal effect but either form at low intensity will produce non-thermal effects [7]. The change direction of ultrasound energy resulting in scattering phenomena which gives the non-thermal effects [20].

Increases in transmitted ultrasound power improve the signal to noise ratio of the image and the biomedical use. However, for ultrasound absorption in the body causes heating which may be harmful in excess, high frequency ultrasound can be dangerous to the human soft tissues. Therefore, it is important to keep the overall power to a minimum sufficient to produce the needed therapeutic function. Literature has shown some evidences that intense ultrasound radiation may damage bone as well as delay healing process [6].

As an example, study in 2004 concluded that temperature increases in human intramuscular by pulsed ultrasound have equivalent impact with continuous ultrasound at half of intensity. That situation occur given the frequency and exposure time are similar. Ter Haar [6] proposed the theoretical method applied to the variables in the spatial-average temporal-average (SATA) intensity formula. Pulsed ultrasound of 3 MHz, 50% duty cycle at minimum value of 0.5 W/cm^2 might impose temperature increase of 3^o C. Theoretically, such amount of temperature could accelerate the blood flow which is risking to be detrimental during the acute stage of healing. Based on the study in [22], clinicians should cautiously consider the SATA level when selecting pulsed ultrasound parameters.

Another distinctive impact of temperature increase is an acceleration of biochemical reaction in which at 45° C denaturation of enzymes may occur. For instance, aberrations in human lymphocyte chromosomes caused by commercial ultrasound fetal pulse detector was reported in '70s. In the end of that decade, human lymphocyte sister chromatide exchange (SCE) frequency as an indication of chromosome damage was increasing and suggested pertinent to exposure from diagnostic ultrasound system. Accurate and precise procedure to measure the output of ultrasound equipment was still lack. Consequently, that equipment was not characterized to be used in identifying the exposure level on human [23]. Ramirez et al. [24] reported cell destruction with the use of pulse 1 MHz ultrasound under water at SATA intensity of 0.08 W/cm^2 which is cited in [25]. Fahnestock et al. [26] reported cell lysis caused by exposure on neuroblastoma cell lines with continuous 1 MHz at spatial peak dose of 1 W/cm^2.

In adjacent case, for a given amount of energy, hyperthermia and cavitation could be occured. These distinctive physical effects depend on the received acoustic intensity. Long period exposure with low intensity (in treatment of benign prostatic hypertrophy) may induce hyperthermia, while brief touch but high peak intensity (as is during extracorporeal lithostripsy case) goes to cavitation [27].

Thermal effects of diagnostic ultrasound on the embryo / fetus have also been a topic of strong interest. This consideration probably has resulted in better and more versatile ultrasound systems. Apparently negligible damage can be done to microvasculature by ultrasound at the lung surface at the highest outputs [28], as can extremely focal vascular leakage from bubble oscillations in high-amplitude ultrasound fields [29]. The only known location of a potentially substantial effect is in the kidney, where the high blood pressure gradients can cause enough haemorrhage for loss of the nephron [30].

Both diagnostic and therapeutic ultrasound energy can be described in terms of acoustic pressure and also intensity. Calculation can be based on either maximum pressure in field or averaged pressure in certain area. The former is often called spatial peak and the latter is spatial average intensity. In addition to averaged pulse mode, it should be considered whether the averaging is applied on active (on) or including inactive (off) time. According to those circumstances, the pulse average and the temporal average become their label respectively [6].

Several intensity units are defined: I_{SPTA} (spatial-peak temporal-average intensity), I_{SATA} (spatial-average temporal-average intensity) and I_{SPPA} (spatial-peak pulse-average intensity). The I_{SATA} can be used as a good forecaster for heating effect. For cavitation effect, peak negative pressure is the main parameter of such condition [6].

The IEC standard for physiological equipment gives two kinds of restriction: temperature and intensity. Temperature limit is 41° C when ultrasound probe is operated in water with initial temperature of 25° C. The effective intensity of 3 W/cm^2 should not be overcome. Extending that intensity could increase the temperature to some level which damage tissue at the surface of bone. The protection of those exposed ultrasound arises as responsibility of both manufacturer and operator. The manufacturer should offer appropriate equipment design and the operator should offer appropriate use. For that purpose, IEC standards have been made to ensure the used acoustic quantity has been appropriately measured. IEC 61102 along with IEC 61220 deal with frequency range of 0.5-15 MHz for measurement of acoustic beams using hydrophones in water. Therefore, manufacturer must meet the top limits on derated spatial-peak temporal-average intensity I_{SPTA}, attenuated spatial-peak pulse-average intensity I_{SPPA}, mechanical index (MI) and thermal index (TI) [31]. A test was conducted in 2003 by Daniel and Rupert [32] found 44% of 45 ultrasound units at chiropractic clinics failed either calibration or electrical safety inspection. Tests were performed with a new Bio-Tek Instruments Model UW-4 wattmeter employing de-ionised, distilled, and de-gassed water. Regulations established by the Food and Drug Administration (FDA) [33] states that “the error in the indication of the temporal-average ultrasonic power shall not exceed 20% for all emissions.” Power setting of 5 W is common therapeutic dosage. However, actual power output from 1.72 W up to 7.1 W are concluded to 5 W by the failed devices. What worse was number of those devices were one-third of units tested. Thirty seven percents failed because of high output and another sixty three percents because of low output. Besides, at lowest power setting, five units gave no power at all.

The need for regular calibrations of ultrasound equipment is of multi-importants. The patient may be receiving no therapy effect when the actual output is less than the indicator. On the other side, damage would occur because of thermal effects when output is higher than indicated [32]. Another research described in [34] tested 85 therapy machines with 81% had output error by more than 20%, and 69% gave more than 30% error. Among them, newly devices under 5 years old gave 86% error exceed 20%. The calibration standard for power output is considered by the FDA code of federal regulation title 21, part 1050.10 which says that temporal-average ultrasonic power shall not exceed ± 20% for all emissions greater than 10% of the maximum value [33].

1.3 Problem Statement

Recent years of widespread availability of equipment still be acquainted with poor calibration status of physiotherapy tools. Thus, it is beneficial to propose a simple and inexpensive technique that can be applicable both at manufacturer and user side [3]. Furthermore, the ultrasound therapy machine used in the hospital may be grossly inaccurate. There are available products which are able to measure the machine's output parameters accurately to ensure the correct operation and safe uses of ultrasound for specified applications. Monitoring of output power levels also provides a means of monitoring the performance of the equipment. The products are the ultrasound power meter. Yet, those products are mainly depend on radiation force balance which introduces complexity in wave calculation and approximation. Another kind of power meter employed great acoustic impedance and power-loss ceramic sensor. Moreover, ceramic sensor does not closely match with low-impedance human tissue. There are many devices in local south-east Asia with untested safety because of the ultrasound power meter is expensive and manufactured overseas.

In complement, most of ultrasound transducers are made of high power piezo-ceramic e.g. lead zirconate titanate 4 (PZT-4) [6]. Meanwhile, studies on characterization of PVDF are being conducted for various fields of applications. However, there is no specific characterization on ultrasound power meter application. Equivalent circuit and power equation cannot be modeled and derived. Therefore, it is important to describe an ultrasound system's simulation for power measurement.

To sum up, there are several problems to solve in the current ultrasound power measurement methods and products:

1. Limited only for high power and therapeutic purpose or low power diagnostic, but not both.

2. Only show accumulated result power.
3. No possibility for further analysis using software.
4. Not enhanced in real-time process

Overall, the most distinctive problem is lack of quickly applicable measurement methods that also cost-effective at the point of treatment. Commercially available radiation force with better than ±10% uncertainty of power level tends to be expensive and needs expertise to set and operate. Those characteristics render them inappropriate for end user. Therefore, there is a necessity for novel type of measurement device which is compact and simple in construction, low-cost, easy and quick use, but still provide a good output of ultrasonic quantity [35] [36].

Field-Programmable Gate Array (FPGA) technology promises to design and prototyping the system quickly and cost-effectively. Since this work looks forward to produce marketable device, the low non-recurring engineering and debugging cost of FPGA are found to be very attractive. It consequently has shorter time-to-market. Furthermore, device manufacturers can expect to supply updates to the product as FPGA has the ability to be reprogrammed in the field of operation. This is very beneficial in measurement system which needs frequent calibration and even to keep on track with standardization especially regarding ultrasound exposimetry.

However, FPGA alone cannot acquire raw data so that external circuitry should be responsible for signal acquisition. The front-end of system, which is the sensor, need to be constructed in such manner so that the ultrasound signal could be captured with acceptable signal-to-noise ratio. It has been occurring as design challenge since the very beginning employment of actuation concept. Between them, interfacing of analog and digital domain should also be considered. It might be common in digital system to work with megahertz range. On the contrary, analog high frequency design introduces much more restrictions, constrains, and trade-offs. Moreover, the bottleneck is being tightened when it comes to layouting in printed circuit board with discrete components.

This thesis is trying to overcome the preceding issues. The work will be exposed in each chapter with bottom-up point of view.

1.4 Objective of the Research

Pulled from subsections before, there are various procedures to determine the ultrasonic output power underwater. They are the radiation force balance technique [37], the use of piezoelectric hydrophones [38], acousto-optic [39], thermo-acoustic [40], calorimetry [41] and ultrasonic power through electro-acoustic efficiency of transducers [42].

As will be explained in the next chapter (Chapter 2), radiation balance method introduces calculation and calibration complexity while calorimetric come with inaccurate result comparing to the standard. On the other hand, application of piezoelectric sensor in hydrophone-based power measurement requires advancement on processing device and technique. Therefore, objectives of the research are:

1. To design a receiver circuit and mechanical casing for PVDF sensor.
2. To develop an algorithm for ultrasound power conversion.
3. To design the architecture of ultrasound power measurement system and prototype on an FPGA platform.

1.5 Scope of the Research

This project will develop a measurement system for novel low cost ultrasound power meter. This includes investigation of optimized signal processing hardware for ultrasound power meter and development of signal acquisition hardware to capture signal from PVDF sensor, and result display panel. The algorithm to convert ultrasound signal output to be intensity will be explored and implemented in FPGA using Verilog HDL (Hardware Description Language).

This research output is a FPGA prototype of Ultrasound Power Meter (UPM). The device contains sensors, analog circuit, digital circuit, personal computer (PC), and embedded system implementation. It is prepared to measure 1 mW/cm^2 – 10 W/cm^2 power range with 0.05 mW/cm^2 of minimum resolution while working frequency is 0.5 MHz up to 10 MHz. Two PVDF sensors plus one temperature sensor would be used. Ultrasound machine's probe which is covered to be tested is 2.5 cm in radius non-focused. Contact-mode measurement would use gel as medium; while water would be tanked in immerse-mode.

Moreover, for monitoring purpose, each medical device has to display data that is user-friendly. To fulfill that need, the Graphical User Interfaces (GUI) shall also be developed onside hardware instrument. With further help from software application, there are possibilities to do various analysis. The integrity will make the system has a wide range of acceptance for practical implementation. An overall top system architecture diagram is shown in Fig. 1.1.

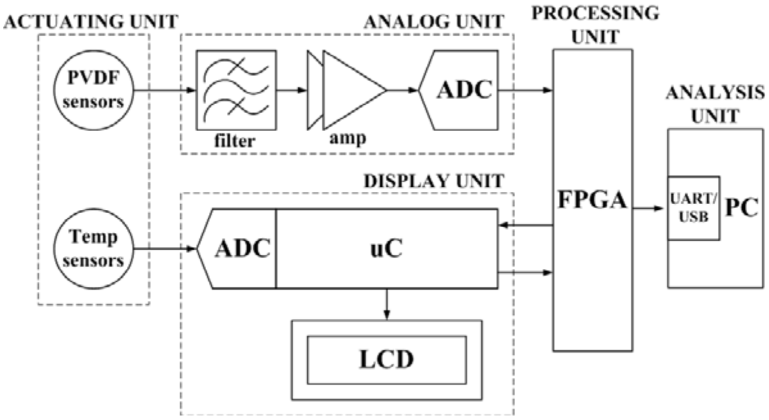

Figure 1.1: Top System Architecture Diagram

Quartus II 9sp2 Web Edition and ModelSim PE Student Edition 10.1b would be used to design the digital system as well as its performance evaluation. Those softwares are used to verify whether the algorithm is correct and proper to download the design into FPGA (Cyclone II starter development board). The software for PIC (PIC18F452) would be built by PICC compiler using C language and the downloader would be PICKit2. Computational software such as MATLAB (from MathWorks) will be employed in characterization and modeling of sensor's data. To build the GUI, Microsoft Visual Studio will be used. Analog and mixed-signal simulation will be done with SPICE family version 9.2 and SIMetrix Intro 6.10. For physical circuit layout design, EAGLE Layout Editor 5.11.0 is going to be employed.

1.6 Importance of the Research

The impact of new technologies on medical care and its costs is enormous. Concerning costs provides a powerful incentive to look for new types of instrumentation which may either be less expensive than present techniques, or allow a breakthrough in accuracy, sensitivity or convenience.

The expected findings of the study are:

1. New sensor design for ultrasound power measurement using PVDF.
2. New algorithm to convert ultrasound sensor output signal to intensity.
3. New-improved ultrasound power measurement system.

This system would enable further data analysis, lessen the cost of ultrasound power meter device, and improve its performance. Moreover, it shall increase the safety of measurement using ultrasound machine for diagnostic and therapeutic purposes.

1.7 Thesis Organization

This thesis is organized as follows,

Chapter 1 Introduction - Background, motivation, problem statement, objective, scope, and importance of the research.

Chapter 2 Reviews of Literatures and Related Works - This chapter will describe a review about ultrasound power measurement. Several literatures, works, patents, and theories are explained.

Chapter 3 Research Methodology - The work flows and the method which is used to complete the work will be discussed in detail in this chapter.

Chapter 4 System Design and Algorithm - In this section, every part of design will be discovered in detail. It explains system description, algorithm, and software consideration.

Chapter 5 Characterization and Simulation - Elucidates simulation of system that is useful to verify the preliminary design also forecast system specification and hardware requirements

Chapter 6 System Verification and Result Analysis - This chapter shows implementation of sensor with analog signal conditioner, digital processing circuit, and microcontroller module building the system and measurement analysis.

Chapter 7 Conclusions - Summarizes the thesis, re-stating the contributions, and suggests directions for future research.

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