The Implementation of Cost-Effective Data Acquisition System for Acoustic Emission Sensor using Variable Gain Preamplifier and STM32F4 Microcontroller Interface

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***Abstract*— this paper presents the Data Acquisition (DAQ) system that particularly collects Acoustic Emission (AE) signals in the range of 1 kHz to 500 kHz from the sensor, and transmits to a personal computer for further signal analyses. The proposed system comprises two major components, i.e. a variable gain preamplifier and a STM32F4 microcontroller. The variable gain preamplifier is implemented using BiMOS operational amplifier model CA3140 which provides relatively high input impedance and high-speed performance. The signal is subsequently digitized by STM32F4 Microcontroller and transmits to data analysis software via serial communication (RS232). Simulations are performed through Orcad PSpice and a MATLAB Simulink. Signal quality analysis involves frequency response, Total Harmonic Distortion (THD), and Power Spectral Density (PSD). Experiments show that the proposed system offers a potential alternative to commercially available data acquisition systems.**

Keywords*— *Data Acquisition System, Acoustic Emission Sensor, Variable Gain Preamplifier, STM32F4 Microcontroller.

I. Introduction

Machine condition monitoring and fault diagnosis system are necessary tools for the condition base maintenance. The input signals for these systems are generated by various kinds of sensors and transducers such as temperature, pressure, flow, vibration, and especially Acoustic Emission (AE) signal [1]. Acoustic emission is a sound wave, which is generated when a material undergoes stress due to an external force. The AE signal is a phenomenon occurring in, for example, mechanical loading generating sources of elastic waves. Such occurrence is the result of a slight surface displacement of materials produced from stress waves, which is generated when the energy in materials or on its surface is released rapidly [2].

In order to obtain AE signal for purpose of monitoring, the Data Acquisition (DAQ), this is a process of measuring an electrical or physical phenomenon such as voltage or current. Fig.1 illustrates the typical acoustic emission sensor detection system where AE transducer provides AE signals to the preamplifier, filter, amplifier, signal conditioning and event detector [3,4]. Such a typical system is relatively complicated as numerous devices are required. Typically, the DAQ system consists of sensor input, measurement hardware, and a computer with programmable software. Despite the fact that commercially available DAQ system exploits the processing power, productivity, display, and connectivity capabilities of industry-standard computers with high effectiveness, the price is relatively costly and may not be suitable for some applications especially Small and Medium Enterprises (SME). Considerations on the typical acoustic emission sensor detection system shown Fig.1 and general requirements for DAQ system used in AE sensing system lead to the possibility to simplify the system using simple, but robust devices.

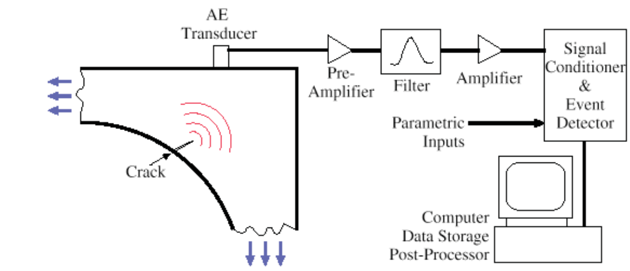


Fig. 1. Typical acoustic emission sensor detetcion system.

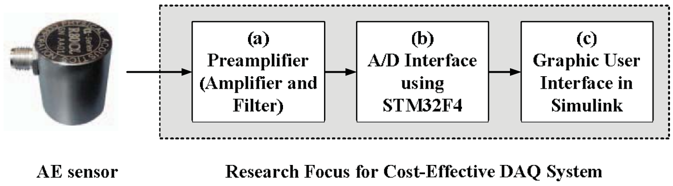
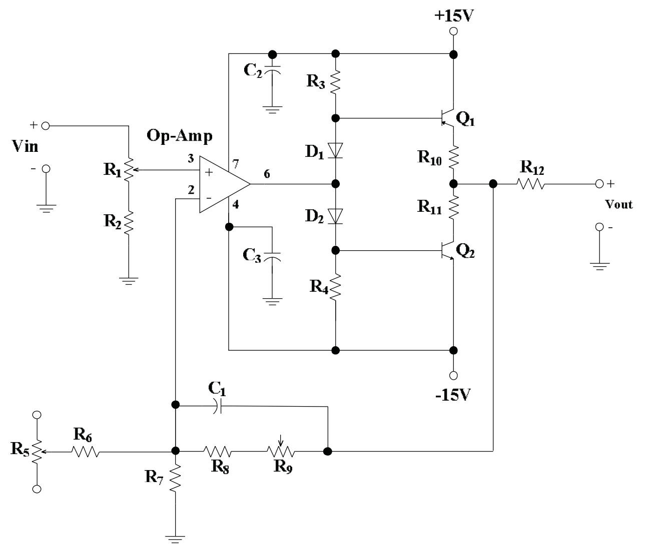
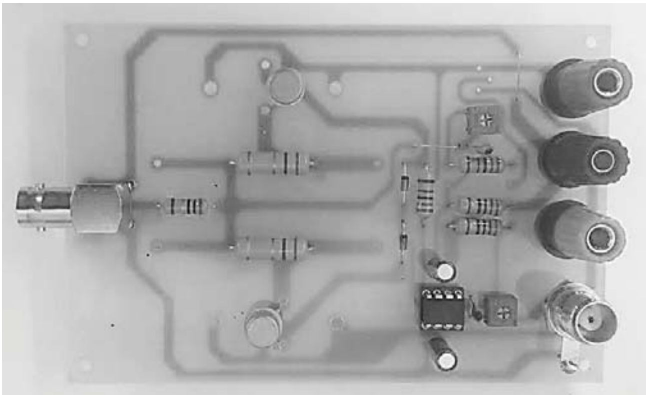


Fig. 2. Overall System Designs with research focus on cost-effective DAQ Board



(a)



(b)

Fig. 3. The preamplfier circuit designs; (a) circuit diagram, (b) circuit implemenation on board.

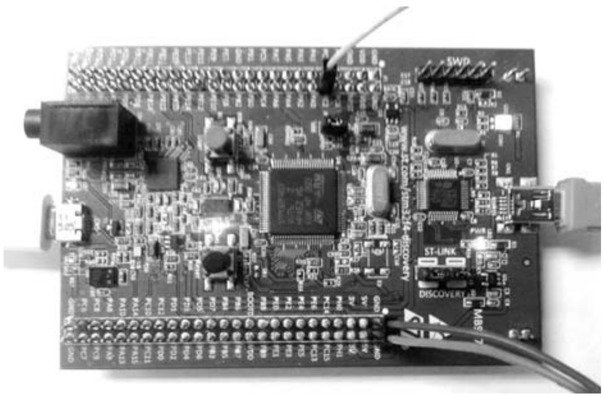


Fig. 4. The photograph of the utilised STM32F4 microcontroller as an interface device for A/D converter.

Although there has been numerous research reports for AE signal feature characterizations that include commercially available DAQ system [5-10], no particular research focuses has been investigated on a simple-but-robust DAQ system. This paper therefore proposes a new cost-effective DAQ system in which a preamplifier and a filter is implemented through BiMOS operational amplifier model CA3140 providing relatively high input impedance and high-speed performance. Analog-to-Digital (A/D) converter is implemented by Real-time Operating System (ROS) hardware. Signal quality analysis will include time-domain analysis, frequency response, Total Harmonic Distortion (THD), and Power Spectral Density (PSD). Simulations will be performed using Orcad PSpice and a MATLAB Simulink. Experiments will achieved by an integrated circuit on a prototype board and STM32F4 microcontroller

TABLE I.
SUMMARY OF PREAMPLIFIER CIRCUIT PARAMETERS AND PART NUMBERS

Preamplifier Circuit Parameters					
Resistors		Capacitors		Integrated Circuits	
Parts	Values	Parts	Values	Parts	Numbers
R_1	2kΩ	C_1	2pF	Op-Amp	CA3140
R_2	200Ω	C_2	50µF	Diode D_1	1N914
R_3	2.2kΩ	C_3	50µF	Diode D_2	1N914
R_4	2.2kΩ	-	-	Transistor Q_1	2N3053
R_5	10kΩ	-	-	Transistor Q_2	2N4037
R_6	3kΩ	-	-	-	-
R_7	200Ω	-	-	-	-
R_8	2.2kΩ	-	-	-	-
R_9	50kΩ	-	-	-	-
R_{10}	2.7Ω	-	-	-	-
R_{11}	2.7Ω	-	-	-	-
R_{12}	51Ω	-	-	-	-

II. PROPOSED COST-EFFECTIVE DATA ACQUISITION SYSTEM FOR AE SIGNAL DETETCION

A. *Overall System Designs*

Fig. 2 summarizes overall System Designs with research focus on cost-effective DAQ Board. The proposed system consists of three major blocks. First, an integrated amplifier and filter, which is so called preamplifier, that is used to amplify the input signal with variable gain and filter noises in environment. Second, the A/D converter interface using STM32F4 controller which operates realtime and has an ability to connect to computer through MATLAB program. Last, the graphic user interface system exploits MATLAB display capability to show the realtime-signal and various signal characteristics analysis. In this paper, the AE signal is considered to be a sinusoidal signal, which represents the AE signal acoustic at a single harmonic signal, for analysing the DAQ characteristics.

B. *Pre-Amplifier Circuit Descriptions*

Figs.3 (a) and (b) show the preamplifier circuit designs. The variable gain preamplifier is implemented using BiMOS operational amplifier model CA3140 as a high slew rate, wideband amplifier. The amplifier circuit is designed base on a non-inverting amplifier which analog input signal is connected at the input terminal which signal level can be adjusted by R_1 before input of CA3140. Gain of preamplifier can be adjusted via R_9 and output DC level can also be adjusted by R_5 to keep output signal at the output terminal in

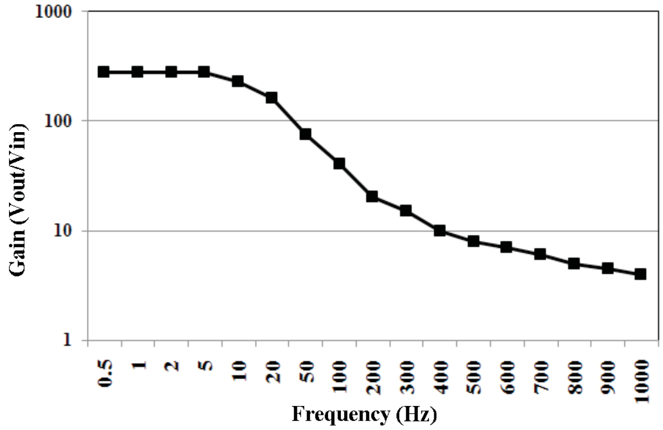


Fig. 5. Frequency characteristics of the proposed preamplifier

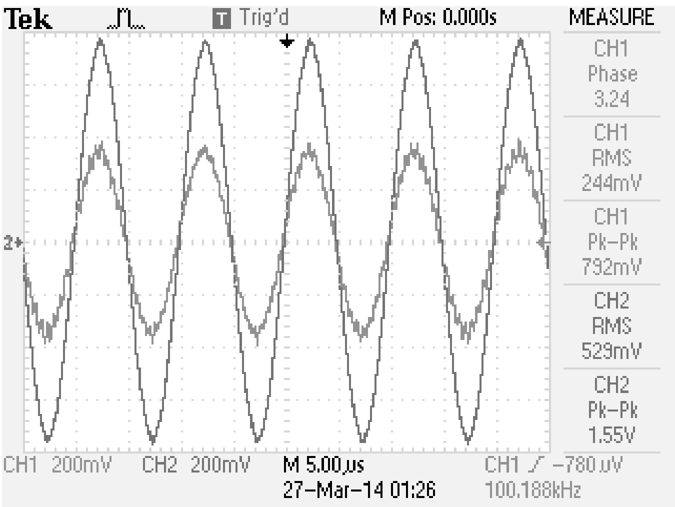


Fig. 6. Illustration of sinusoidal singnal in time domain.

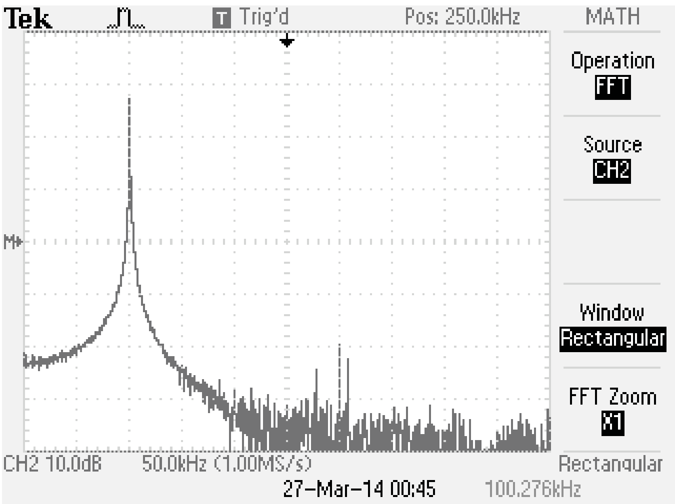


Fig. 7. Illustration of the Fast Fourier Transform for THD calculations.

the range of 0-5 V that compatible with STM32F4 Controller. The push-pull class AB output circuit using transistors Q_1 and Q_2 are exploited in order to adjust full peak-to-peak swing.

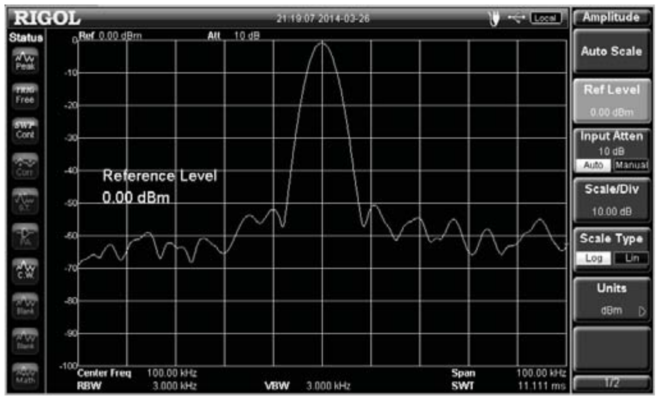


Fig. 8. Illustrations of the power spectral density showing the bandwith of the signal at 0dBm level.

C. STM32F4 Microcontroller Interface Operations

As mentioned earlier, this paper utilizes the STM32F4 controller, which is based on the high-performance ARM®Cortex™-M4 32-bit RISC core operating at a frequency of up to 168 MHz, for analog-to-digital conversion. This device offers three 12-bit ADCs, two DACs, a low-power RTC, twelve general-purpose 16-bit timers including two PWM timers for motor control, two general-purpose 32-bit timers. Therefore, the input analog signal is digitized with the performance of 3×12-BIT AMD 2.4 MSPS.

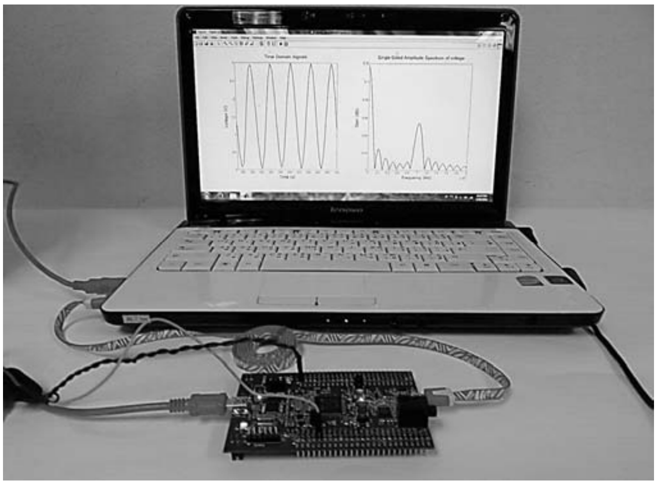
III. Experimental Results

The experimental results have been performed through the protoboard corresponding to the block diagram in Fig. 2. The demonstration condition is a sinusoidal signal input of 20mV at 100 kHz, corresponding to the low-frequency signals. Fig. 5 shows frequency characteristics of the proposed preamplifier. It can be seen from the graph that the preamplifier establish the low pass filter characteristic where the low frequency has a very high gain of above 100 but at the high frequency, for example 1 MHz, the gain is still greater than 0. For the frequency of interest at 100 kHz the gain is approximately at 20dB. Fig. 6 illustrates the sinusoidal signal in time domain. It can be seen that the non-inverting amplifier can amplify the input signal to the larger signal without phase shift.

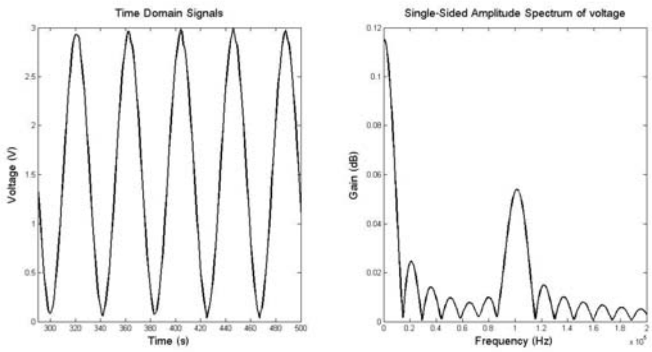
Fig. 7 illustrates of the Fast Fourier Transform for THD calculations. Using the rectangular window transformation, the peak signal at 100 kHz has the highest peak where the noise floor is about 200 kHz far from the center frequency. Since FFT transformation was used for the THD calculation, Table 2 summarized the THD in percentage at difference value of particular gain under region of interest between 5-20. It is seen that the THD is in the range of 3-5%. This is acceptable for the preamplifier that amplifies the AE signal in real application. Fig. 8 illustrates the power spectral density showing the bandwidth of the signal at 0dBm level. It is seen that the noise floor is approximately -60dB and the bandwidth is about 4 kHz. Fig. 9 demonstrates the STM32F4 and the graphic user interface; (a) Experimental setup, (b) the display of signal in time and frequency domains.

TABLE II.
SUMMARY OF PARTICULAR GAINS (V_{OUT}/V_{IN}) AND SHOWING THE CORRESPONDING THD IN PERCENTAGES

Particular Gains	THD (%)
5	3.2362
10	3.7334
15	5.4146
20	5.6488



(a)



(b)

Fig. 9. Demonstration of STM32F4 and the graphic user interface; (a) Experiemntal setup, (b) the display of signal in time and frequency domains.

IV. CONCLUSIONS

This paper has presented the data acquisition system that particularly collects AE signals in the range of 1 kHz to 500 kHz from the sensor, and transmits to a personal computer for further signal analyses. The proposed system comprises two major components, i.e. a variable gain preamplifier and a STM32F4 Microcontroller. The variable gain preamplifier is implemented using BiMOS operational amplifier model CA3140 which provides relatively high input impedance and high-speed performance. It is obviously seen through the results that the quality signal analysis were strongly satisfy including high frequency response at high voltage gain, obtain the peak of signal at 100 kHz. The generated signal was successfully digitized by STM32F4 Microcontroller and transmits to a MATLAB Simulink via serial communication (RS232). In addition, the proposed system offers a potential alternative cost-effective data acquisition to commercially available data acquisition systems in the same range of frequency response such as National Instrument (NI), Physical Acoustics Corporation (PAC) etc. in which the cost could be reduced to approximately 80% comparing to the specified DAQs.

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IV. Conclusions

In this experiment the 2-(Diethylamino)ethanol (DEAE) is chosen to be a CO_2 absorbent and the solubility of carbon dioxide in aqueous 5M DEAE solution is measured at 313.15, 333.15 and 353.15 K and the partial pressure of carbon dioxide in range from 5-100 kPa. The solubility data in aqueous 5M DEAE solution is compared with aqueous 5M MEA solution. The result is shown that aqueous 5M DEAE solution is the better CO_2 absorbent than aqueous 5M MEA solution because it provides higher cyclic capacity up to 861%.

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