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RESEARCH ARTICLE

Wireless Acoustic Signal Monitoring Using MEMS sensor and ATmega on LabVIEW Platform

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Abstract— Acoustics and vibrations caused on machine structures can result in faulty or collapse of the whole mechanical system. These acoustics produced by machinery are vital indicators of machine health. Acoustic signals analysis can be used as a tool for locating the problem and thus taking necessary actions. MEMS sensors provide high accurate low size and low cost microphones which can be even used in low cost space applications such as sounding rockets, nano-satellites etc. This paper explains the algorithm to extract acoustic signals from ADMP401, which is a high quality, high performance, low power, analog output, bottom-ported omnidirectional MEMS microphone. The sensor output will give the error free data even in noisy conditions. ATmega microcontroller is used to read the data from the sensor and send to LabVIEW software running on the computer which will extract and display the data from the serial port in real time. As rotating structures are those machine parts which may experience high vibration and acoustic noises, the same is implemented in wireless also which helps in extracting acoustic signals from rotating as well as inaccessible parts of the machinery.

Keywords— Acoustics, MEMS, ATmega, LabVIEW, ZigBee

I. INTRODUCTION

Defects on rotating machine produce a broad sound spectrum and they are usually monitored by vibration in low frequency. However some specifics defects produce acoustic waves with a rich content in high frequencies: impacting for bearings and gearboxes, friction or rubbing for lubrication and cavitation for pumps. Acoustic emission (AE) is defined as the elastic wave generated by the released strain energy within the materials under a certain load. The main source of acoustic emission is the interaction of each machine structure over the other. The characteristics of the wave change with any variation of process parameters during the actual machine process. AE signal is used to control of thermal damage, gap detection, wheel wear, dressing strategies etc. in a grinding machine.

Micro Electro Mechanical Systems (MEMS) fabrication techniques can be useful situations of very low size for their ability to build very small sensors with precise geometries. Microphones and other low-level differential pressure transducers are often used in aero acoustic measurements for noise characterization, flow thermal mapping via acoustic pyrometry as well as airplane flight tests [1,2,3]. Some of the more developed MEMS areas for space are summarized in references [4] and [5] and references there in, and can be grouped into the following classes: Inertial Navigation, RF Switches and Variable Capacitors, Atomic Force Microscope, Bio and Microfluidics, Bolometers, Optical instrumentation, Optical Switching and Communication, Thermal control, and Micro propulsion .The degree of maturity of components for use in space is generally described by their Technological Readiness Level (TRL), a scale ranging from 1 (basic principles observed and reported) to 9 (flight proven). MEMS devices for space are mostly approximately between TRL 2 and TRL 5, with only the few devices that have flown being at TRL 9. Reliability is a key concern for space hardware, in view of the near impossibility of carrying out repairs, and the long expected lifetime (15 years for a typical telecom satellite). The main space-specific reliability concerns are radiation, thermal cycling and thermal shocks, vibration and mechanical shock, and operation in very high vacuum. Ionizing radiation affects MEMS devices primarily by charging dielectrics, leading to performance changes or failures for electrostatically operated devices, as reviewed in [4]. MEMS reliability for space is reviewed in [6]

Overstraining material results in localised zones of cracking. Thereby elastic energy is set free, which propagates through the structure in the form of elastic waves that can be recorded as transient acoustic emission (AE) signals. By investigating their origin and characteristics, AE techniques provide an insight into deterioration processes of a tested object. AE is the class of phenomena whereby transient elastic waves are generated by the rapid release of energy from a localized source or sources within a material, or the transient elastic wave(s) so generated. Thus, an acoustic monitoring system essentially requires two integral components: a material deformation that becomes the source, and transducers that receive the stress waves that are generated from the source. Typically, the signals collected can be represented by characteristic parameters such as amplitude, duration, etc., as shown in Figure 1.

The ADMP401 is a high quality, high performance, low power, analog output, bottom-ported omnidirectional MEMS microphone. The ADMP401 consists of a MEMS microphone element, an impedance converter, and an output amplifier. The ADMP401 sensitivity specification makes it an excellent choice for both near field and far field applications. The ADMP401 has a high SNR and flat wideband frequency response, resulting in natural sound with high intelligibility. Low current consumption enables long battery life for portable applications. The ADMP401 is available in a thin, 4.72 mm × 3.76 mm × 1.0 mm surface-mount package. It is reflow solder compatible with no sensitivity degradation[7].

Microchip ATmega16 [8] is used to read the analog data from the sensor, which is then sent to the serial port of a computer wirelessly through ZigBee communication. IAR Embedded workbench for AVR is used to compile and AVR Dude GUI is use to burn the hex code to ATmega controller. National Instruments graphical programming tool LabVIEW is used to read the response from the ATmega through ZigBee transmission of data. The algorithm developed will extract and convert the acoustic data to digital format. LabVIEW is also used as graphical user interface to display and plot the real time acoustic output.

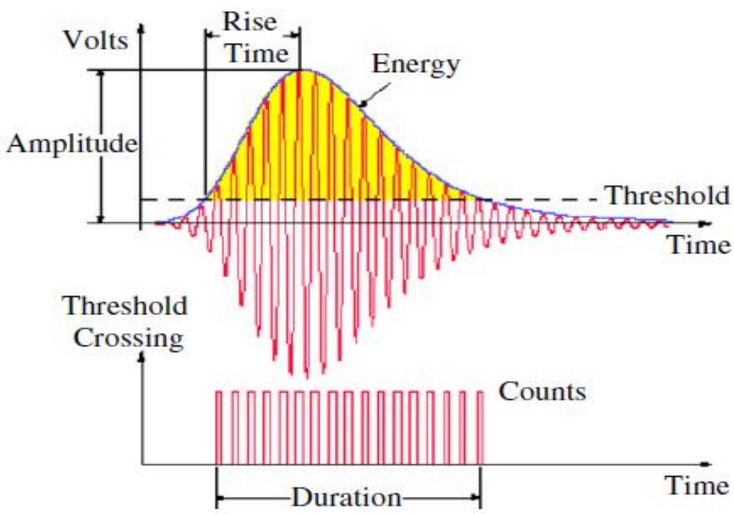


Figure.1. A typical AE signal

II. SYSTEM DESCRIPTION

A. *MEMS Acoustic Sensor*

The ADMP401 is an analog MEMS microphone whose output can be connected to a dedicated codec microphone input or to a high input impedance gain stage. A 0.1 µF ceramic capacitor placed close to the ADMP401 supply pin is used for testing and is recommended to adequately decouple the microphone from noise on the power supply. A dc-blocking capacitor is required at the output of the microphone. This capacitor creates a high-pass filter with a corner frequency at

$$fc = \frac{1}{2\pi RC} \tag{1}$$

where *R* is the input impedance of next stage.

ADMP401 output can be affected by noise as its in analog domain and using microcontroller these signals can be digitized. ADMP401 output is of low noise and so it is followed by a high pass filter and a op-amp gain stage of ADA4897.

B. *ATmega Controller and ZigBee module*

Interfacing of ADMP401 is done using ATmega16. ATmega16 Port A which is the Analog to Digital converting channels continuously monitor the acoustic data output and is converted to digital format of 10 bits resolution power. These digitized values are send to Zigbee serial data receive pin and is transmitted through ZigBee transceiver. These data can be continuously send to computer and is accessed to the LabVIEW code.

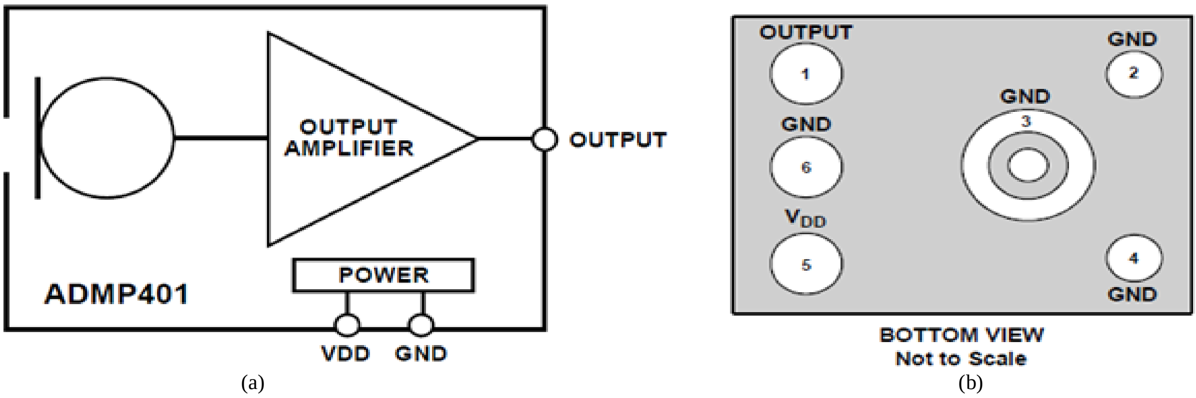


Figure.2.ADMP401(a) Functional (b)Pin Configuration

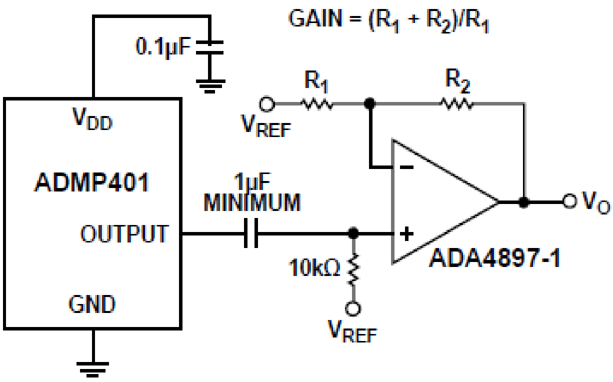


Figure.3. Connecting ADMP401 to an op-am gain stage

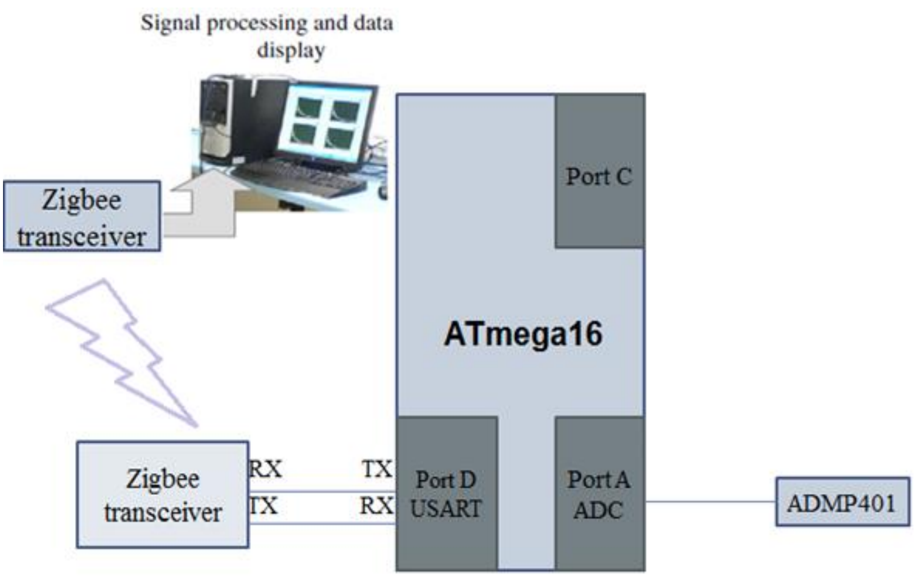


Figure.4. Hardware interconnection of overall system for wireless implementation

C. *LabVIEW*

LabVIEW (Laboratory Virtual Instrument Engineering Workbench) is a graphical programming language that uses icons instead of lines of text to create applications. ADMP401 bit streams through ZigBee receiver is continuously accessed to LabVIEW code which extracts the data into time domain signals and necessary signal processing steps has been done.

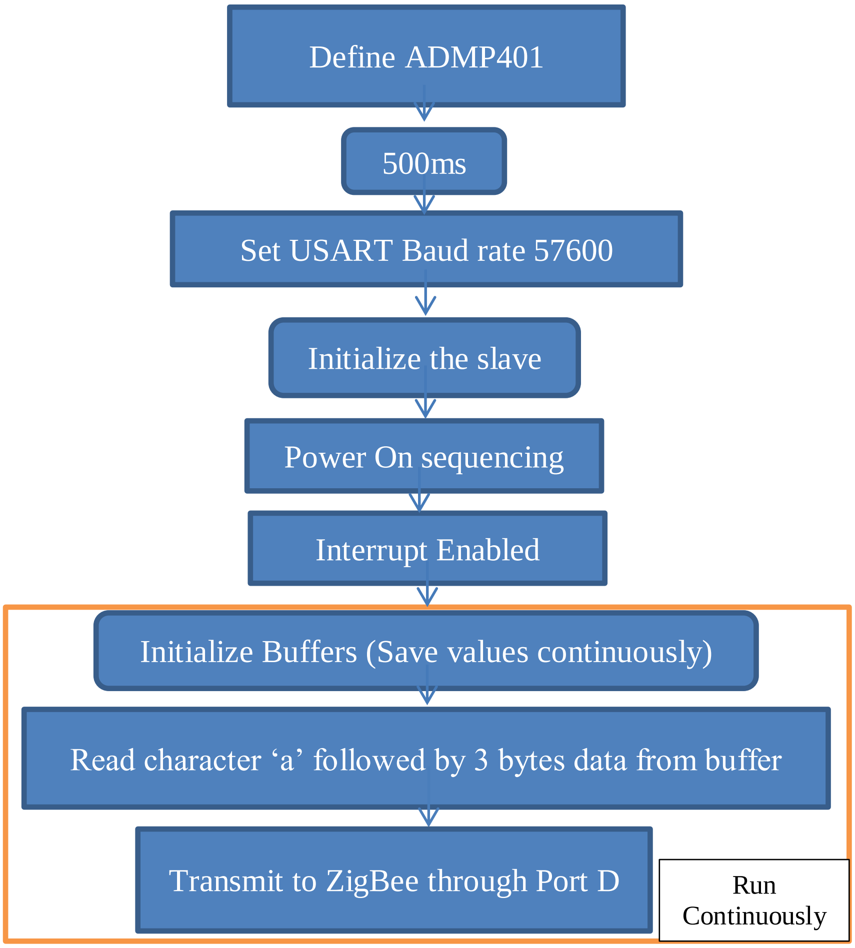


Figure.5. Flow chart of ATmega coding

III. SOFTWARE DESCRIPTION

Program for ATmega16 was written in IAR Embedded workbench for AVR. The hex code is burned to ATmega using AVR Dude GUI burner. The baud rate for communication is set as 57600. A character 'a' is purposefully introduced before each 3 byte data value. The LabVIEW code is written in such a format that once the character is received the code will start converting received binary values to decimal. This received signal is converted to its time domain and power spectrum is calculated. The flow chart of ATmega code and LabVIEW code is explained in Figure 5 and 4.

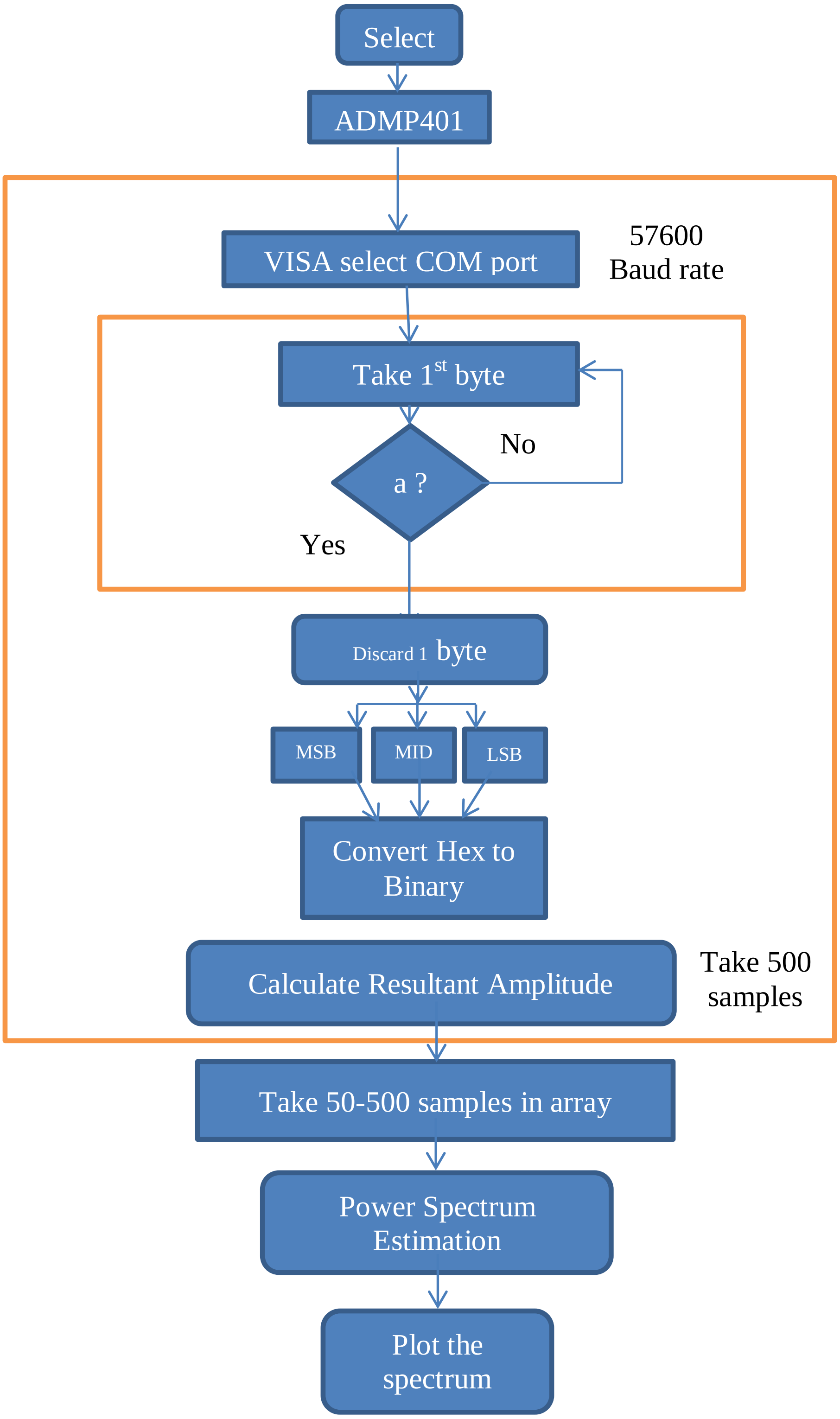


Figure.6. Flow chart of LabVIEW code

IV. RESULTS AND DISCUSSIONS

The output from ADMP401 was initially interfaced to LABView using National Instruments cDAQ-917 data acquisition module. The sampling criterion for the data acquisition module was not matching with the minimum frequency in which the acoustic has to be sampled. And so the output seen on LABView was highly distorted as the sensor output was square waves unlike sine. The output was seen on DSO for different frequency acoustic signal inputs and saved in .csv format. Different frequency sound signals as input signal was generated using LABView itself. These output datas are used to plot the input-output linearity curve and frequency spectrum of ADMP401(Figure 8 and Figure 9).

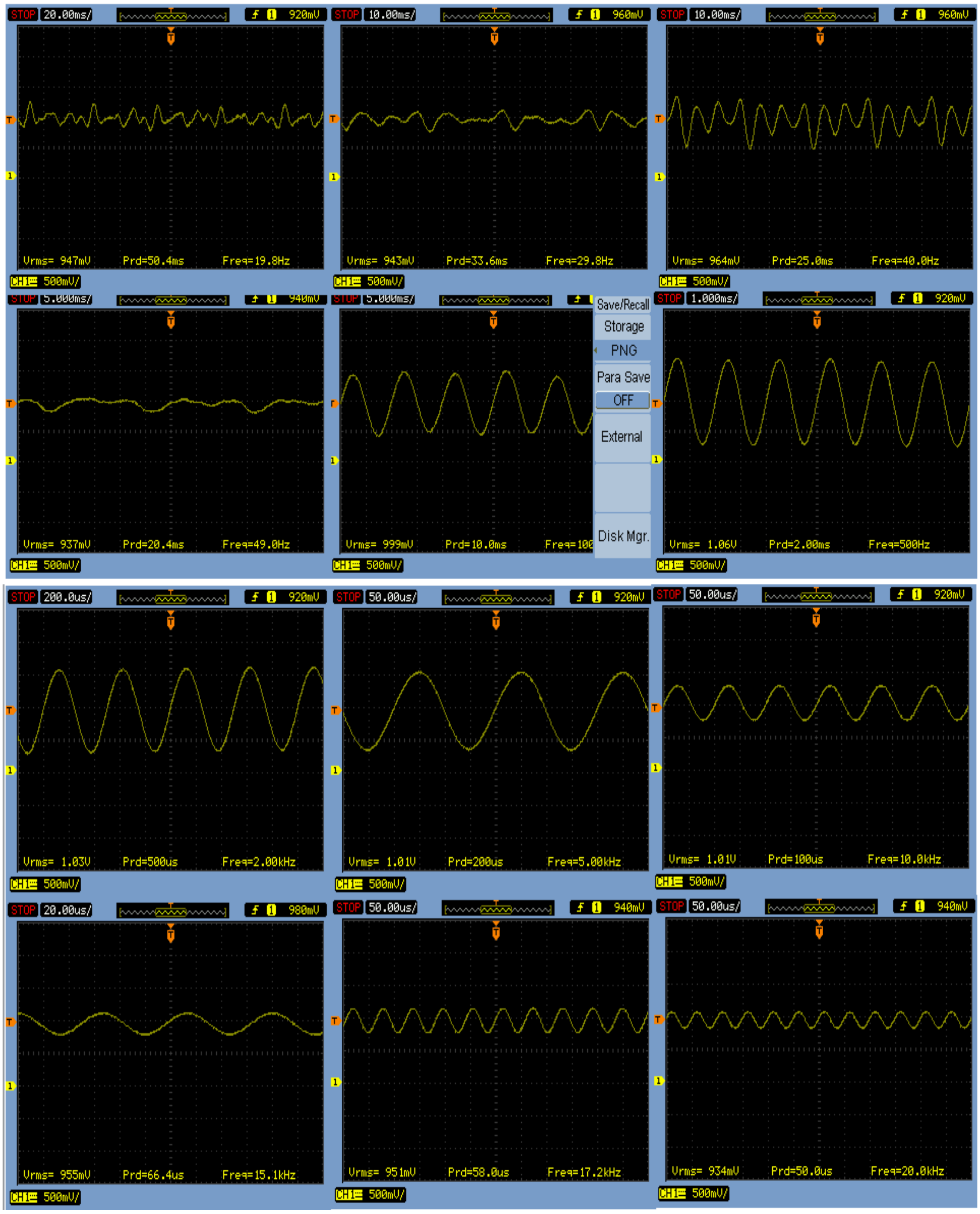


Figure.7. DSO output for different frequency acoustic signals

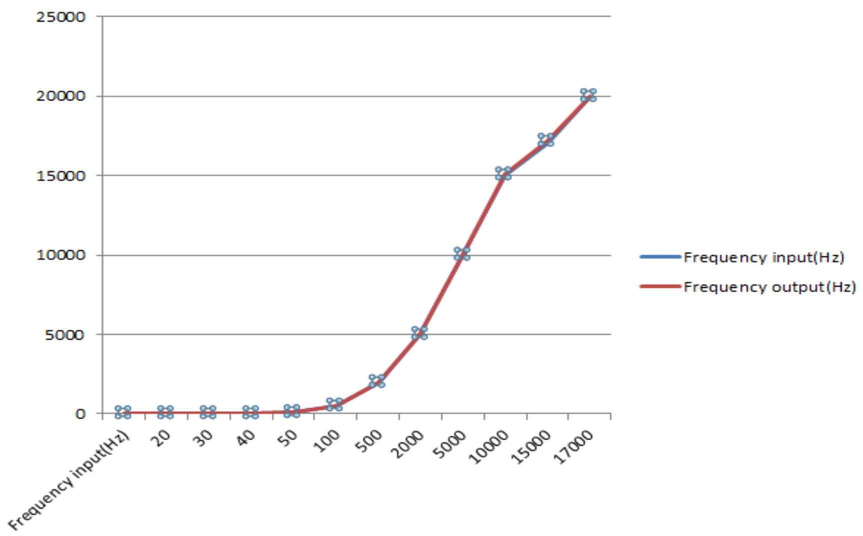


Figure.8. Linearity check for ADMP401

Table.1.Data for Frequency Spectrum of ADMP401

Data for Frequency Spectrum		
Frequency(Hz)	**Output amplitude(V)**	**Gain(dB)**
20	0.947	-0.473
30	0.943	-0.50977
40	0.964	-0.31846
50	0.937	-0.56521
100	0.999	-0.0086
500	1.06	0.50611
1000	1.04	0.34066
2000	1.03	0.256744
5000	0.01	0.08642
10000	1.01	0.08642
15000	0.955	-0.39993
17000	0.951	-0.43639
20000	0.934	-0.59306

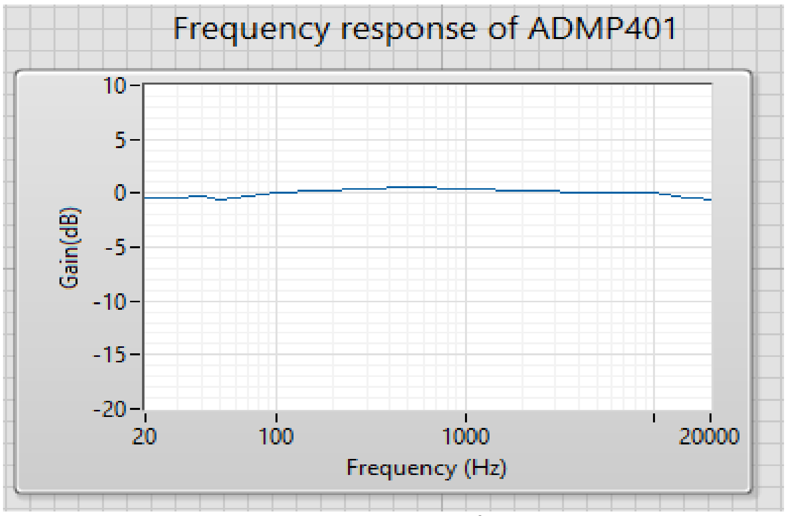


Figure.9. Frequency response of ADMP401

The proposed algorithm is simulated using LabVIEW code and the results displayed on LabVIEW front panel are shown in Figure 10. Some machine structures such as Bench grinder, Circular wood saw, DC shunt motor, DC series motor is selected for the study.
The specifications of these structures are as follows.

<u>Bench Grinder:</u>

- 0.75 HP
- 2880 RPM
- Diameter of grinding wheel : 200mm
- 3-phase,440V

<u>Circular Wood Saw:</u>

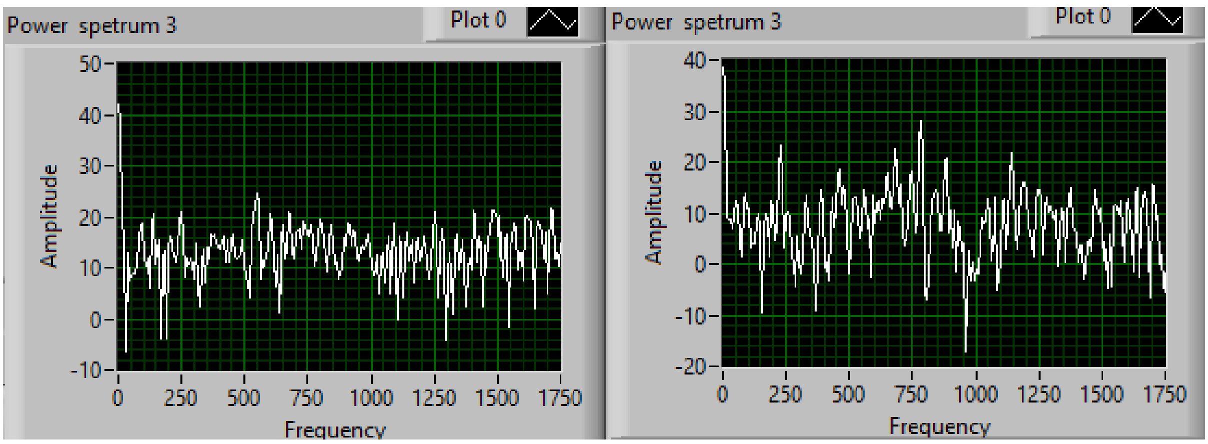
- 3 HP
- 1440 RPM

<u>DC Shunt motor:</u>

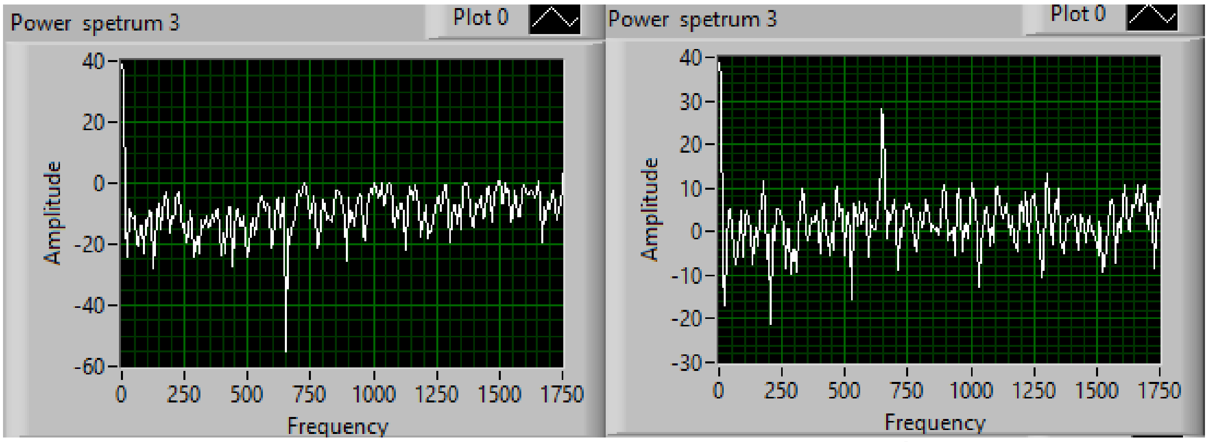
- 220V, 18.6A
- 1500 RPM

<u>DC Series motor:</u>

- 220V,20A
- 1500 RPM



(a) (b)



(c) (d)

Figure.10.Power spectrum of output from ADMP401 when mounted on (a)Bench grinder (b)Circular wood saw (c) DC shunt motor (d) DC series motor

The frequencies corresponding to the peak values of the graphs show the dominant frequency in which acoustic noises are generated in the systems. Proper control measurements have to be done for avoiding such high amplitude noise signals in the system for machine health.

V. CONCLUSION

MEMS sensors have promising applications in high accuracy low size criterions such as space, biomedical and in sophisticated as well as huge mechanical systems. The recent advances in embedded system technologies such as MEMS sensors hold great promise for the future of acoustic measurement based condition monitoring which is a much cheaper alternative. In this study Analog Devices, leading MEMS sensor manufacturing company's acoustic sensor ADMP401 has been used to monitor wirelessly acoustic noises that generates on different vibrating mechanical structures. These signals can be used for machine health monitoring system and the design of control circuitry which prevents further damage to the system. The performance of the sensor is also evaluated. Further study of the same in different space parameters has also to be done so that it can be used in low cost space applications such as sounding rockets, nano satellites etc.

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