



**SILESIA UNIVERSITY OF TECHNOLOGY**  
**FACULTY OF ELECTRICAL ENGINEERING**

Department of Power Electronics, Electrical Drives and Robotics

## **Master's thesis**

**To be determined**

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### 1 WHAT IS ENERGY HARVESTING?

Energy Harvesting is a process of using ambient energy by converting it into a usable form, i.e. electricity or heat. It is important to point out that energy harvesting has been around for quite a long time, since solar panels, wind turbines and water turbines are in constant use for a few decades, providing people with environmentally clean energy [1].

There are some important issues related to any energy source that could be potentially used for harvesting. First of all, it is crucial to evaluate intensity and availability of that source. Subsequently, one should find out a cost-effectiveness of the solution as well as the influence of the harvesting process on the primary energy source [1].

Vibration-based Energy Harvesting incorporates a number of different fields of study, i.e. material science, mechanics or electrical engineering, just to name a few. Last sentence implies that the analysis of a piezoelectric generator itself is not a straightforward process. The electromechanical response of this device relies thoroughly on the source of ambient energy [2].

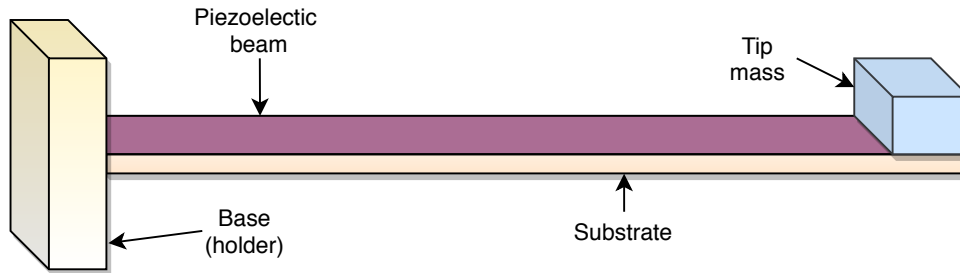


Table 1.1: Common data for some of Energy Harvesting Sources [1]

Type	Conditions	Power Density	Area or Volume	Energy/Day
Vibration	$1m/s^2$	$100\mu W/cm^3$	$1cm^2$	$8.64J$ (continuous vibration)
Solar	Outdoors	$7500\mu W/cm^2$	$1cm^2$	$324J$ (sunny half a day)
Solar	Indoors	$100\mu W/cm^2$	$1cm^2$	$4.32J$ (sunny half a day)
Thermal	$\Delta T = 5^\circ C$	$60\mu W/cm^2$	$1cm^2$	$2.59J$ (heat available for half a day)

### 2 MEASUREMENT SETUP DESIGN

A proper measurement process is a crucial part of this project. Having said that, a custom data acquisition board is to be designed.

First of all, it is vital to highlight most important features required to achieve desired performance. There are four major aspects that have to be taken into account, namely, the ADC resolution as well as the input voltage range, the bandwidth and high input impedance of the analog front-end. Apart from that, one should take care of easy interfacing to personal computer, thus compact size and USB interface would be considered as huge assets.

The previous paragraph introduced briefly main functionalities of the target device. It is quite easy to notice that there would be a lot of trade-offs to consider through the design process. Compact size and the complex analog circuitry usually do not mix, especially when

planning to get a device of USB mass storage size. These facts are forcing the designer to look for a microcontroller that provides decent ADCs, also in terms of the sampling rate. Since the project is dealing with piezoelectric generators, there is always a risk of relatively high voltages at the input terminals, especially when harvesters are not connected to any load. To face this problem, the data acquisition board would be equipped with two different means of protection. The first one takes care of the input stage of the device. The second one is a classic galvanic isolation between the microcontroller (as well as the analog front end) and the personal computer. This way, there is no risk of damaging host devices utilizing the data acquisition system. The summary of the above-mentioned description is presented in the Figure 2.1.

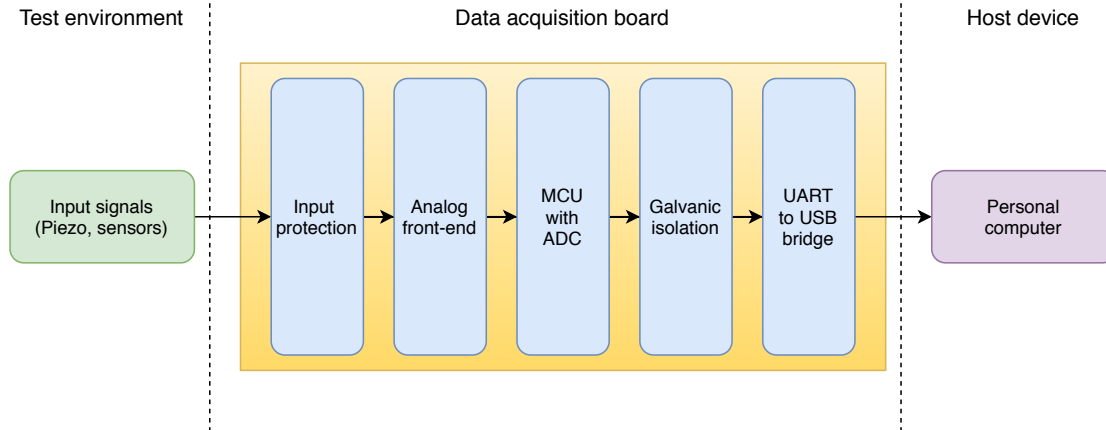


Figure 2.1: Measurement setup overview

### 2.1 Design requirements

The first step of the design process is to determine desired input ratings as well as data acquisition capabilities. The piezoelectric device used in this project would be the major signal source during all experiments. Its datasheet [3] does not state any fixed maximum ratings. Instead, it provides exemplary results obtained by varying acceleration amplitude, frequency, tip mass and load resistance - see Table 2.1.

Table 2.1: Exemplary piezoelectric harvester response. Data from PPA-1001 datasheet [3]

Acceler. ampl. ( $g$ )	Freq. ( $Hz$ )	Tip mass ( $gram$ )	RMS power ( $mW$ )	RMS voltage ( $V$ )	RMS current ( $mA$ )	Load ( $k\Omega$ )
0.25	132	0.0	0.1	1.1	0.1	17.9
0.50	131	0.0	0.2	1.9	0.1	18.3
1.00	131	0.0	0.7	3.4	0.2	15.7
2.00	129	0.0	2.2	5.4	0.4	13.0
0.25	60	1.9	0.1	2.9	0.0	61.0
0.50	60	1.8	0.5	3.3	0.2	20.8
1.00	60	1.7	1.8	7.1	0.3	28.6
0.25	22	22.8	1.4	9.0	0.1	60.4
0.50	22	22.8	4.4	17.3	0.3	67.6

As mentioned in the previous paragraph, there is no constrained area in terms of vibration frequency and level stated by the manufacturer. Based on the data presented in the Table 2.1,

the designer is relatively free to determine the operating frequency range as well as input signal range recorded at the harvester's output. When considering bandwidth and sampling rate, it is important to take into account the Nyquist criterion. It states that the sampling rate has to be twice the highest frequency in the signal [4]. Assuming maximum vibration frequency of 500Hz, more than 1000 samples per second need to be captured.

Of course, this sampling rate only allows to reproduce an incoming signal (sinusoidal wave) as a corrupted triangle, since there is not enough data points to accurately reflect the sine shape. To solve this problem, the sampling rate should be increased by factor of 5 or so, what ultimately yields at least 5000 samples per second (sps). To illustrate the problem, Figure 2.2 is introduced. It can be easily seen that sampling rate as high as twice the input signal frequency is definitely not enough. Having said that, the minimum expected sampling rate is to be at least 5000 sps.

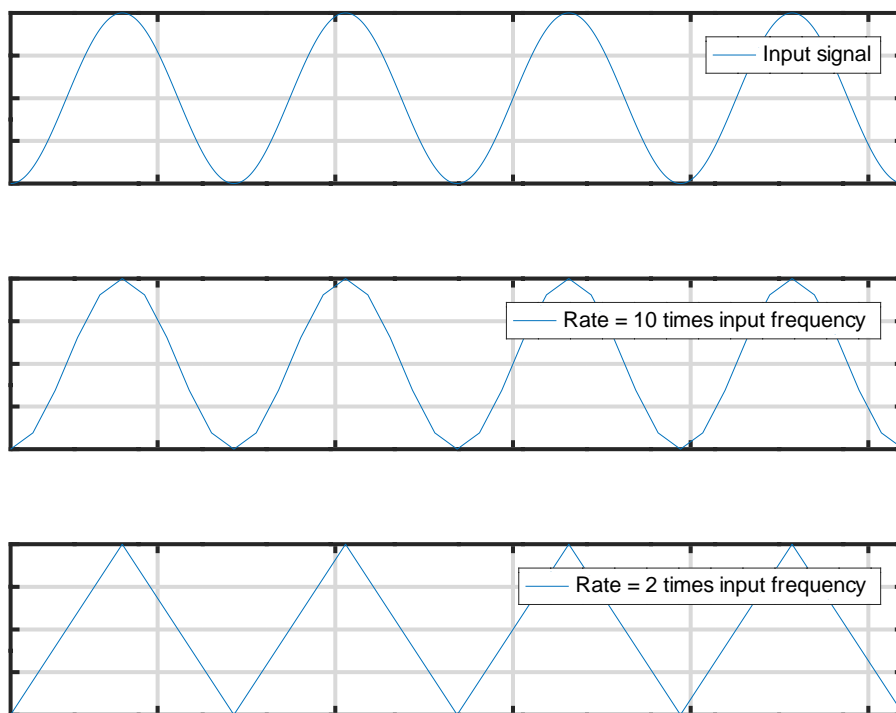


Figure 2.2: Captured waveform versus sampling rate

It is likely that the microcontroller used in the data logger would use some kind of a serial communication protocol. Assuming that more than one signal is recorded at the time and the baud rate is fixed at the same level, the maximum input signal frequency would be divided by the number of active channels. For example, for 2 channel measurement, the maximum input signal frequency is 250Hz and so on.

One of the previous paragraphs mentioned the piezoelectric harvester as the main input signal source. Knowing that the device produces a sinusoidal output, the analog front-end has to be able to capture AC signals, preferably of a relatively high amplitude. This requirements force the designer to develop symmetrical power supply for the input section as well as the circuitry allowing to add offset to the signal before it reaches the ADC input. A reason is that the ADC of the microcontroller is likely to accept only unipolar signals within tightly specified range. Remaining channels would be able to interface DC signals only, what makes them suitable for

external sensors such as the accelerometer.

When considering the maximum input signal level, one has to note that it should not exceed supply voltage of operational amplifier used in the input section. In case of the designed device, the power supply would be industrial  $\pm 15VDC$ , as it helps to maintain compatibility with wide range of available operational amplifiers. Based on the last sentence, the maximum input voltage is specified to  $\pm 15V$  for the AC input and  $+15V$  for DC inputs. In order to assure proper operating conditions for the analog-front end, an additional input protection is to be provided.

There are two last aspect that need some care. The first one is the resolution of the ADC that would be used to capture the incoming signal. The second one is the input impedance of input channels.

As to the first point, it is useful to have a look at technical details of commonly available oscilloscopes, since they can be treated as a nice reference. Most of them utilize 8 or 10-bit ADCs, mostly because of bandwidth requirements as well as the sampling time. In case of this design, the bandwidth is significantly reduced, what allows to look for a bit more resolution, of course still bearing in mind that all the processes are handled by one modest microcontroller. Putting it all together, an 14-bit ADC is going to be a desired data converter.

The last point relates to the impedance of analog inputs. Piezoelectric harvesters are high output impedance devices [1], therefore it is desirable to maintain as high input impedance of the analog front-end as possible, in order not to disturb the incoming signal. There are two potential problems that may occur when designing the input stage. As it can be guessed, the input signal has to be divided before it gets to the analog-to-digital converter. The easiest way to go is to put a voltage divider directly at the output of the harvester. Unfortunately, this circuit would have a significant influence on the impedance seen from piezo generator's output terminals, thus posing a risk of changing its operating conditions. To deal with this problem, the incoming signal is to be buffered before any further processing. This is where low input bias current operational amplifiers would come in handy. The second risk is related to the protection circuitry attached to input terminals. Once the input signal gets to high, it would be clamped in order to protect the data acquisition board. Unhappily, it would also disturb the measured object due to rapid change of the impedance seen at mentioned harvester's output terminals. The only way to deal with this issue is to provide relatively high supply voltage for buffering amplifiers and adjust the load as to meet the input voltage requirements.

As a summary of design considerations included in this subsection, Table 2.2 has been created.

Table 2.2: Summary of requirements for the data acquisition board

Requirement	Value
Max. input signal frequency (Sine)	500Hz
Min. sampling rate	5000sps
Min. ADC resolution	14-bit
Max. input voltage range (p-p)	15V
Input impeadnce	TBD



### ***REFERENCES***

- [1] N. W. Stephen Beeby, *Energy Harvesting for Autonomous Systems*. Artech House, 2010. ISBN: 978-1-59693-718-5.
- [2] D. J. I. Alper Erturk, *Piezoelectric Energy Harvesting*. John Wiley & Sons, Ltd, 2011. ISBN: 978-0-470-68254-8.
- [3] Midé Technology, *PPA Products. Datasheet and User Manual*, 2016. Revision No. 002.
- [4] J. Louis E. Frenzel, *Electronics Explained*. Newnes (Elsevier Inc.), 2010. ISBN: 978-1-85617-700-9.