Design of a Self-Powered Wireless Transmitter

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***Abstract* — This paper deals on converting mechanical impact on piezoelectric plate into electrical energy and using this harvested energy to power a wireless sensor node (WSN). Here we discuss on the power processing unit which consists of rectification, storage and regulation of voltage. The wireless sensor node senses the ambient vibrations around it and uses the harvested energy to send unique identification information from a microcontroller. Different capacitances have been tested and an optimized value is chosen depending on current and voltage requirements. Finally the prototype has been tested and its performance is analysed under normal conditions.**

Keyword- Piezoelectric plate, MSP430G2231, ambient vibrations, wireless sensor node, capacitance, energy harvesting.

I. INTRODUCTION

In the latest trends that are emerging, controlling battery powered devices has become a major field of study. Creating devices with intelligent battery-less option is growing slowly. Mainly commercial and military fields demand such kind of products. They usually rely on wireless sensor nodes (WSN) with low power consumption. Mostly all such devices would be provided with super capacitors to give it longer life span. Even with such features these devices are deployed to replacement of batteries when they are drained out. So the need of self-powered devices comes into picture. These devices usually take energy from ambient environment by harvesting the required power for the device. Depending on need, such harvesting schemes can be of continuous mode or instantaneous mode, this paper employs the latter mode of harvesting.

Sensors are placed into ambient environment to collect data related to the surrounding and send it to the receiver for processing. These include humidity, temperature, speed, and ample number of other parameters. Such data will be of paramount importance for scientists and researchers who need to analyse the wireless node. So this information is needed to be precise and error free. Low power transmitters and receivers are needed with high throughput and sensitivity. Hence design of WSN node includes a harvesting module, processing module and transmitting module, all working in low power modes.

Usually the ambient sources available for harvesting are solar energy, vibrational energy, RF energy etc. Using the vibrational energy and making a magnet move through a coil we can generate energy of 100µJ [3]. It can be sufficient to design a wireless switch capable of sending RF packets. Smart buildings in metropolitan cities, also called positive energy sources, are constructed using number of sensors, capable of harvesting energy and saves around 10-30 % of total energy [4]. Another possible source of harvesting can be done by using temperature difference, also called the Seebeck effect. Such effect generates an open circuit voltage in a thermocouple maintained at two different temperatures. In case of continuous need of power, harvesting energy from RF field can be a feasible option. Such a design using GSM band can generate power densities of 0.1-10mW/m^2[5].

Self-powered wireless transmitters usually needs to be minimized in size and highly efficient in transmitting data, so that they can be placed in remote places where humans can’t reach. But if the device is meant for human use we generally prefer using vibrational energy for harvesting and self-powered remotes can be designed by converting the pressing force into electrical energy to send data. Using efficient protocols, maximum energy can be used to increase the throughput of the device.

This project is an experimental work to know how ambient energy sources can be used to send data using a RF transmitter. Ambient energy can be any kind of source from solar to electromagnet. This paper focuses on using human kinetic energy and to convert it into electrical energy. Possible sensor to do such a conversion is piezoelectric plate. We deal with, how a small press on the plate is capable of sending RF packets to destination node. The receiver processing is not done in this project and is left for further analysis. The design shown in this project is just a prototype on how piezoelectric plate is a possible sensor that can be deployed for harvesting energy. The miniaturization and improvement in design for other applications is left for future work.

This paper is organized as follows: Section II briefs about the experimental setup for our design. Required equipment’s for the project and their mechanical and electrical equivalents are discussed. Section III here deals with the construction of different blocks in our design. Each block and their constituents and the reason for their use are explained. Section IV discusses the design of sensor node. It mainly deals with information generation and its transmission. Section V shows the performance of the node. Different experimental data is provided which is generated after testing the node to prove its performance. Finally conclusions are given in Section VI.

II. General Experimental setup

Piezoelectric plate consists of two electrodes implicitly moulded around the ceramic. Wires are drawn from these plates making the positive end and negative end. Different sizes of plates are available in general. The dimensions of the plate that is used for the project includes a bronze disk of diameter 35mm and 0.25mm thick and a piezoelectric ceramic disk of diameter 23mm and thickness 0.25mm. The piezoelectric plate is clamped between two rubber corks. A known spherical mass (26.393g) dropped freely from a known height (80mm). This leads to a polarization across the piezoelectric plate terminals. The general setup is shown in Fig 1.

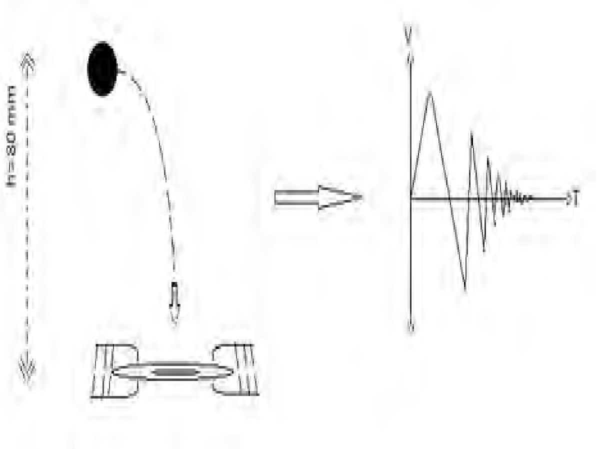


Fig 1: Setup for Experiment

The electrical equivalent circuit for the above phenomenon is shown in Fig 2, and has been discussed in detail in [1]. The components R_m, L_m, and C_m are equivalent to freely falling body and C_d and R_d make the piezoelectric plate's equivalent capacitance and dielectric loss respectively. R_L is the external load connected to piezoelectric plate.

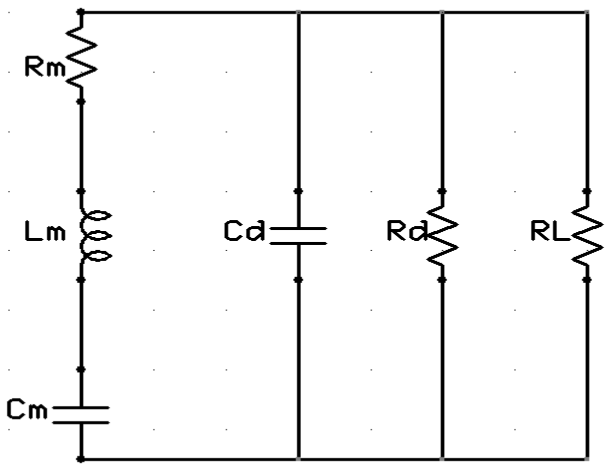


Fig 2: Equivalent circuit

III. Design of energy harvesting system

The general piezoelectric plate is shown in Fig 3. It is used for various purposes like buzzers, pressure sensors etc. The spherical mass is dropped on the piezoelectric plate with the help of hollow cardboard tube, so as to prevent the mass from rolling over the piezoelectric plate after the mass comes to rest. This mechanical vibration produces an AC signal across the piezoelectric plate and its voltage level depends upon the mass of the spherical ball and the height from which it is dropped. The dynamic polarization capability of piezoelectric ceramic generates a high voltage AC signal [2].

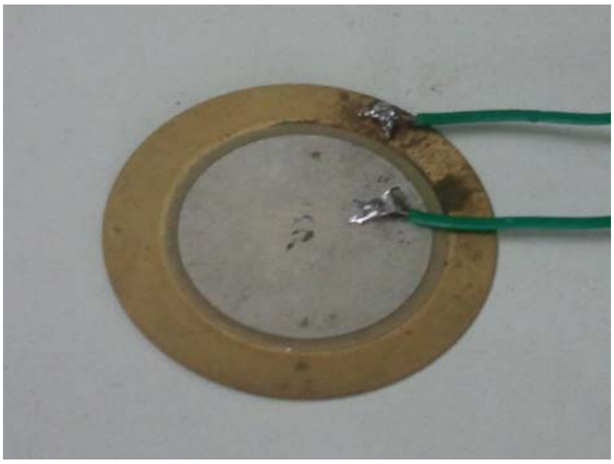


Fig 3: View of piezoelectric plate

A simple block diagram showing different segments of the harvesting and processing modules is given in Fig 4. The output from the piezoelectric plate is an alternating signal due to vibrational input. This signal first needs to be rectified using a set of bridge rectifiers. The rectified output is stored in a storage capacitor. The capacitor also acts as a voltage clamper as the signal from the harvesting source is of short duration. Plus, the capacitor acts as a filter to smoothen the ripples in the voltage signal.

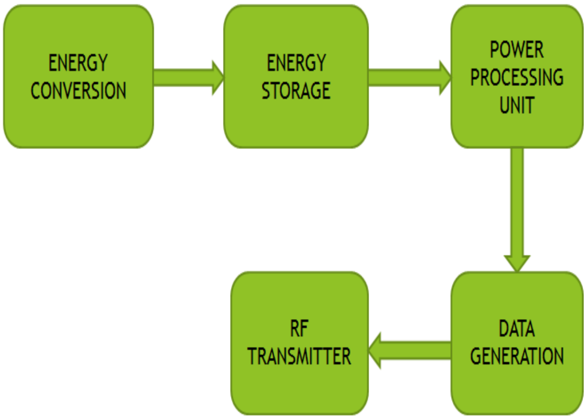


Fig 4: Block Diagram

For longer duration storage purposes we can use rechargeable batteries. But this option usually has some concerns like the life span of rechargeable batteries is low; they lose their capability within a few years. And the circuit is mainly aimed to bring about miniaturization to design, but these batteries occupy more space which causes implementations constraints. Another feasible option is the use of super capacitor. These capacitors have larger power densities and longer life span (measured in terms of discharge cycles). Hence this project uses capacitor to support the WSN as the end device.

The output from the capacitor is generally an unregulated DC voltage. But most of our everyday applications prefer regulated voltage for their proper functioning. This is done using a linear regulator. The output from this linear regulator is held constant until the entire voltage across the capacitor is discharged below the threshold level. By theory we know that the difference between the input and output voltages of the regulator is needed to be kept minimum for maximum efficiency since this causes a low voltage drop across the regulator, which means a very little amount of energy is wasted at the regulator point.

Usually linear regulator with ultra-low quiescent current is used. Switched regulators contain ripples in output due to switching rates and have low quiescent current requirements [2]. But in our harvesting unit load current is in the order of micro-amps. Though switched regulators have additional advantages, our project uses linear regulators based on our hardware constraints. Fig 5 shows the schematic design for the harvesting module.

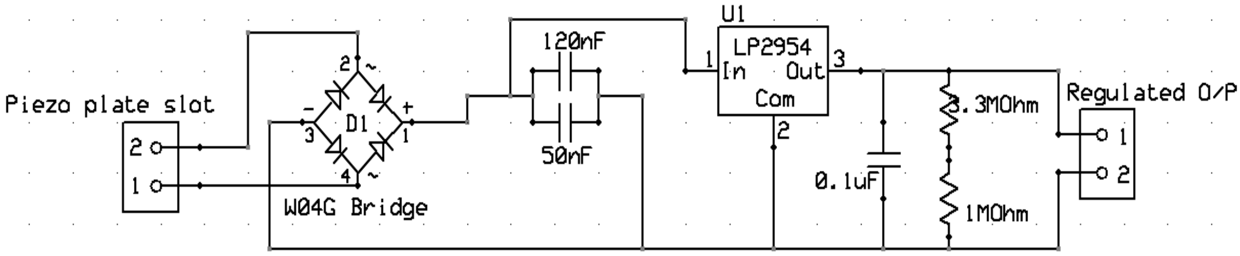


Fig 5: Schematic of harvesting module

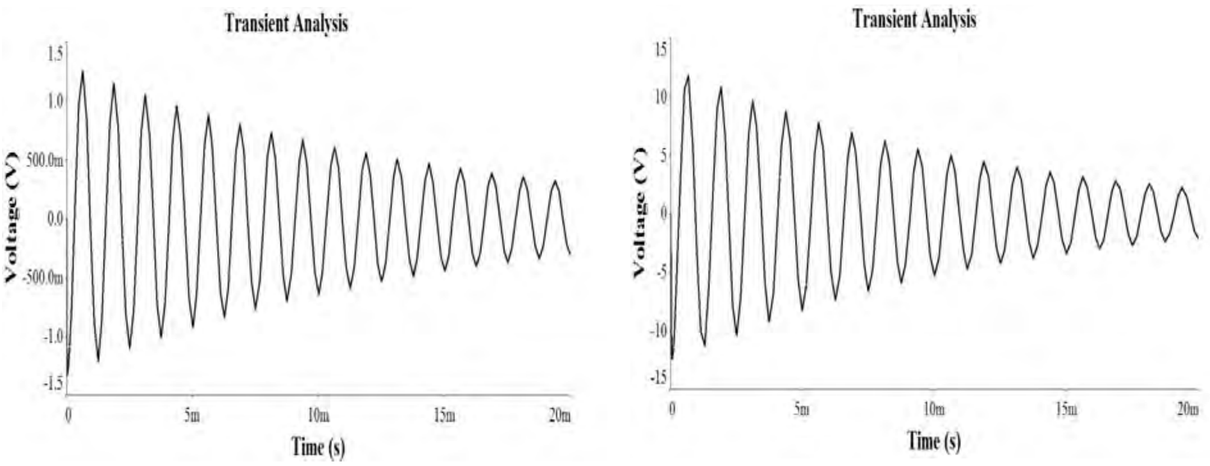
IV. MATHEMATICAL ANALYSIS

As shown before Fig 2 is the equivalent circuit of the harvesting node. We analyse the behaviour of the circuit under various load conditions. The values of the elements in the circuit are obtained from [1], where we consider only one position i.e. vibrator and mass together. These values are listed TABLE I below:

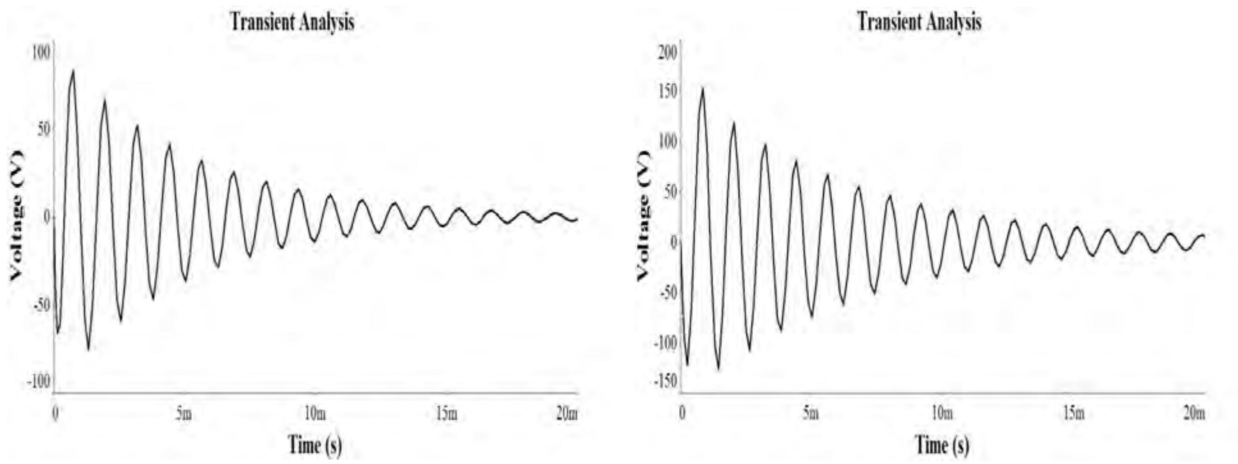
TABLE I: Equivalent Circuit parameter values

Element	Value
R_m	3.596k Ohm
L_m	21.68H
C_m	1.643nF
C_d	13.92nF
R_d	51.37k Ohm

Now we vary our load from 100 Ohm to 100k Ohm, and see the voltage waveform across the load. The output obtained is given in Fig 6 using PSpice. We see that for 10k Ohm load the damping is faster, which makes it a better matching value.



(a) (b)



(c) (d)

Fig 6: Voltage across load for (a) 100 Ohm (b) 1k Ohm (c) 10k Ohm (d) 100k Ohm

Also the input impedance offered by the circuit at load 10k Ohm is verified using MATLAB. Fig 7 below shows the impedance response of the circuit. Clearly at 0.8 kHz we get minimum impedance which means a maximum admittance. So a source with frequency near to 0.8 kHz can bring about resonance giving a maximum efficiency.

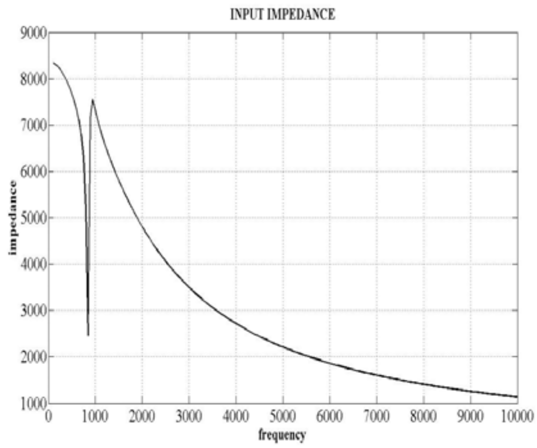


Fig 7: Frequency response of equivalent circuit

Similarly the storage capacitance has to be optimized keeping in mind the quiescent current requirements of the regulator. We perform an experiment where we drop the mass on the piezoelectric plate from height of 80mm and check the voltage drop across the capacitor. TABLE II gives list the recorded data. To get a graphical view of the data, we use MATLAB to get the voltage and capacitor charge curves as shown in Fig 8. We have chosen 0.2µF as our storage capacitance.

TABLE II: Experimental data

Capacitance	**Voltage**
10µF	1.25 V
4.7 µF	1.75 V
2.2 µF	3.19 V
1 µF	4.69 V
0.5 µF	6.94 V
0.47 µF	7.00 V
0.33 µF	7.20 V
0.25 µF	8.30 V
0.2 µF	9.10 V
0.047 µF	20.80 V
0.015 µF	51.90 V

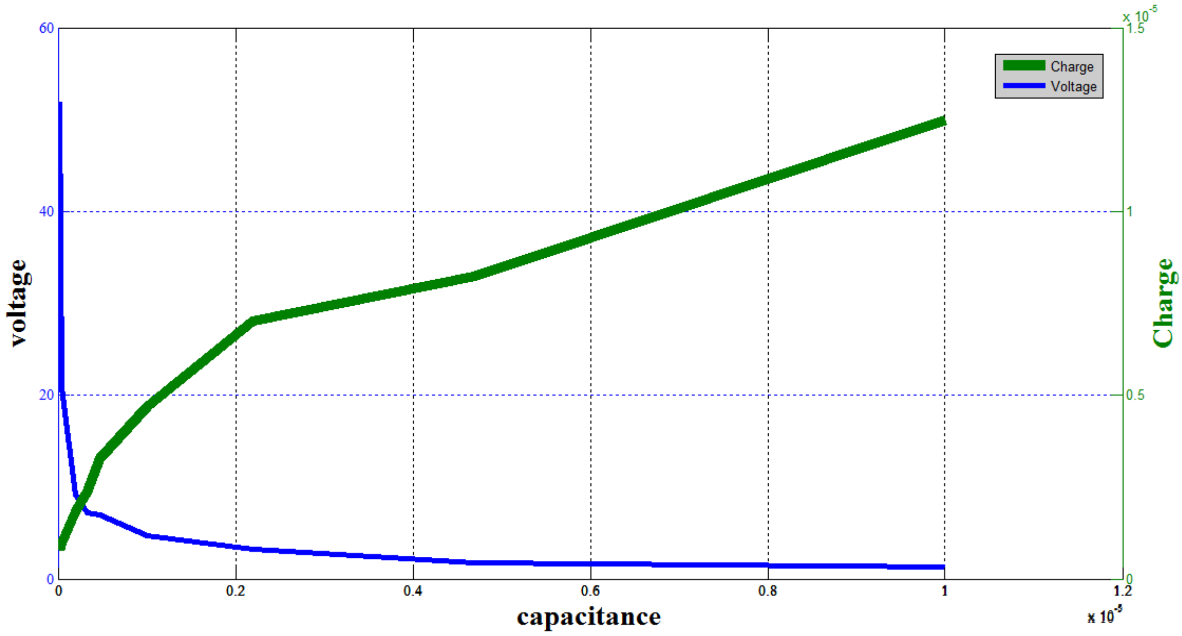


Fig 8: Voltage and Charge curves

V. Design of WSN using MSP430G2231

Now the harvested energy is needed to be used for some applications. This paper discusses one such application where we design a wireless sensor node (WSN) capable of sensing the ambient vibrations, such as a press on the push button. When energy harvested from the source wakes up the controller it sends the information stored to the receiver station. Here we only focus on the transmitter part.

Using the piezoelectric plate serves two purposes: firstly as a harvesting source and second as a sensor producing a reset interrupt to the controller. Such sensors are of great use in knowing the values of pressure, or for sensing the location of pressure produced by sending a corresponding data to the receiver. Wireless switches or battery-less remotes are possible products from such sensors.

The data to be sent is stored in the controller and whenever a reset interrupt is activated a burst of data is sent depending on how long the power supply is available. The data can be changed from time to time depending on our need. For proper reception of data a small burst of packets is sufficient, taking into consideration the wireless signal loss that could possibly occur. For the current application we make use of standard 9600 baud rate, with one start bit and one stop bit, and no parity bit.

Most beneficial feature of MSP430 is that it consumes very small amount of power for working. Moreover we can place the controller in low power modes when no work is being done by the controller. Since in our case the harvested power is very low we go with MSP430G2231 series of controller for transmission and reception. We have used a 433MHz transmitter (KST-TX01C) with low current consumption (Typically 11mA).

VI. Performance of WSN

Whenever the mass is dropped from different heights, a different amount of energy is harvested. The harvested energy also varies with the mass of the object. But dropping the mass from huge heights could cause damages to the ceramic of the piezoelectric plate. So the height as well as the mass is maintained low, for better life span of piezoelectric plate. For our project we drop the mass of 25g from a height of 80mm. The performance of the complete harvesting module and the WSN is discussed below.

When the mass is dropped on the plate an open circuit damped voltage is obtained across the terminals of the plate, where the damping coefficient depends on the number of bounces the mass makes on the plate. Fig 9 below shows the CRO output across the piezoelectric plate.

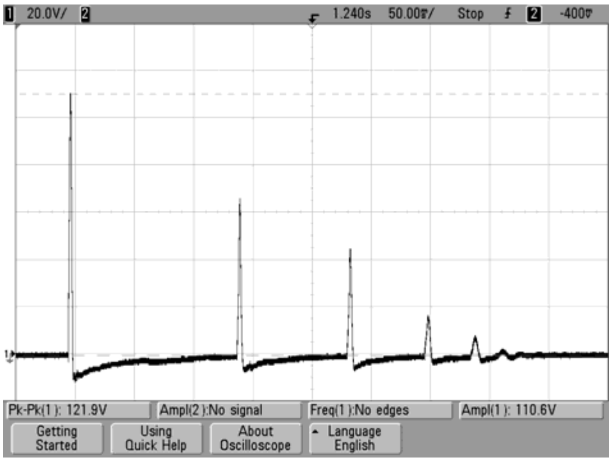


Fig 9: Piezoelectric Output

We can see in the figure that the peak voltage obtained is 122 volts p-p. Depending on the number of bounces on the plate we get different peaks. We can observe that the voltage of the peaks keeps reducing since the height from which the mass drops after each bounce reduces. The figure indicates that the ball de-bounces five times before coming to rest.

As we observe the output from piezoelectric plate is sinusoidal, we need to rectify the signal. Thus we use a full bridge rectifier to get DC output. We can also observe that the signal frequency is very high. Hence we need to use fast switching diodes for rectification process. The CRO output from the full wave rectifier is shown in Fig 10. On rectification the peak voltage reduces to 57 volts.

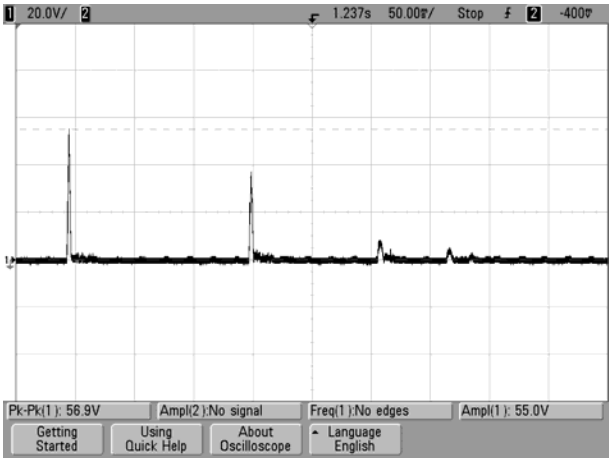


Fig 10: Rectified output

Now this rectified output can be used to charge up a capacitor and store the energy. Usually capacitors are used to elongate the regulated voltage duration, depending on our need. As mentioned before we use a 0.2µF capacitance as our storage unit. This capacitance can be charged up to 20 volts. Fig 11 shows how the capacitance gets charged up and discharges thereafter. Practically depending on the peak voltage we can state that the power harvested is around 40 micro-joules.

Once the capacitor is charged, we can give its output to a regulator. Usually regulated voltage is needed for most of our applications. We regulate the capacitor voltage to 5 volts for our application. Depending on how long the capacitor voltage remains above the threshold voltage of our regulator, we get pure regulated voltage of 5 volts. Below the threshold voltage the regulator acts as a buffer. As shown in Fig 11 we obtain a regulated voltage for duration of nearly 50ms. This period is sufficient to transmit data from controller using RF transmitter.

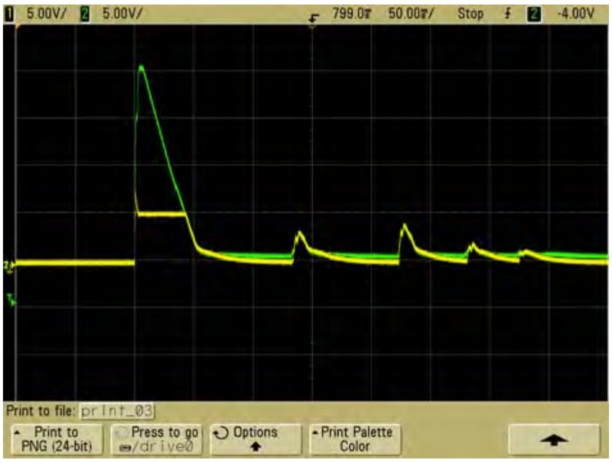


Fig 11: Storage and regulation

Depending on the duration for which we get pure 5 volts, we can see the number of packets that can be transmitted are nearly seven. For proper reception of data more number of packets can be transmitted by increasing the baud rate. In our application we use a 9600 baud rate for transmitting data. Fig 12 shows the packets being generated and Figure 13 shows the information in each packet sent. The controller transmits the character ‘G’ to the base station.

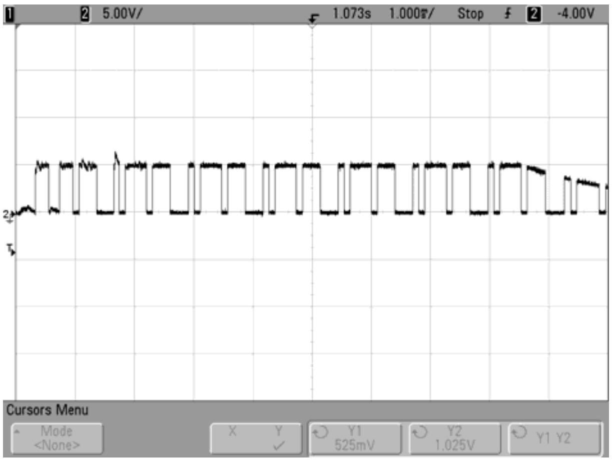


Fig 12: Burst of data generated

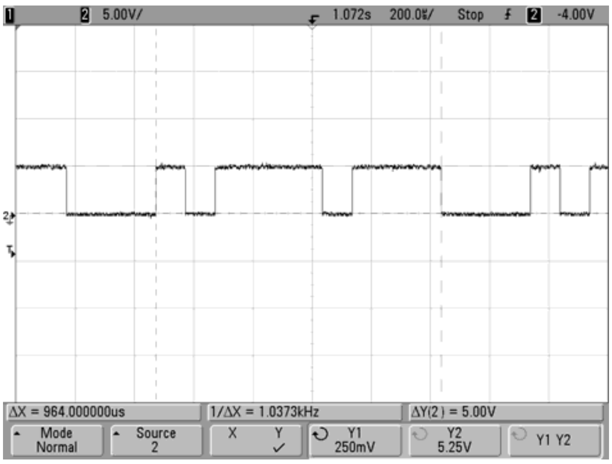


Fig 13: Data in each packet

VII. CONCLUSION

This paper has successfully proved that piezoelectric plate can be used as an energy harvesting unit to transmit data. We have shown how the harvesting unit can be designed for the piezoelectric plate and how that energy can be used to transmit data. The transmitter part is discussed in this paper but its corresponding receiver part is left for further analysis. The future work that can be done in this area would be the miniaturization of the design for better implementation in remote regions. And also how various smart and intelligent systems can be designed which can work without any conventional power sources.

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