

# A piezoelectric pulse generator for low frequency non-harmonic vibration

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**Abstract.** This paper reports a new piezoelectric prototype for pulse generation by energy harvesting from low frequency non-harmonic vibration. The pulse generator presented here consists of two parts: the electromechanical part and the load circuit. A metal rolling rod is used as the proof mass, moving along the substrate to achieve both actuating of the piezoelectric cantilever by magnetic coupling and self-synchronous switching of the circuit. By using this new approach, the energy from the piezoelectric transduction mechanism is regulated simultaneously when it is extracted. This allows a series of tuneable pulses to be generated, which can be applied to self-powered RF wireless sensor network (WSN) nodes.

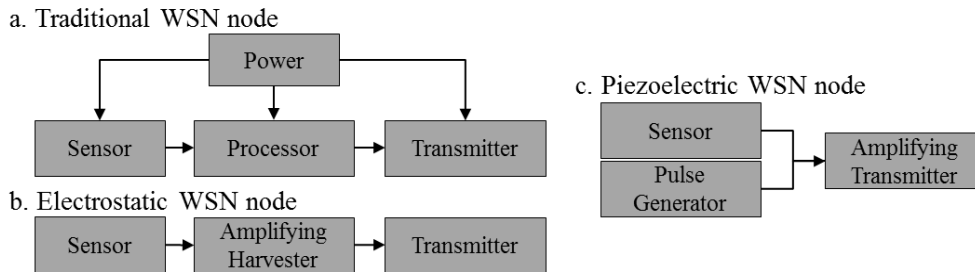
## 1. Introduction

With increasing demand of highly mobile and portable electronic devices, it has become a popular topic to seek for new power approaches such as motion energy harvesting instead of using batteries as the external power of traditional WSN nodes as in figure 1(a) [1]. Previous work of our group has realised a self-powered WSN node platform using electrostatic transduction without any external power sources [2][3]. It is the first ever device that uses a rolling rod as the proof mass to allow operation with non-harmonic vibration. As shown in figure 1(b), signals from the sensor are supplied as the priming voltage to the electrostatic energy harvester and can be amplified and transmitted wirelessly through the device. However, the power density of this prototype is significantly restricted by the amplitude of the priming voltage from the sensor, and weakness of the electrostatic transduction due to the low variable capacitances achievable, and only 2 nJ per pulse can be extracted from it. Taking advantage of the rolling rod actuation mechanism, another energy harvester from our group using piezoelectric transduction has managed to increase the power density dramatically, compared to the electrostatic transduction [4]. This device can only function as an energy harvester due to its non-regulated output, since the waveform of the piezoelectric energy directly depends on the mechanical behaviour of the rolling rod and the piezoelectric cantilever. A piezoelectric pulse generator in [5] can provide a well regulated output for wireless sensing, but uses a mass-spring-damping construction, which cannot operate at a random low frequency. The piezoelectric pulse generator proposed here combines features of the two prototypes in [3] and [4], and is designed to generate a series of reliable and tuneable pulses which is aimed at power for WSN nodes as shown in figure 1(c). This proposed architecture connects the sensor and the pulse generator in parallel instead of in series, which eliminates the priming voltage restriction of the electrostatic prototype. A simple load circuit is





designed to work together with the piezoelectric transduction mechanism, in order to achieve self-regulation of the piezoelectric energy.



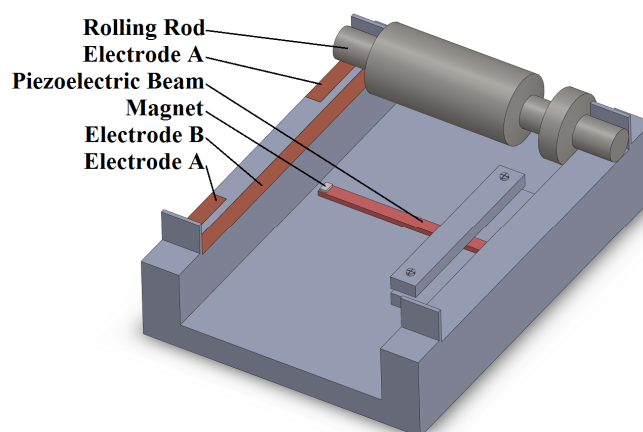
**Figure 1.** Comparison of different WSN node architectures.

This paper presents the operating mechanism of the proposed pulse generator, and experimental data measured from the scalable prototype are illustrated. Simulation results are provided for further application to the WSN node.

## 2. Operating mechanism of the pulse generator

The pulse generator consists of two parts. The electromechanical part is used to actuate the piezoelectric cantilever for energy generation, and the electrical part, which is the load circuit, is connected to the piezoelectric cantilever for instant energy storage and regulation.

Figure 2 shows the architecture of the electromechanical part. A metal rolling rod is used as the proof mass, and aligned on the side wall of the substrate to travel back and forth. A block magnet is attached to the tip of the piezoelectric beam for magnetic coupling together with the rolling rod. When the rod is excited by the motion source and rolls from one end to the other (one charge and discharge cycle), it attracts the tip magnet to deflect the piezoelectric cantilever and afterwards release the cantilever to vibrate. A fixed amount of piezoelectric energy is generated both from the deflection and vibration, since the surface charge is proportional to the tip deflection of the cantilever [6].

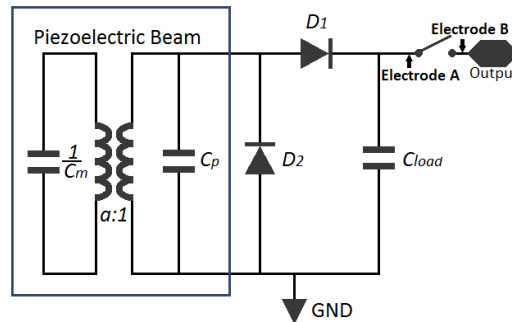


**Figure 2.** Electromechanical part of the pulse generator.

The electrical part shown in figure 3 is connected to the piezoelectric beam as a storage load. When the piezoelectric beam is deflected, diode  $D_1$  is forward-biased and the piezoelectric charge is shared with the load capacitor,  $C_{load}$ , instantaneously for each of the charge and discharge cycles. As the rod moves away to let the beam vibrate, the charge is reversed, and  $D_1$  is reverse-biased, disconnecting  $C_{load}$  from the beam, while  $D_2$  is forward-biased allowing the beam to reset to its neutral axis.



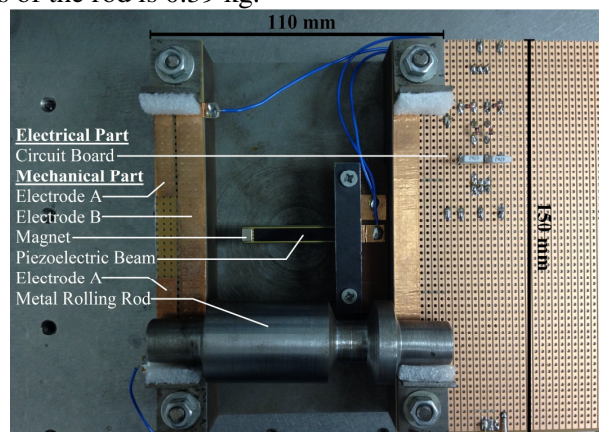
The electrode pair *A* and *B* illustrated both in figure 2 and 3 are made of copper tape for synchronous switching of the circuit together with the metal rod. After the energy is shared and stored in  $C_{load}$ , the rod approaches one of the electrode pair as shown in figure 2, connects the two electrodes, and forms a switch as shown in figure 3. Then the stored energy can be discharged to the load of the pulse generator.



**Figure 3.** Schematic of the electrical part of the pulse generator.

### 3. Experimental set-up and measurement results

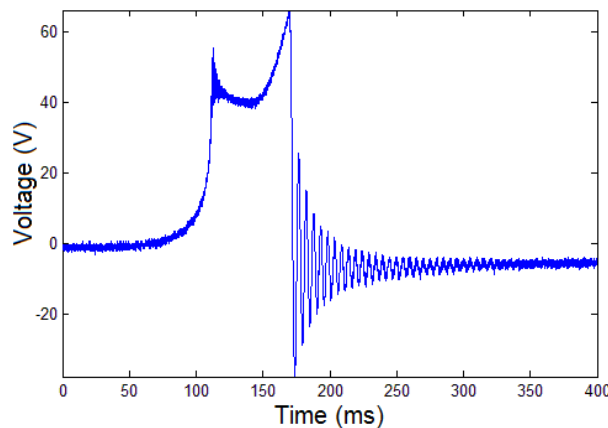
A large scale prototype is used to demonstrate the proposed concept of the pulse generator as shown in figure 4. The testing circuit is fixed on the side wall of the electromechanical stand, and is used as the track of the rolling rod. The piezoelectric beam is clamped by a small platform, which is mounted on the substrate and can be removed to adjust for piezoelectric beams of different dimensions. The cantilever under test is a piezoelectric bimorph from Johnson Matthey. The free length of the beam is 38 mm with  $\sim 45$  nF capacitance for each piezoelectric layer. The dimension of the tip magnet (N45 neodymium) is  $5 \times 4 \times 1.5$  mm. The load capacitor used in the set-up is 47 nF to match the piezoelectric capacitance, and the mass of the rod is 0.39 kg.



**Figure 4.** Large scale prototype of the pulse generator.

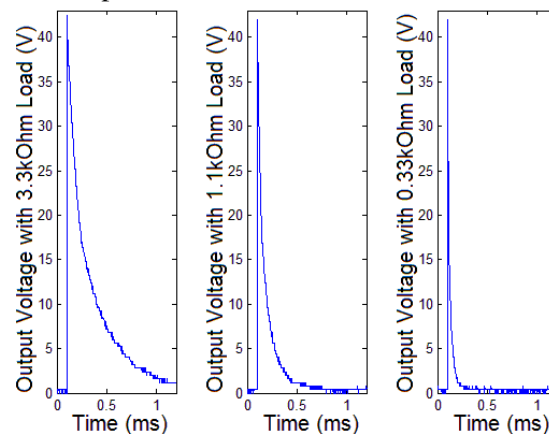
Figure 5 illustrates an output of the present prototype but actuated in the manner presented in [4]. The first pulse with two positive peaks is generated during the deflection of the piezoelectric beam. After the beam is free to vibrate a series of resonating waves are generated. According to figure 5, the width of the deflection pulse depends on the speed of the external rolling rod, whilst the frequency of the resonating waves is the natural frequency of the beam. Although this approach provides an excellent performance for energy harvesting, it leaves the output result not directly suitable for WSN nodes, due to its unclear shape with many resonating cycles, and its width cannot be tuned since it is dependent on either the deflection speed caused by the magnet-rod coupling or the natural frequency of the beam.





**Figure 5.** Output voltage without the load circuit.

By contrast, the piezoelectric energy extracted from the proposed prototype in figure 4 is stored simultaneously as the generator is operating, and is regulated and discharged to the load of the device synchronously from the self-switching of the rod-electrode pair mechanism. Figure 6 illustrates the output pulses with different load impedances.



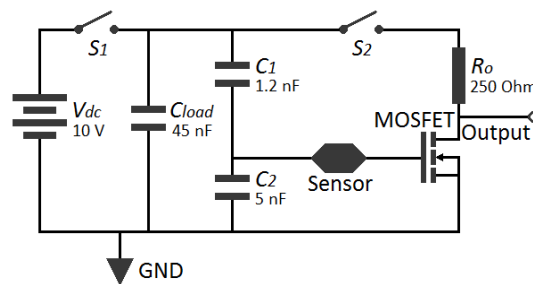
**Figure 6.** Output pulses from the generator connected with different load resistors.

During the storage and self-regulation of the energy, a charge penalty is inevitable. As can be seen from figure 6, the amplitude of the pulses decreases to 42 V compared to the highest peak in figure 5, which is 62 V, due to charge sharing between two capacitors. The energy extracted in each charge and discharge cycle is the energy shared and stored to the load capacitor, and up to 41.5  $\mu\text{J}$  per pulse can be achieved with the 47 nF load capacitor, which is still high enough to power a WSN node. In addition, since the energy is stored in a load capacitor before discharge, the pulse width is dependent on the electrical components rather than the physical behaviour of the beam, making it tuneable with different load impedances as shown in figure 6.

#### 4. Signal amplification and simulation

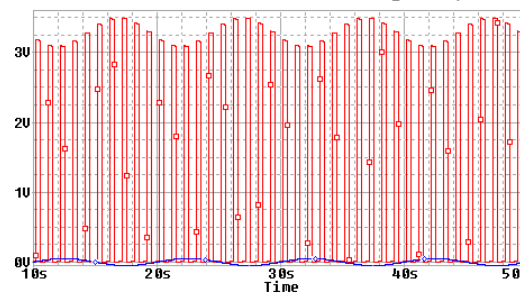
In order to realise signal processing, a single MOSFET amplifier as illustrated in figure 7 is used to simulate the application. To simplify the simulation, a load capacitor charged by a DC voltage is used to represent the pulse generator, which is connected to the amplifier as a discrete power source. Capacitors C1 and C2 are used to provide a bias voltage for the signal from the sensor and the synchronous switching by the rod-electrode pair mechanism is represented by voltage controlled switches.





**Figure 7.** Schematic of the amplifier.

Instead of powering a MOSFET amplifier with a DC voltage source, the pulse generator can inject a series of pulses to the amplifier to achieve signal amplification and sampling at the same time. Figure 8 illustrates the simulation results of the schematic. As it is shown, the blue sine wave represents the unbiased sensor signal, whose peak-to-peak amplitude is 100 mV, and the red pulsed signal is the output of the circuit. It can be observed that the original signal from the sensor is amplified and sampled through the circuit, and the peak-to-peak amplitude of the pulsed sine wave is 400 mV, providing an amplification of 4. By using the circuit presented, the original signal can be processed for wireless transmission with a resonant radio frequency oscillator as in [3].



**Figure 8.** Simulation result of the amplifier.

## 5. Conclusion

A new pulse generator is proposed to enhance the performance for self-powered WSN nodes by taking advantage of the piezoelectric transduction and the external rolling proof mass. A testing prototype is built to demonstrate that the pulse generator can achieve the function as expected in theory, and simulation results are illustrated to introduce the application of this pulse generator. Self-synchronous switching is successfully implemented using an external proof mass. A reliable pulse with high energy (41.5  $\mu\text{J}$ ) can be generated repeatedly from the model and is capable of being tuned to satisfy the requirement of wireless transmission by load impedance matching.

The geometry of the device is scalable by choosing different dimensions of piezoelectric beams for further miniaturization. In addition, a charge penalty is induced by the charge sharing mechanism, and alternative load circuits may be required to potentially enhance the efficiency of the energy harvesting.

## References

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