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Wireless sensor node with hybrid energy harvesting for air-flow rate sensing

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***Abstract*—This paper presents a hybrid-powered wireless sensor node using enhanced triboelectric nanogenerator (TENG) as both energy harvester and air-flow sensor and two 11 cm2 solar panels as extra power supply. A low budget commercial RF microcontroller is included for data conversion, signal processing and wireless transmission. The method of flow-rate detection depends on the vibration frequency of the film inside the triboelectric generator. Experiment results show that this flow sensor is capable of detecting flow rate from 7.6 m/s to 17.1 m/s, with a standard deviation of 3.4, 3s setup time and 30s charge time. With a Raspberry Pi, the wireless signal can be received and delivered to Internet and therefore, can be monitored easily from any portable terminal with internet-access.**

Keywords*—*flow sensor, hybrid-powered, energy harvester, WSN

I. INTRODUCTION

Wireless sensor networks have a variety of application in environment surveillance and monitoring. However, most sensor node relies solely on batteries as power supply. This requires periodical replacement of battery which is neither economic efficient nor practical in cases where sensor is difficult to reach/track/locate. If it is impossible to replenish energy levels in the sensor nodes, the initial energy levels in the sensor nodes and ongoing energy consumption rates directly affect the operational lifetime and the data transmission capacity of the sensor network [1]. This fundamental limitation drives the research of energy autonomous wireless sensor node.

Recently, more and more researchers are looking for energy harvesting technologies to replace or provide supplementary power to the traditional batteries. Piezoelectric [2-4], electromagnetic [5-6] and electrostatic methods [7-10] were developed to harvest energy from vibration sources. In this paper, we provide a wireless sensor node powered by hybrid energy sources from both triboelectric nanogenerator and solar cell. Studies of how TENG harvests energy have been conducted in [11-14]. As shown in Fig.1, a soft film driven by wind periodically contacts the top/bottom layer. These layers and the soft film are fabricated with special material so that when they contact, the surface potential

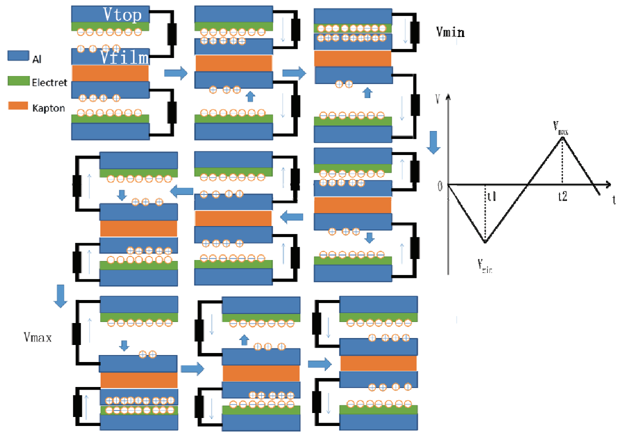

Fig. 1 Principle of TENG devices.

changes due to triboelectric effect. As a result, the voltage across the top/bottom layer and film serves as a voltage source.

Figure 1 illustrates the voltage V between the top layer and film. $V = V_{top} - V_{film}$. V_{min} corresponding to the moment (t1) when film reaches the top layer. Similarly, V reaches maximum (Vmax) when film contacts the bottom layer. Therefore, the vibration period of this film can be measured from the time period between two voltage peaks. Furthermore, vibration of film is due to vortex shedding effect. The relationship between film vibration frequency and flow-rate is well explained and examined in [11]. As a result, this device successfully bridges the connection between air-flow rate and measurable electrical signal.

II. METHOD

A. General structure

The circuit of the sensor node is shown in Fig. 2a, which is similar to our previous work shown in [15]. It can be divided into three parts: TENG and solar panels, power management circuit and micro controller. TENG is used as a power supply as well as a flow sensor to convert the air-flow rate to an electric sensing signal. Two 33 × 33 mm^2 solar panels are added as extra energy supply. Both TENG and solar panels are

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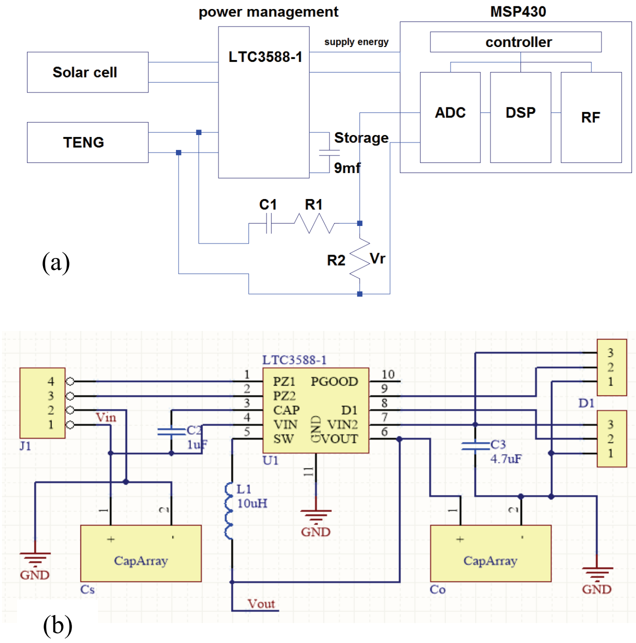

Fig. 2 a) wireless sensor node circuit. b) power management circuit.

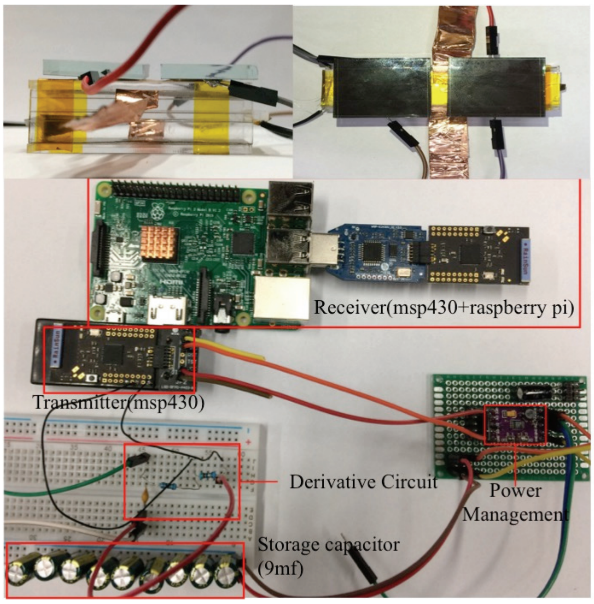

Fig. 3 (a) TENG with two solar panels with side view on the left and top view on the right. (b) Derivative circuit, MSP430, power management circuit and raspberry pi.

connected to the power management circuit and charge a capacitor (9mF) for energy storage. As shown in Fig. 2b, the power management circuit contains an energy harvesting controller LTC3588-1 and two capacitors Cs and Co. Cs is the capacitor to store energy, Co is connected to the ground and used for stabling the output voltage. Temperature data is directly delivered to RF module after data conversion while vibration signal requires more work.

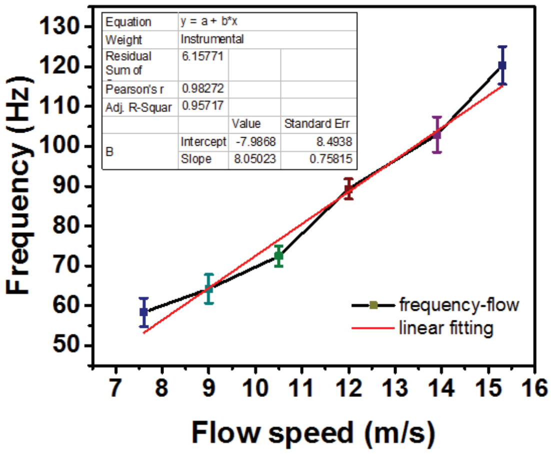

Fig. 4 Flow rate vs frequency.

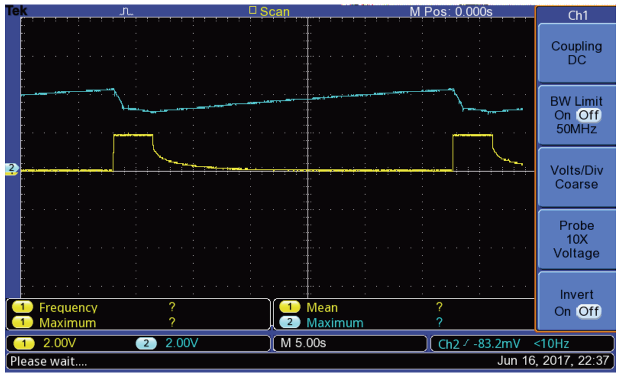

Fig. 5 Setup time and charge time. The blue line correspond to the energy storage capacitor voltage, the yellow line is the MCU input power supply voltage.

B. Vibration Frequency Analysis

To better reveal the vibration frequency, a derivative circuit with capacitor and resistor connected in series is added. A capacitor and two resistors are connected in series. The voltage across resistors corresponds to the derivative of the open circuit voltage. Resistor R2 serves as a voltage divider, which constrains the voltage range to meet the requirement of data conversion. Fast Fourier Transform (FFT) and a linear sorting algorithm is implemented to generate the frequency spectrum of the film vibration and return the frequency with the maximum amplitude to the RF module, which is then transmitted to the receiver and upload to Internet by Raspberry Pi.

III. Experiment Result

In the practical experiments, two solar panels are packaged with the TENG, as shown in Fig.3a, are placed on a linear guide rail which can control the flow speed by moving the slider from a blowing machine.

A. Flow rate

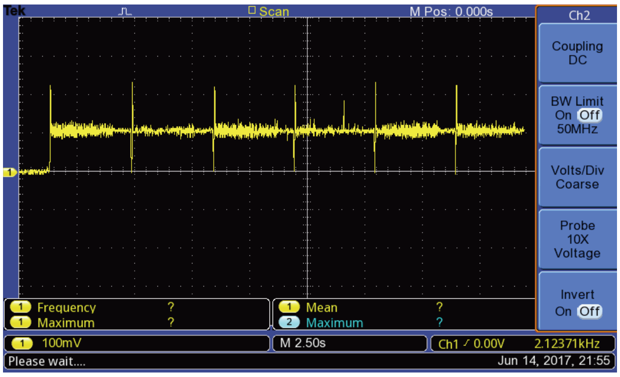

Fig. 6 Power consumption measurement. A 10-ohm resistor is connected in series with the sensor node in order to calculate the current.

Figure 4 presents the result of the frequency analysis method. The vibration frequency increases linearly with the flow rate with standard deviation of 3.4. Due to the memory size of CC430, the sampling size is chosen to be 256, and the sampling frequency is also set to be 256 Hz. This in return limits the maximum detectable frequency to 128 Hz.

B. Setup Time and Charge time

Due to the fact that frequency-analysis approach takes significantly long time (1s) for data sampling and Fourier Transform (2s), a large capacitor is required in order to meet the setup time requirement, which again further increase the amount of time for charging. As demonstrated in Fig. 5, once the voltage of the energy storage capacitor reaches the threshold (4.3V) (blue line), the power management chip will release energy to the MCU (yellow line). The MSP430 reads the data of the chip's internal temperature sensor and the voltage signal across the flow sensor. It takes 30 seconds for the hybrid energy harvester to charge the storage capacitor from indoor light. Better illumination condition will significantly reduce the charge time.

C. Energy Consumption

It is not easy to directly measure the input current. So we connect a 10-ohm resistor in series with the sensor node, and measure its voltage instead. We replace the solar panel and TENG with a DC power supply. The voltage across the resistor is shown in Fig.6 in order to calculate the current. The minimum working condition is 10 mA at 1.9 V, each operation consumes 60 mJ.

IV. Conclusion

Wireless sensor node has been widely used in various domain. In order to catchup with the increase demand in long lifetime working device, we propose an hybrid energy harvesting based flow-rate and temperature sensor. Combined with two 11 cm^2 solar panels and wind energy, the flow-rate and temperature detection can be self-powered during daytime. For low illumination use case, such as during the night or at the rainy weather condition, it can still maintain the temperature monitoring function exclusively powered by wind.

In this paper we 1) establish quantitative relationship between air-flow rate and vibration frequency, 2) implement vibration frequency analysis approach for wind speed detection using a flow-driven triboelectric nanogenerator, 3) quantify the power consumption, setup time and precision, and 4) demonstrate a daily use case of this wireless sensor node for flow-rate monitoring. This frequency analysis approach consumes 60 mJ for each operation, requires 3 seconds to setup and can operate twice per minutes.

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