Event Driven Time-logging System based on Continuous Operation of Real Time Clock towards Perpetual Electronics

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Abstract. This paper presents a novel time logging system using a real time clock (RTC) powered by a vibrational energy harvester to record the time of events when piezoelectric PVDF film as an event-driven sensor is activated. The power-management circuit normally remains in the sleep mode to cut power supply to the micro-processor and the ferroelectric random access memory. On the other hand, the RTC alone is powered by a battery to keep the time by seamless operation, which lowers the standby power consumption as small as 231 nW. As the PVDF film generates power, the developed power management circuit can supply load current upwards of 8 mA at 3.3 V, for external circuit to record the time of events with the energy consumption of 467 µJ.

1. Introduction
The distributed sensor network has been attracted increasing attention to monitor a variety of things by using wireless sensor modules before they cause fatal accidents that put humans in danger, for example, corruption of tunnels, sudden death of infants, and terrorism by explosive substances. They would retrieve tremendous amount of data from all over the place, and the data will be stored in cloud servers uploaded by local area networks (Wi-Fi) or the fifth generation of cellular mobile communications (5G). Although it is important to know the conditions of monitoring objects by the detection of the change of the physical values using such data collection, the time of event is one of the keys to correlate collected data with time stamp information for the subsequent big data analysis, and the timers should be installed in every wireless sensor modules to obtain precise time and data.

To date, there are three types of time acquisition system namely, an atomic clock, a global positioning system (GPS) signal, and RTC. The atomic clock and the GPS signal are highly accurate because they employ electron transition frequency that is constant value as long as external noise does not influence on the atoms. These timing devices are, thus, used for applications which requires high precision of the time, for example global navigation satellite systems. They, however, consume power as high as a few mW to obtain the time, and they are incompatible to wireless sensor modules such that they are operated by energy harvesters with small outputs, or small batteries.

On the other hand, the power consumption of the RTC is as small as a few hundreds of nW. Such a small power consumption enables us to operate it with the outputs power from energy harvesters alone. The precision of time is lower than the atomic clocks and GPS signals, however the time error of the RTC is still as small as 1 s in 6 years, which is sufficient for certain applications, for example, a
tracking service, agriculture monitoring, and suspicious person monitoring. Moreover, the RTC is
developed by conventional CMOS process, and thus, monolithic RTC without battery is feasible to
obtain perpetual time stamp by the integration of the RTC and energy harvesters developed by a
microelectromechanical systems (MEMS) process. In this paper, we report on an circuit architecture to
imprint the time stamp of an RTC into the memory by using a vibrational energy harvester as an event
driven switch.

2. Event-driven Circuit
The RTC timer IC needs to be continuously operated to keep correct time, and hence it is operated by
an energy harvester in the wireless sensor module, as shown in Figure 1. Typical power consumption
of an RTC today is 120 nW, and therefore it could be operated by an energy harvester alone [1]. The
time stamp information is transferred to a ferroelectric random-access memory (FRAM) when the
module is awakened by an energy harvester switch (EHS), which is an alternative operation mode of
an energy harvester.

Figure 2 shows a flowchart of operation. The whole system normally remains in a sleep mode to
save power except the RTC that continuously keeps time [2]. When the circuit is triggered by the EHS
(a piezoelectric polymer PVDF switch), the microcomputer starts the inter-integrated circuit (I2C)
communication to read the time from the RTC and to write the time-date information into the FRAM.
After this cycle, the microcomputer sends a reset signal to the MOSFET to bring itself back to the
sleep mode again.

![Figure 1 Diagram of the wireless sensor module in this work. The timer is powered by the energy
harvester for seamless time logging system.](image1)

![Figure 2 Flowchart of the proposed time-logging system. (Left) Event driven circuit triggered by the energy
harvester switch. (Right) Time-Data logging sequence.](image2)
3. Circuit Characterization

Figure 3 shows the electrical circuit of the event driven mechanism, and Figure 4 shows the voltage waveforms during one cycle of the event driven operation measured at the power supply, the EHS trigger output, the load resistance (1 MΩ), the reset voltage, and the clock signal for the I2C. The circuit is observed to awake by the trigger signal from the EHS and to supply the voltage to the load resistance. The operation cycle is finished by the reset signal RST that stops the power supply.

![Event driven circuit](image)

Figure 3 Event driven circuit to operate a sensor module. Voltages are measured at (a) capacitor, (b) event driven switch, (c) sensor module, (d) RST, respectively, and (e) SCL signal between microcomputer, FRAM and RTC.

![Voltage waveforms](image)

Figure 4 Voltage waveforms observed in one cycle of event driven operation.
The event driven circuit is assembled with a microcomputer, an FRAM, and an RTC as shown in Figure 5 to verify the full-scale operation. Figure 6 monitors the voltage waveforms during one cycle. As designed, the microcomputer starts the I2C communication to read and write the data of time after triggered by the EHS. The entire routine takes 100 ms, including 70 ms before stabilizing the internal clock of the microcomputer. The energy consumption is 470 µJ for one cycle.

Figure 7 shows the signal of data (SDA) and the signal of clock (SCL) in the I2C, both of which are successfully transmitted to the FRAM and to the RTC. The time-data recorded in the FRAM is confirmed by using a PC program as shown in Figure 8.

![Figure 5](image.png)

**Figure 5** Photograph of the sensor module composed of microcomputer, FRAM, and RTC, and its system block diagram.

![Figure 6](image.png)

**Figure 6** Waveforms observed during the event-driven operation for the time-data recording.
Figure 7 Signals of SDA (data, blue) and SCL (clock, red) for I2C communication to log time data in FRAM.

Figure 8 Time data retrieved from the FRAM after event driven operation recorded on 2018, July, 5th, Thursday, at 5PM, 15 minutes, 15 seconds

4. Conclusions
In conclusion, we have developed a perpetual time recording system using the FRAM and the RTC activated by an EHS. This system can be used in an IoT wireless sensor node located at a place where the GPS signal is not available.

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References
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