MEMS based Transducer for Zero-Energy Standby Application

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***Abstract*—The advent of IoT (Internet of Things) is tremendously pushing the development of wireless Sensor network (WSN). This is a quite promising technology that enables endless different applications, for sensing and monitoring of several kinds of infrastructures as in the context of industry 4.0. The most attractive characteristic of a WSN is that it is very easy to install by simply using battery-driven and in rare cases battery-free wireless sensor nodes. Moreover the equipment is rather low cost and the main saving is that the heavy installation work for wiring the power rails is not needed and this provides a further advantage in freedom and versatility for the optimum placement of the sensor nodes. Nevertheless, the main problem of WSN is still how to power the nodes in a cost effective way, especially when those are battery-driven since the maintenance cost to replace or recharge the batteries may be high. One of the possible solutions is to increase battery life by reducing unnecessary energy consumption as much as possible. In many applications standby energy consumption is unnecessary and in this paper we aim to show how to null it by using a kinetic-to-electrical energy transduction based on MEMS technology for all use cases involving vibrations. It will be shown how a MEMS device, used as energy transducer, can provide enough energy to turn on a completely off device.**

***Index Terms*—IoT, WSN, Wireless Sensor Networks, MEMS, Zero Energy, standby, power management, Lithium Ion Battery, Wireless Sensor Networks, Internet of Things**

I. Introduction

Novel achievements in all fields of measurement and instrumentation science and technology have been accounted including several fields as well as of engineering [1], medical and health care [2], [3], archaeology [4] and also industry [5]. In particular focusing the attention on this latter field and IoT architectures, it should be noted that in IoT-related devices battery life must be maximized since it poses a real problem in node maintenance a task often very costly and difficult to perform, and at times even impossible because sensor nodes are often positioned in inaccessible places. To help render IoT truly ubiquitous, a sensor technology is needed to enable the deployment of a large number of wireless, easy maintenance and inexpensive sensing devices that can be used almost anywhere [6]. Several different strategies depending on the kind of system are possible, to alleviate maintenance issues in IoT and WSN: some systems, such as those implementing real time sensors, may require batteries; other systems, such as low duty cycle sensors and measurement architectures, may be able to function appropriately without batteries [7], [8], [9], [10], [11], [12]. A significant reduction in maintenance can be achieved by reducing or eliminating standby power consumption [13]–[16]. During standby, power management circuits are permanently on in standby, and depending on the duty cycle, can consume unnecessarily high percentages of battery charge [17]. Nulling standby is a significant energy saving which can be translated into prolonged battery life or a reduction in battery size, which is beneficial in terms of cost and system miniaturization [14]. The interest to implement MEMS based transducer regards the possibility to realize miniaturized devices and very small power consumption which are very low cost in a large scale production. It is worth to mention that this kind of devices can be easily integrated and, as a consequence, small and compact measurement systems can be achieved. In particular in this paper we mean to address the idea to realize a small scale zero standby solution based on a suitable integrated transducer realized in PiezoMUMPs [18], [19], able to generate power in the order of few nW. Those transducers coupled with a specifically designed silicon integrated circuit will generate enough energy to turn on a completely off device.

II. Working Principle

The basic idea is to turn on a completely off device by using the energy provided by a MEMS energy transducer. It should be noted that device is intended to toggle from the off to the on state and that standby is no longer considered. The main advantage to use MEMS compared to other existing technologies such as PZT is the higher reliability, the maturity and the wide diffusion of this technology that inherently leads to low cost solutions. Moreover a MEMS can be eventually reused as sensor in the application when the system is on. Thus, the aim is to use the MEMS device both as energy transducer to turn on the application and as a sensor while the system is active. This clearly poses some challenges to face such as a MEMS device is normally used as a sensor rather than as an energy transducer due to its tiny (in the order of few nW) available electrical power and the very low open circuit voltage, as low as 100 mV, provided by those devices. Those challenges pose design issues to be solved both in the design of the MEMS which must specifically designed in order to be energy efficient as transducer and with an open circuit voltage high enough to be able to trigger the system to turn on. The PiezoMUMPs [18] technology has been used to realize the MEMS device, Fig. 1 shows some details of the process, Fig. 2 shows the layout of the MEMS and the implementation of the transducer prototype.

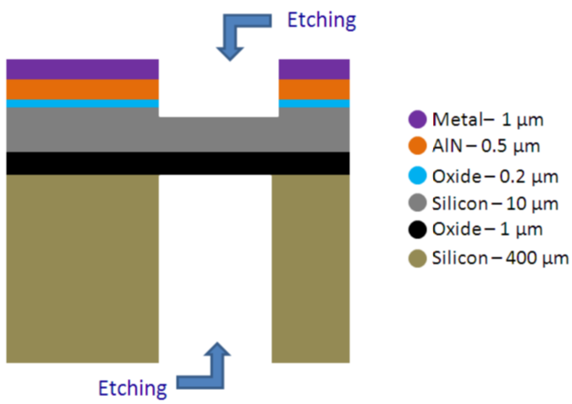

Fig. 1. PiezoMUMPs process details

III. System description

Fig. 3, represents a battery driven system such as a WSN which is composed by three main sections, the vibration-based transducer, a power management, and the final load that in a typical application, consists of sensors, micro controller units, and generic transceivers (i.e., Bluetooth, RF, Wi-Fi, etc.).

The vibration-based transducer for Zero-Energy standby applications is composed of two sections: a MEMS device that works as a mechanical to electrical energy transducer able to convert external vibrations (such as shocks and induced movements) into electrical energy and a logic architecture able to efficiently manage power and convert the level shift the low voltage output of the MEMS device. The idea is to supply the power requested by the electronic equipment only when the appliance must be turned on by inducing kinetic energy through an induced movement. It consists of a MEMS energy transducer which converts kinetic movement to an electric signal, V(mems), with enough energy to enable the power path between the battery source V(vcc) and the output V(vout) of the power management block. This supplies a regulated voltage to the loading section. The logic section of the power management block does not have any static power consumption, as long as the enable signal is low, the only current flowing through the battery is the negligible leakage (few pA) of the equipment. This block also ensures that the enabling signal of the voltage regulator can stay on even when the kinetic energy has faded out. Since the output voltage of a

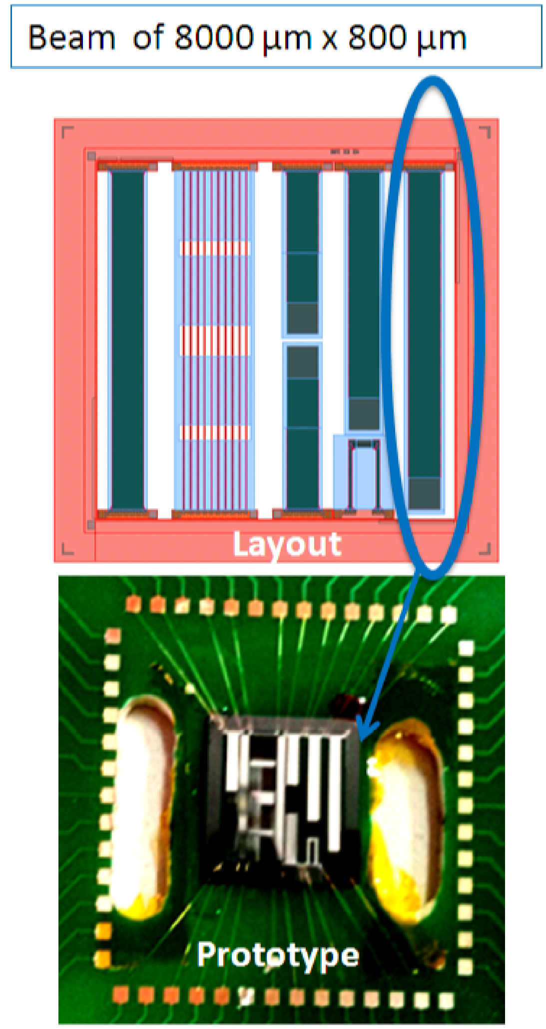

Fig. 2. PiezoMUMPs Layout and Prototype

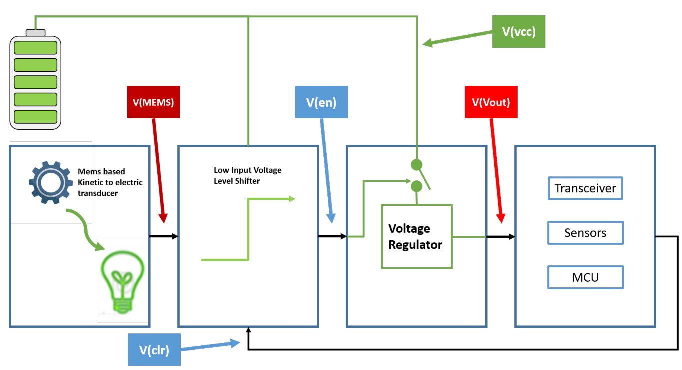

Fig. 3. System Block Diagram

MEMS is very low, as low as 100 mV, it want be able as it is to enable the voltage regulator which normally requires a voltage as high as 'vcc' to be turned on. For this reason a special level shifter is needed to interface the MEMS based transducer with the enable digital input of the voltage regulator.

The main purpose of the level shifter is to convert the small voltage provided by the MEMS device when moved by a mechanical force into a suitable logic level to enable the power management to bias the sensor node. In order to null standby power consumption is fundamental that the circuit does not consume any power when the system is off. With reference to the Fig. 4

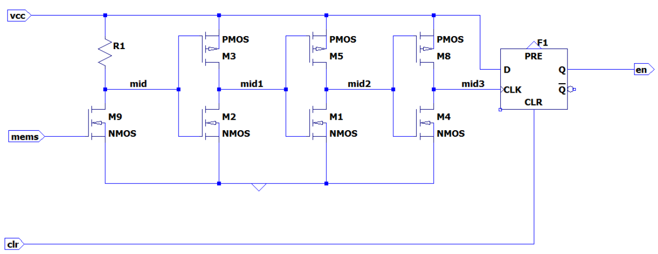

Fig. 4. Level Shifter

a visual inspection of the circuit shows that if the voltage ’v(mems)’ is zero, the transistor M9 is off and even considering the leakage current the voltage v(mid) will be high and equal to the voltage ’vcc’ so that the inverter with transistors M2 and M3 is in a digital stable state with ’v(mid1)’ set to zero and no current flowing through the transistors M2 and M3. The rest of the circuitry is digital and thus does not consume any power as shown in Fig. 5.

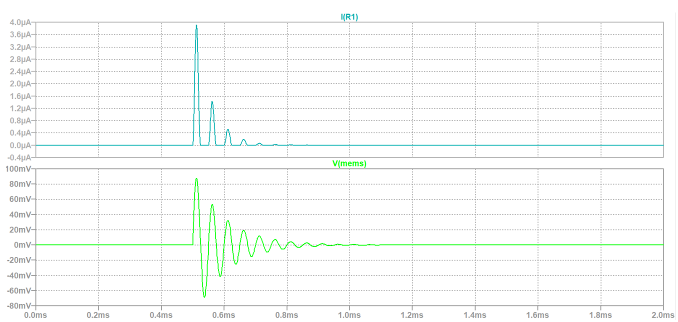

Fig. 5. Current Consumption in Standby and Active State

as shown in Fig. 6 the final flip-flop stays in its reset status that is low so that the enable signal ’en’ is low and the power management is off as well as the rest of the system which is not consuming any power.

In order to show how to turn on the system from its off state by means of an induced movement with reference to the Fig. 7 once a movement has been induced to the system, the MEMS device provides the signal ’v(mems)’ that is also the input at the gate of the transistor M9, which while working in sub threshold, allows a tiny current that flowing through the impedance of the resistor R1 is able to pull down the voltage v(mid). The Following inverters will add gain to the signal v(mid) so that the signal v(mid3) will have sharp edges to latch the signal en through the D type flip-flop F1.

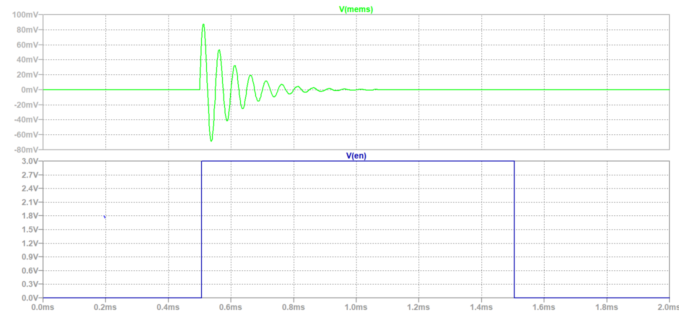

Fig. 6. Enable Signal

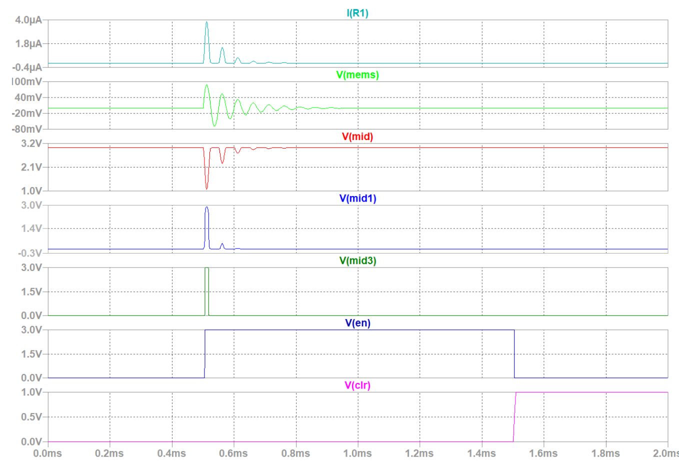

Fig. 7. Turn-on Sequence

It can be noted that before the system has not been moved v(mems)=0, the current through the resistor R1 is zero, then after 500 us the system is moved and v(mems) has a peak voltage not higher than 100 mV that allows a tiny current to flow through the large resistor R1, providing a voltage drop in v(mid) of 2 V which brings v(mid) down to 1 V, being the circuitry biased at 3 V. Since the voltage threshold of the M3 and M2 transistor inverter is higher than 2 V the signal v(mid) gets inverted in the signal v(mid1). The two following inverters will buffer the signal v(mid1) finally providing the signal ’v(mid3)’ that is used to latch the high voltage at the output ’Q’ of the d-type flip-flop, so that the signal ’v(en)’ goes high. It can be noticed that since now on, even if the system is not moved any longer it will stay enabled as long as it is needed. It can be eventually turned off by providing the signal v(clr) high in order to reset the flip-flop and reset the signal v(en) to zero which will bring back the system to off with no current consumption.

Conclusion

This paper introduced a novel measurement system, based on a MEMS based piezoelectric transducer for Zero-Current Standby applications. In particular we investigate the possibility of fusing an integrated device of (i.e. about 8000 um x 800 um) to activate a suitable microelectronic circuit. The architecture here proposed shows with simulations how to null standby power consumption by using a kinetic-to-electrical energy transduction based on MEMS technology for all use cases involving vibrations. It is worth noting that the MEMS device, used as energy transducer, can provide enough energy to turn on a completely off device and can be also used as motion sensor during the active phase of the circuit. The work is in progress with an experimental validation and a metrological characterization of the transducer.

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