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Low Power RF Transceiver using Piezoelectric Vibration Energy Harvesting Technique for Wireless Sensor Node

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Abstract

In a wireless sensor network the sensor nodes are placed at remote location and they operate on batteries .The major issue in wireless sensor network is the power consumption of the sensor node. Even though the sensor nodes operate on batteries, the batteries are to be changed after specific time interval. The battery replacement is not a viable solution as it is costly and time consuming .So some alternative method for battery replacement is to be used .The ambient energy can be used to power up the sensor node. The technique of converting ambient energy into electrical energy is called energy harvesting .In this paper the piezoelectric vibration energy is used as energy harvesting technique. The technique generates electrical energy which is used in place of batteries for wireless sensor node. The hardware of the system consists of RF transceiver CC2500, microcontroller MSP 430, piezoelectric crystal and other components. Batteries are not required for the system. The system is maintenance free and coves a distance upto 300 ft. The current consumption is from few microampere to 20 mA from wakeup to transmission.

Keywords*:* RF Transceiver; Energy harvesting; piezo electric effect.

INTRODUCTION

Energy harvesting is a technique used to convert the ambient energy present in the environment into electrical energy. This technique has the capability to act as an independent power supply for wireless microsystems, as an alternative to use batteries. The wireless sensor nodes are using batteries and operates at extremely economical energy budget. Since battery replacement is not a viable solution, these low power wireless sensor nodes need an alternative type of power source instead of traditional batteries. Renewable power can be obtained by generating electrical energy from the environment. Thus extracting power from the ambient sources is called energy harvesting or energy scavenging [4]. The available energy sources for harvesting are light, wind, motion, RF electromagnetic radiations .In this paper a nonlinear vibration energy harvester is used to power a low power wireless RF transceiver device. This RF transceiver is powering itself or self-powered and no batteries are required. It is able to transmit the data at few meters distance such as temperature and operated in 2.4 GHz ISM band. The rest of the paper includes details of vibrational energy harvester, the hardware part of the system and the system evaluation.

ENERGY HARVESTING

As a part of energy harvesting the solar and wind energy have been widely used to provide electrical energy during the last decade. The power consumption of sensor node has been significantly reduced due to recent advancement in low power electronics. Hence ambient harvesting energy may provide a long term solution and reduce the dependency on batteries [2]. The fig 1. shows energy harvesting as alternative for micro powering. The figure consists of energy harvesting generator, temporary storage system and an electronic device which is being charged up. The energy harvester generator can be piezoelectric, electrodynamic, photovoltaic or thermostatic. The temporary storage system can be ultra-capacitor or rechargeable batteries. This stored power is then given to any electronic device like low power devices, wireless sensors, MEMS actuators or any consumer electronic device.

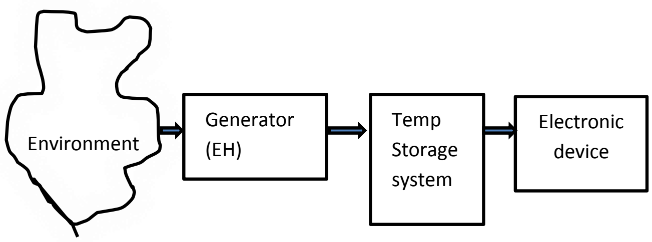

Figure 1: Energy harvesting as alternative for micro powering

Energy harvesting from vibrations and movement has recently become promising for powering sensor nodes .Kinetic energy in the form of small scale vibrations is a common form of energy freely available in the different environment. So here the main focus is on converting kinetic energy into electrical energy. The fig.2 shows the details of vibration energy harvesting. It consists of vibration energy harvester, circuit regulator and storage, and wireless sensor device. The vibration energy harvester can be electromagnetic, electrostatic/capacitive, piezoelectric, and magnetostrictive. We are using piezoelectric device to generate electrical energy. There are two types of piezoelectric devices: Direct force and inertial force devices. Inertial generators are more flexible than direct force devices because they require only one point of attachment to a moving structure allowing a greater degree of miniaturization. A double layered piezoelectric cantilever is used for conversion using a piezoelectric technique.[3] The dimensions are 38 X 16 X 0.8 mm and the layer is made up of PZT material.(Lead Zirconate Titanate) This is most commonly used ceramic today. The two layers are connected in parallel to obtain higher current and low internal equivalent impedance.

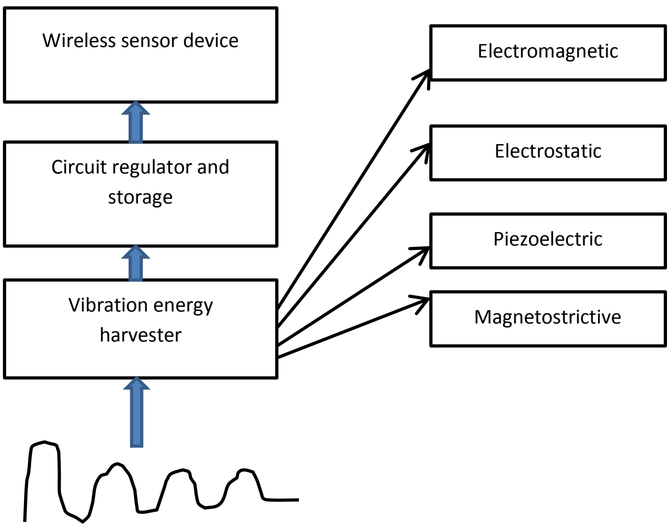

Figure 2: Vibration energy harvesting

The mode used for working is nonlinear bistable mode .The real vibrations obtained are not monotonal but they are widely distributed over the range of tens, hundreds or thousands of hertz. When a mechanical stress is applied to piezoelectric material, it generates an electric charge. This property makes a piezoelectric material suitable for energy harvesting.

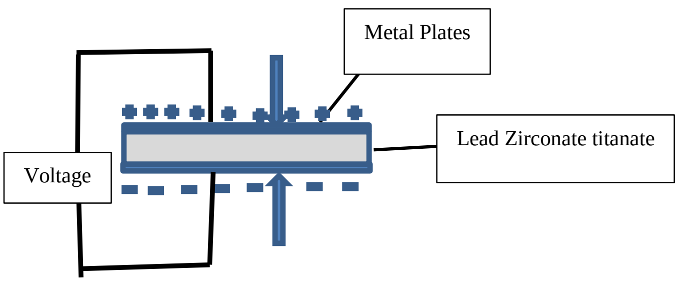

Figure 3: Compressing produces energy

The relation between mechanical and electrical variable associated with piezoelectric material can be described as follows

$$Si = S_{ij}^{E}\, T_j + d_{mi}\, E_m \qquad \text{----------------------- [1]}$$

$$D_m = d_{mi}\, T_i + \epsilon_{mk}^{T} \qquad \text{----------------------[2]}$$

This can be written as

$$\begin{matrix} S \\ D \end{matrix} == \begin{bmatrix} s^E & d_t \\ d & \epsilon^T \end{bmatrix} \begin{matrix} T \\ E \end{matrix} \qquad \text{--------------------------------[3]}$$

Where

S= mechanical strain E= electric field D= charge density

s= mechanical compliance T = mechanical stress

d= piezoelectric strain constant ∈ = permittivity

i j m k = direction of stress, strain or electric field.

Eq.2 describes the electric field that is induced by piezoelectric material in response to applied mechanical stress.[16]

Depending upon applications different types of piezoelectric generators (PEG) can be used for energy harvesting. Eg: stack, bimorph, membrane or spiral rotational springs. Each has specific advantages and design limits. LTC3588-1[15] is used which is nano power energy harvesting power supply. It is shown in fig.4. It consists of full wave bridge rectifier with high efficiency buck converter to form a complete energy harvesting solution optimized for high output impedance energy sources like piezoelectric, solar or magnetic transducers. An UV quiescent current under voltage mode allows charge to accumulate on an input capacitor until buck convertor can efficiently transfer a portion of stored charge to output. The buck converter turns on and off to maintain the regulation

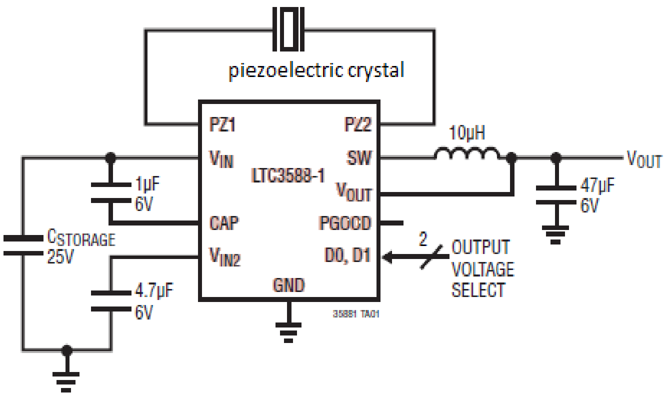

Figure 4: Technique for harvesting energy

The IC has two pins D0 and D1 which can be set high and low for required output voltage. Table 1 shows the selection of D0 and D1.

Table 1: Output voltage selection

D0	D1	Vout (V)	Current (nA)
0	0	1.8	44
0	1	2.5	62
1	0	3.3	81
1	1	3.6	89

The advantages of Variable Energy Harvesting (VEH) are long lasting operability, cost saving, no chemical disposal, safety, maintenance free, no charging point, flexibility. The technical limits of VEH are Narrow bandwidth, small inertial mass, low output voltage, limited power density miniaturization issues, versatility and adaptation to variable vibration sources.

System Hardware

The hardware is designed using only off the shelf components. The complete block diagram is shown in the fig 5. The MSP430 family of TI is ultra-low power microcontroller consisting of different sets of peripherals targeted for various applications.[7] The microcontroller is 16 bit RISC CPU, having 16 bit register When the power is obtained the microcontroller is turned ON. The task is to measure the supply voltage and control RF transceiver to prepare them for transmission and reception of the data. The CC2500 is a low cost 2.4GHz transceiver designed for very low power wireless applications. It uses a 2.4GHz ISM band and SDR (Short range device) frequency band.

The following table gives power densities of energy harvesting technologies

Table 2: Power densities of energy harvesting technologies

Sr No	Source	Power density (microwatt/cu.cm)	Information source
1	Solar	15000(direct sun)	Commonly available
2	Solar (indoor)	6 – office desk	experiments
3	Vibration	100-200	Roundy et.al
4	Daily temp variation	330	Theory
5	Acoustic noise	0.003 at 75 db	Theory

CC2500 is having configurable base band modem.[6]

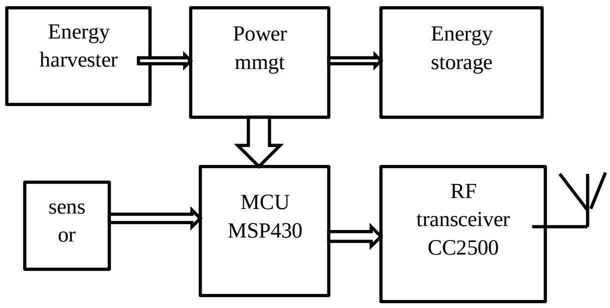

Figure 5: Block diagram of the system

The modem supports OOK, 2FSK, GFSK and MSK modulation and has configurable data rate from 1.2 to 500 kbauds. The RF output power can be adjusted from -30dbm to +1 dbm.The microcontroller is interfaced with CC2500 as shown in fig 6.The microcontroller uses four i/o pins for the SPI configuration interface.(SI,SO,SCLK and Csn).The CC2500 has three pins (GDO0 to GDO2). These pins can be used to generate interrupts on the MCU.[9]The selection criteria for protocol depends upon country/region of operation, data rate needed for communication, battery life, range of operation. As the frequency is 2.4GHz, low bandwidth, range selected is 300 ft. The protocol used for transmission is SimpliciTI. The current requirement for the system is variable from few microamperes to 22 micro amperes from wake up to transmission.

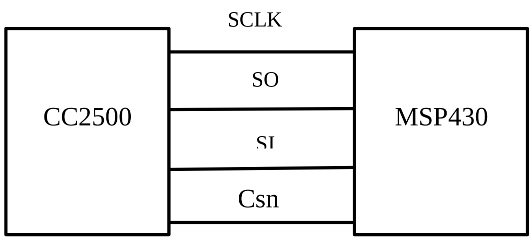

Figure 6: Interfacing of CC2500 with microcontroller MSP430

The detailed circuit diagram is shown in the fig 7 below. The circuit consists of LTC3588-1, MSP430, CC2500 and temp sensor IC LM35. The piezo electric crystal is connected to the two terminal of the LTC 3588-1 IC .The storage capacitor is 1000uF, 25 V. DO,D1 pins of IC LTC 3588-1 are set to 1,1 respectively so as to achieve 3.6 V.

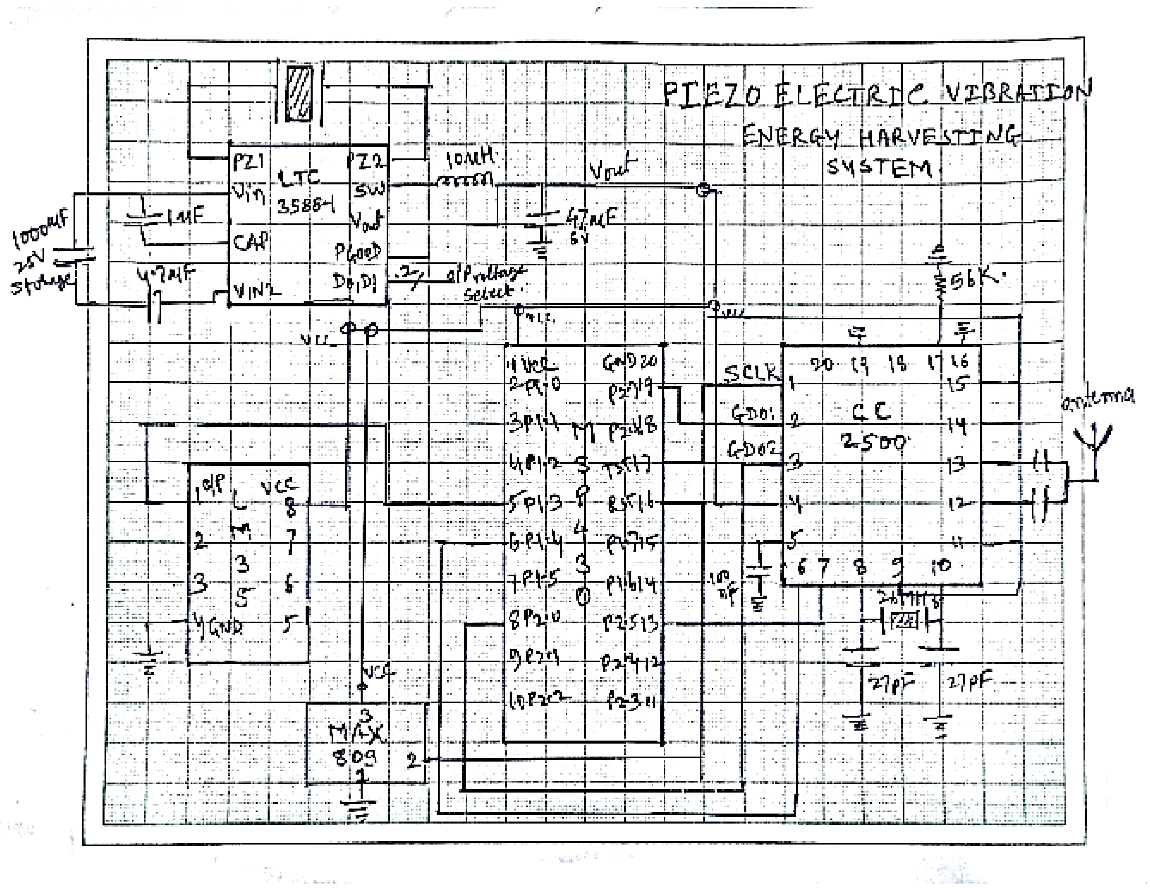

Figure7: Detailed circuit diagram of the system

The flow chart for interfacing MS P430 with CC2500 is shown in fig.8. Here first MSP 430 is to be initialized for SPI interface.CC2500 is to be power up after initializing. The RF setting of CC2500 are done. The I/O's of MSP430 are configured. CC2500 is set to receive mode. Once the data is received then the controller goes to sleep mode.

System Evaluation

The graph of output Vs Device performance is shown in the fig 9.When the device CC2500 goes in transmit and receive state the output decreases from maximum to a certain level. Also when the device goes into sleep mode the output reaches the maximum. During the power ON of the circuit the issue of slew rate of the supply voltage is faced. The slew rate of any circuit is rate of change in output voltage caused by a step change in the input. It is measured as voltage change in given time. (V/microsec).The energy produced by energy harvester is stored in high capacitor of value 1000 microfarad. The charging time for this capacitor is long as the time constant is high. Due to this the microcontroller is not able to start because the slew rate is very low.

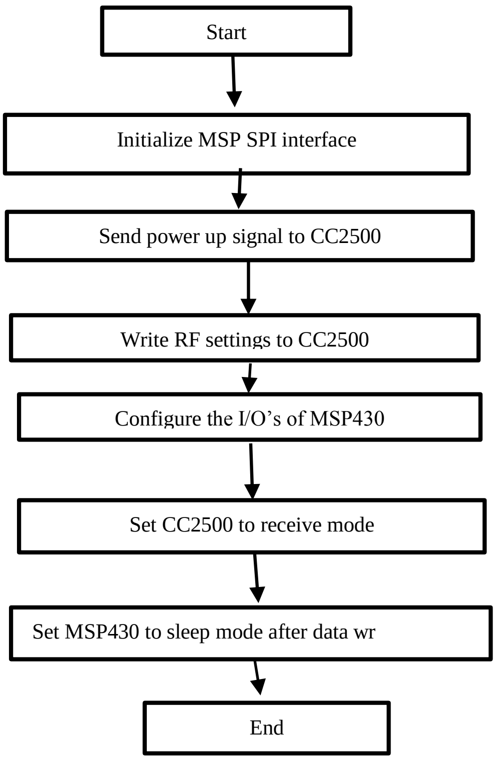

Figure 8: flow chart for interfacing CC2500 with MSP430.

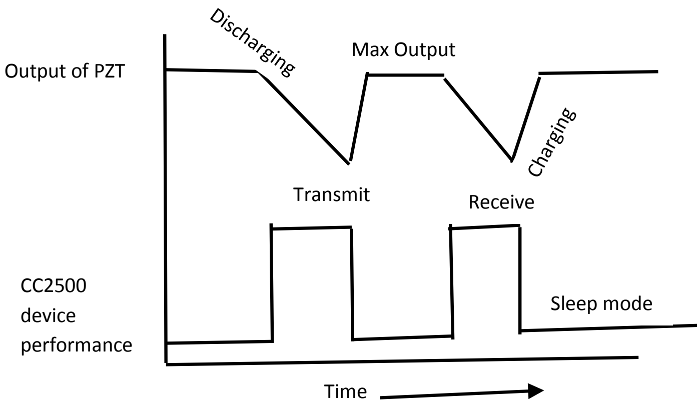

Figure 9: Output Vs Device performance

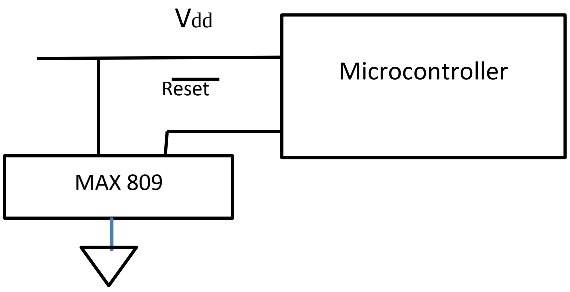

Figure 10: A three terminal supervisory IC with voltage monitoring

To overcome this issue a voltage supervisor is required to maintain the disconnection of load and to make the connection only when supply voltage is above a minimum level. Voltage supervisor circuits are used to monitor the supply voltage to microcontroller system for under voltage condition. If under voltage condition is detected then the supervisor circuit will reset the microcontroller and keep it in that state as long as the under voltage condition persists. The MAX809 IC [8] is cost effective system supervisor circuit designed to monitor Vcc and provide a reset signal to host processor when necessary. The reset output is driven within 10 sec of Vcc falling the reset voltage. It is shown in the fig 10.The system can also be provided with power conditioning circuit as the voltage output from the energy harvester is very variable. When the vibrations are very low it is in terms of tens of millivolt and may vary up to few tens of volts when the vibrations are high. The digital electronic circuit requires a constant power supply with a voltage varying from 1.8 volts to 3.6 volts.The power conditioning circuit consists of voltage rectifier for the generator, and voltage coupler and voltage regulator .The output is connected to 1000 microfarad tantalum capacitor . This is the only storage device and no batteries are required. The comparison of previous work done is shown in table 3.

Table 3: Comparison with previous work done

Sr No	Previous work	Output Power (uW)	Frequency(Hz)
1	Panthongsy 2015 [11]	82.29	50
2	Torah 2008 [12]	58	52
3	Roundy 2004[13]	375	120
4	Hameed 2015 [14]	32	
5	This work	79.2	50

CONCLUSION

In this paper an autonomous RF transceiver is designed and tested. The components used are off the shelf components. The working of the system depends only with the energy coming from piezoelectric vibrations energy harvester. The batteries are not required for the system .The use of non-linear bistable energy harvester is the main focus of increasing the power efficiency of the vibration energy harvester. Using the energy harvesting technique the system can work without any limitation and the system is maintenance free. The generated output power can be used for an application through LTC3588-1 IC. The result shows that the system is best suitable for 300 ft range with 2.4 GHz frequency and low bandwidth. The current requirement for the system is variable from few microamperes to 22 micro amps from wake up to transmission.

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