IJSTE - International Journal of Science Technology & Engineering | Volume 3 | Issue 10 | April 2017
ISSN (online): 2349-784X

Design and Development of Self-Powered Temperature Measurement and Wireless Data Transmitting System

K. Ranjithkumar
Assistant Professor
Department of Electrical & Electronics Engineering
Kongu Engineering College, Perundurai, India

Dharani.M
Department of Electrical & Electronics Engineering
Kongu Engineering College, Perundurai, India

P.Sai Krishna
Department of Electrical & Electronics Engineering
Kongu Engineering College, Perundurai, India

Abstract

In this paper, it has proposed to replace the batteries by thermoelectric generator (TEG) assembly. Usage of batteries in high or medium temperature monitoring system affects the lifetime and required frequent maintenance also. Here TEGs used instead of batteries and output voltage of TEG also measured under various temperature difference level between hot and cold junction. The generated voltage from TEGs boosted and maintained to Three Volt using TPS61200 booster converter. The combination of TEGs and Booster converter investigated under various loaded conditions to test power-delivering capacity. This boosted voltage used to provide energy to the temperature measurement, microcontroller and wireless data transfer circuit in the transmitter module. Microcontroller was programmed to read temperature and to send data at every second once through RF transmitter module.

Keywords: Thermoelectric Generator (TEG), Booster converter, Transmitter module, Thermistor

I. INTRODUCTION

The self-powered Wireless temperature monitoring system, monitors temperature from remote location. The transmitted module consist of following unit.

- Power management unit
- Sensing unit (Temperature Sensor)
- Low power Microcontroller unit
- RF Data Transceiver unit

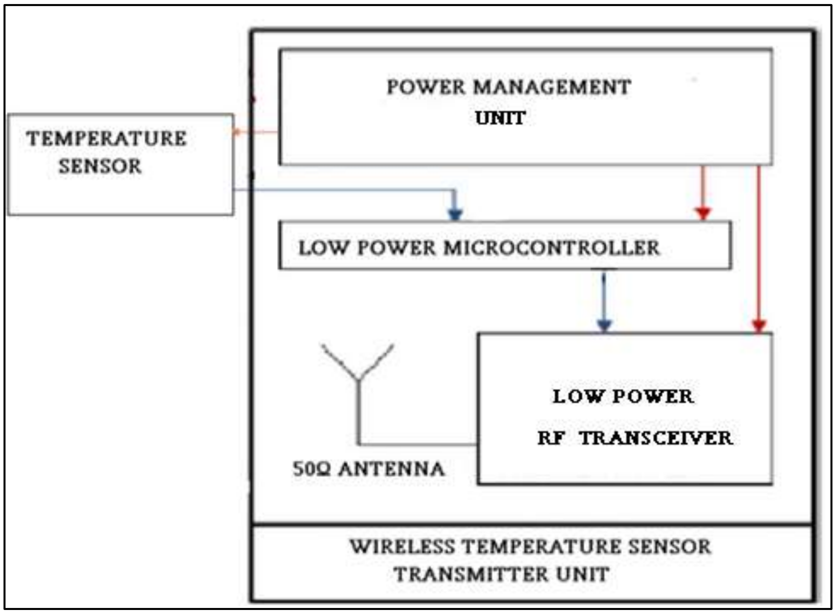

Fig. 1: This picture depicts Transmitter module block diagram

A. Power Management Unit

This unit supplies the electrical energy required for the whole transmitter module. Customarily a three-volt battery will act as power source for low power transmitter module. However, due to the following reasons TEGs supersede battery.

- Enhances performance
- Amends internal discharge or local action losses
- Reduces cell voltage for a given current
- Promotes charging current for a given voltage
- Minimizes life and required Periodic supersession

B. Sensing Unit (Temperature sensor)

This unit converts physical quantity (Temperature) into electrical quantity. Here thermistor resistance changes with deference in temperature.

C. Low Power Microcontroller Unit

MSP430F2274 microcontroller function is to interface and control all units in the transmitter module. It reads analog data from the temperature sensor and converts into digital form. This digital data send to transmitter unit. Also synchronizes all the process in transmitter unit.

D. R.F Data Transceiver unit

IC-CC2500 Used to send digital data through RF digital transmission mode. It modulates data and transmit through 50-ohm resistance antenna.

II. THERMO ELECTRIC POWER GENERATOR

A. Principles of Thermoelectric Power Generator

In a typical temperature measurement application, thermocouple A is used as a "reference" and is maintained at a relatively cool temperature of Tc. Thermocouple B is used to measure the temperature of interest (Th) which, in this example, is higher than temperature Tc. With heat applied to thermocouple B, a voltage will appear across terminals Tl and T2. This voltage (Vo), known as the Seebeck emf, can be expressed as:

$$Vo = S_{xy} \text{ x } (T_h - T_c)$$

B. Thermoelectric Generator Module

Thermoelectric generators (TEGs) are all solid-state contrivances that convert heat into electricity. It contains no moving components in it. A thermoelectric module used for power generation has certain similarities to a conventional thermocouple. Let us look at a single thermoelectric couple with an applied temperature difference as shown in Figure 2.1

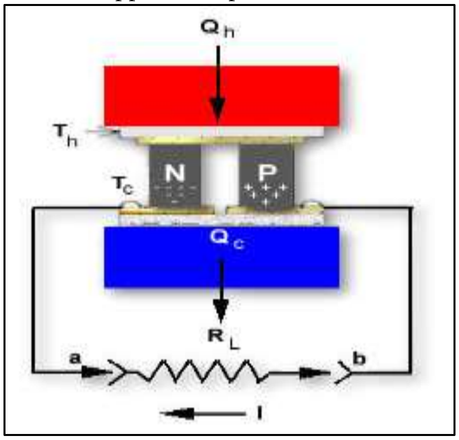

Fig. 2.1: Thermoelectric Generator

Single Thermoelectric Couple where Th > Tc with no load (RL not connected), the open circuit voltage as measured between points a and b is:

$$D_T = T_h - T_c \quad (1)$$

$$V = S \text{ x } D_T \quad (2)$$

Where,

V is the output voltage from the couple (generator) in volts.
S is the average Seebeck coefficient in volts/°K.
D_T is the temperature difference.
The power output Po from the module in watts is:

$$P_o = R_L \times I^2 \quad (3)$$

It is possible that thermoelectric generators contain a number of individual modules which may be electrically connected in series parallel arrangement. A typical generator configuration is illustrated in Figure 2.2. This generator has a N_T number of modules with N_S number of modules connected in series and N_P number of modules connected in parallel. The total number of modules in the system is [1]-[5]:

$$N_T = N_S \times N_P \quad (4)$$

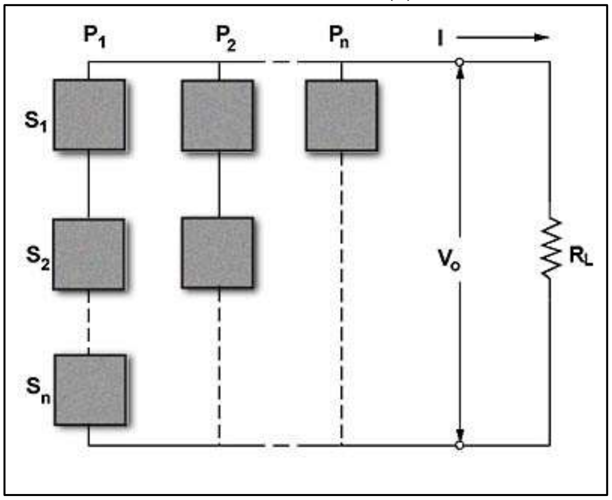

Fig. 2.2: Series-Parallel Arrangement of Thermocouples

The efficiency of the generator is:

$$E_g = \frac{P_o}{Q_h} \times 100\% \quad (5)$$

Where,
E_g is efficiency of the generator.
P_o is power output in watts
Q_h is heat input in °K

C. *Performance of Teg Under Different Loads*

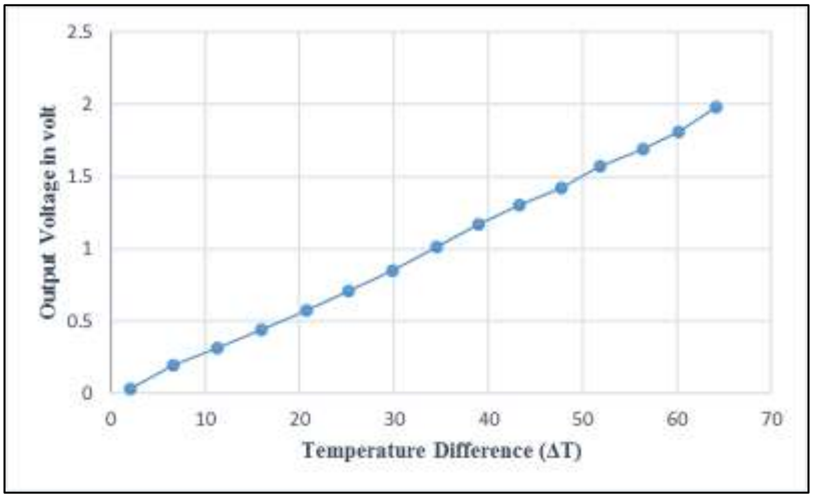

Fig. 2.3: TEG's response under no load

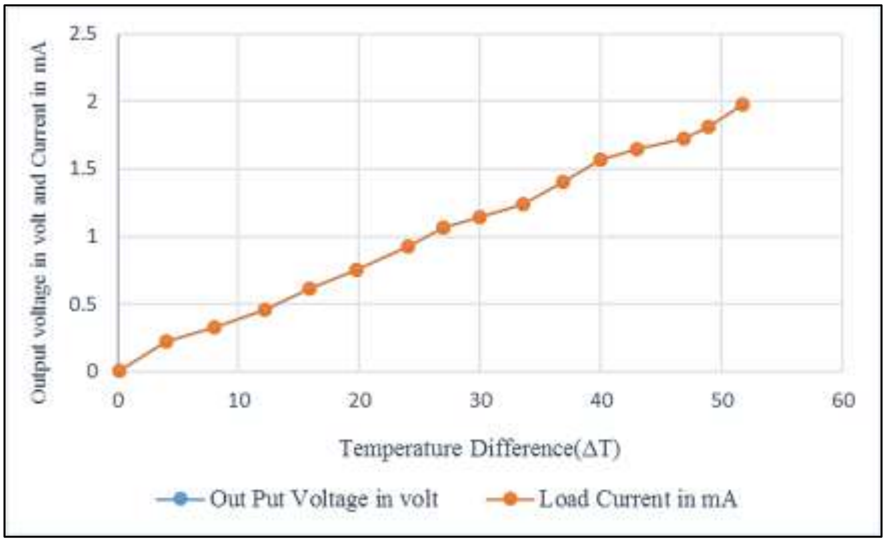

Fig. 2.4: TEG's response under 1Kohm load

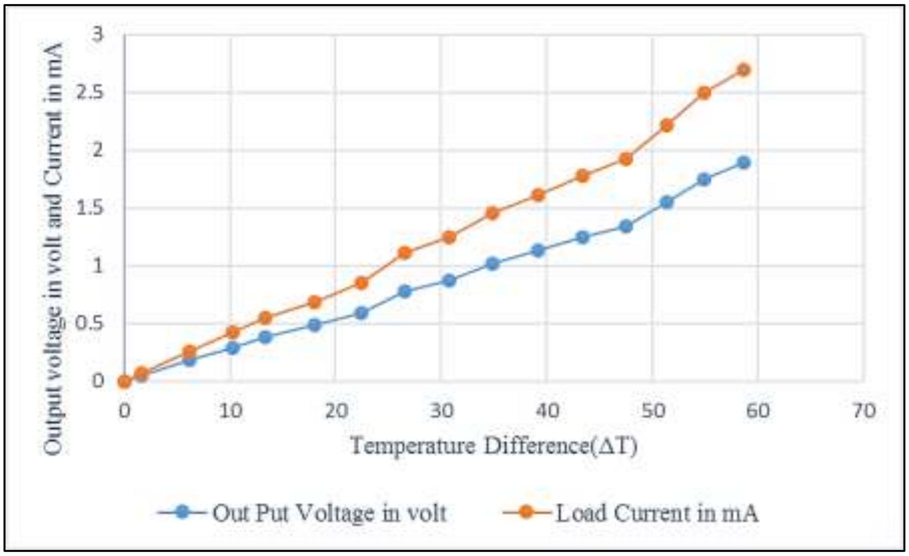

Fig. 2.5: TEG's response under 750ohm load

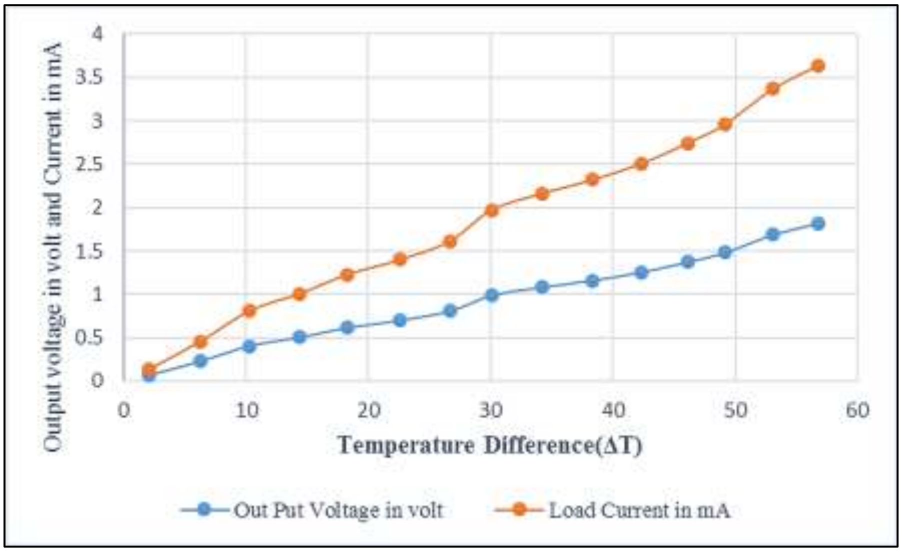

Fig. 2.6: TEG's response under 500ohm load

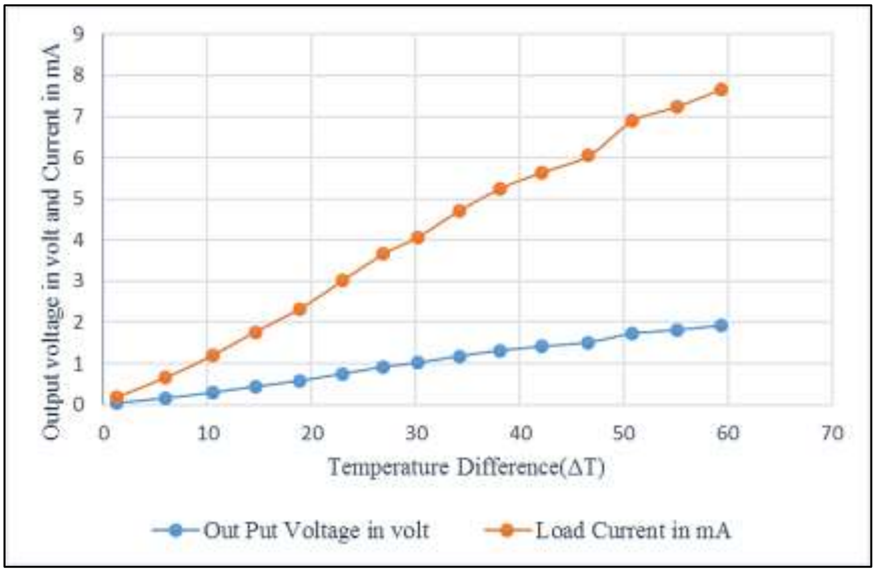

Fig. 2.7: TEG's response under 250 ohm load

D. Observation

Thermocouple connected and tested across various load conditions. It is observed that Thermocouple can deliver constant voltage to a particular temperature difference irrespective of load values. As the load resistance reduces from no load to 250 Ω resistance, the current value is getting increased. So power sourcing also increased and reached maximum value of 36mW.

III. THERMISTOR IN CIRCUIT

Thermistors are mostly Negative Temperature Coefficient (NTC) characteristics. In order to measure temperature, Thermistors are connected in voltage divider circuit as shown in figure 3.1. As the temperature increases the Vout of the divider circuit increased.

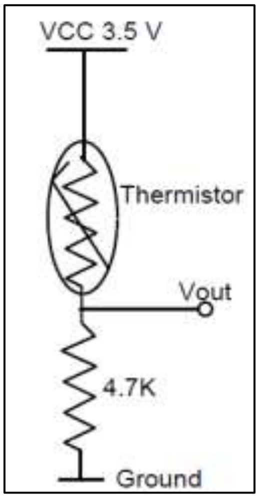

Fig. 3.1: Thermistor in Circuit

In the above figure the output voltage

$$\text{Vout is} = \frac{Vcc\ X\ 4.7\ X10^3}{4.7\ X10^3 + R_T} \qquad (6)$$

Where,
Vcc is the supply voltage in volt
R_T is thermistor resistance in ohm

According to the formula as the temperature increases thermistor resistance getting reduced, so that output voltage is increased proportionally. The characteristics of thermistor in voltage divider as shown in figure3.2.

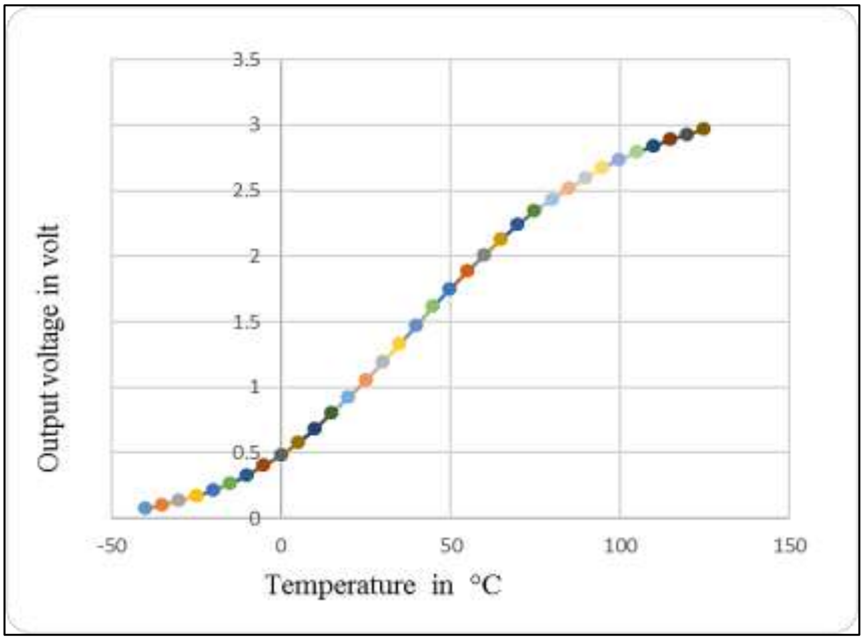

Fig. 3.2: Thermistor output voltage for various temperature levels

A. Observation

From the characteristics of divider circuit, it is observed that as the temperature increases from -40ºC to 125 ºC the output voltage increases almost linearly. So that output voltage will be proportional to the temperature measurement [6]- [10].

IV. POWER MANAGEMENT UNIT USING TEG

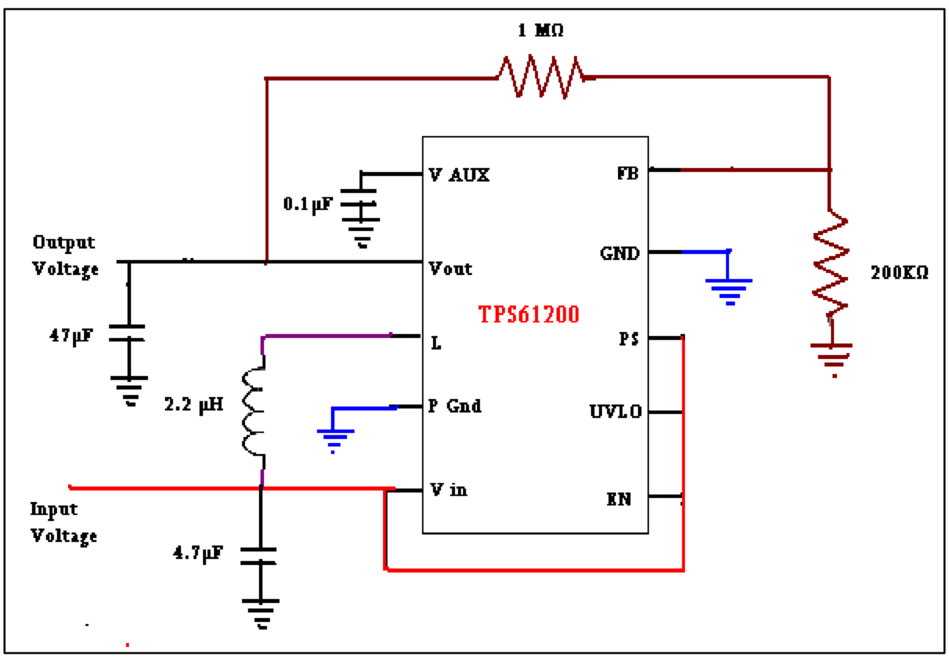

Fig. 4.1: Voltage Booster

B. Voltage Booster

The TPS61200 devices used along with TEG module to provide power supply. The boost converter is based on a fixed frequency, pulse-width-modulation (PWM) controller using synchronous rectification to obtain maximum efficiency. At low load currents, the converter enters the Power Save mode to maintain a high efficiency over a wide load current range. The Power Save mode can be disabled, forcing the converter to operate at a fixed switching frequency. Operating Input Voltage Range from 0.3 V to 5.5 V. The response of TPS61200 Under various load conditions as shown in Figure 4.2 [11].

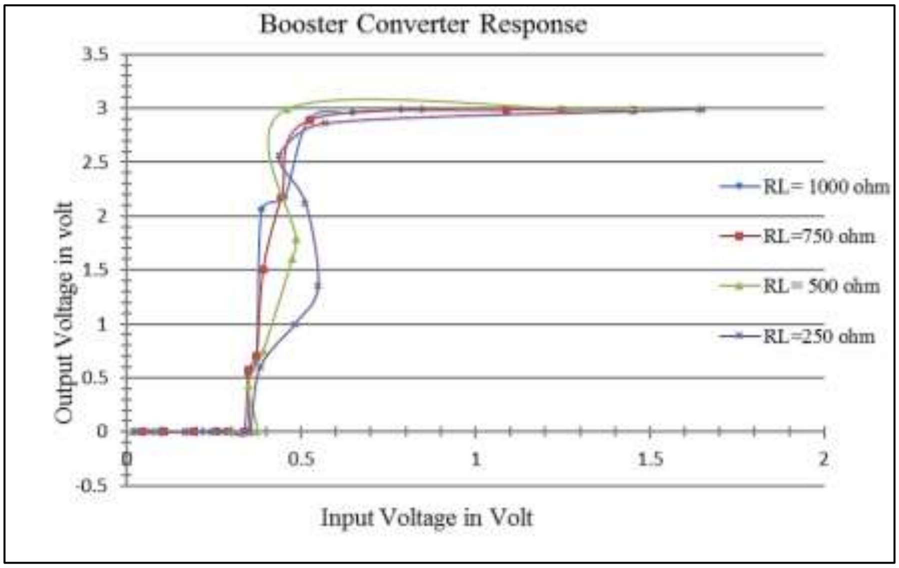

Fig. 4.2: Booster responses

C. *Interfacing Booster with Teg*

As previously mentioned booster is interfaced with TEGs in order to provide a constant power to the transmitter circuit. Thermocouple is connected at the input of booster converter as shown in figure 4.3. These two combinations are called as power management unit. Positive terminal is connected at the input and negative terminal is connected at the ground.

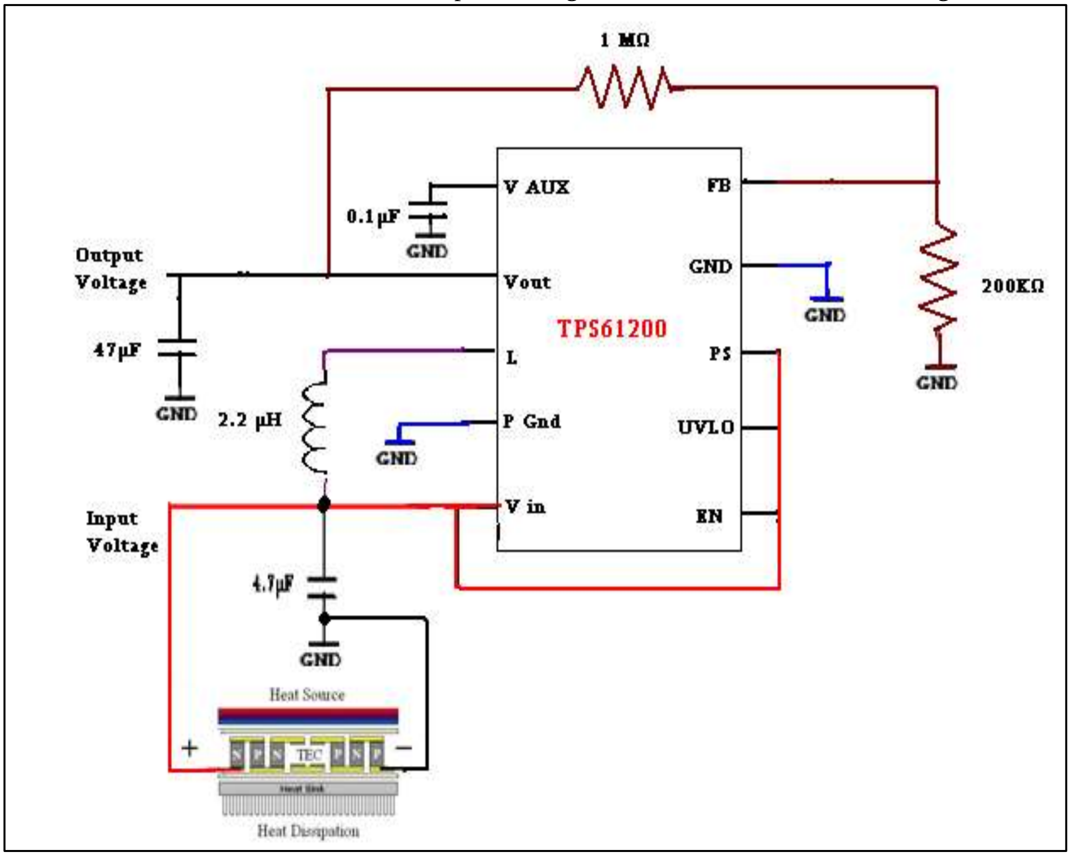

Fig. 4.3: TEG Interfaced with Booster

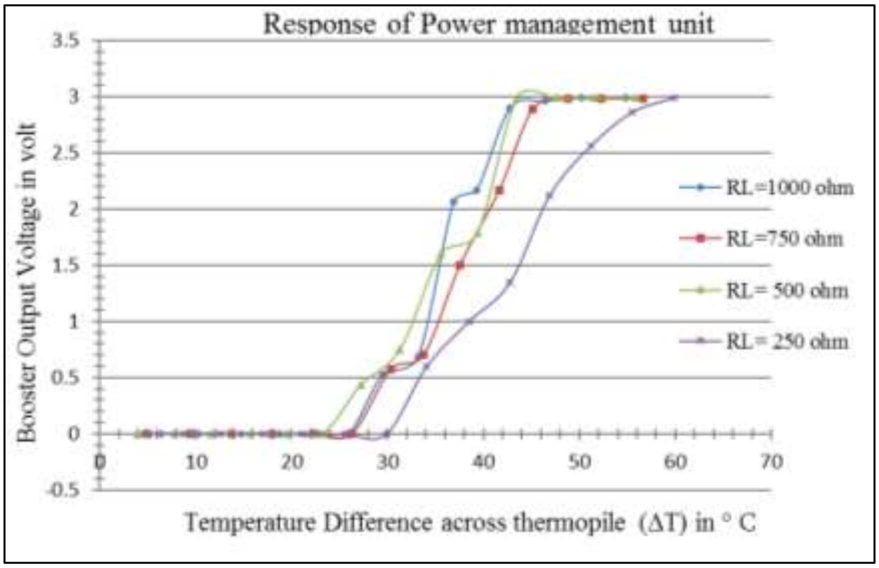

Fig. 4.4: TEG Interfaced with Booster

From the response of Power management unit, it is observed and concluded that if the temperature difference between hot and cold junction of TEG is maintained above 45 ºC the booster can able to produce and maintain 3 volts in the output.

D. Power Sourcing Capacity

Power management unit were studied under various load condition in order to study the power sourcing capacity. It is observed from the graph that from the load 250 ohm to 1Kohm power sourcing capacity getting reduce. It almost reaches 36mW for 250ohm resistance (Best case) and 9mW for 1Kohm resistance (Worst case).

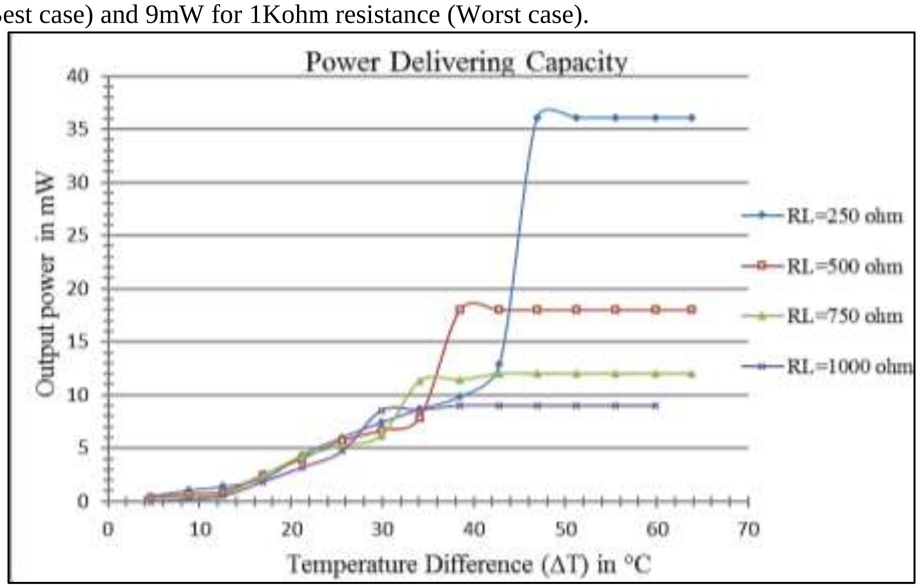

Fig. 4.4: Representation of power sourcing capacity

Table – 1
Energy delivered by source:

Energy supplied for 10 minutes when temperature difference (ΔT) above 45°C	*Worst case*	*Best case*
	*9mW * 600 Sec*	*36mW * 600 Sec*
	5.4 Watt Second	*21.6 Watt Second*

V. TRANSMITTER MODULE

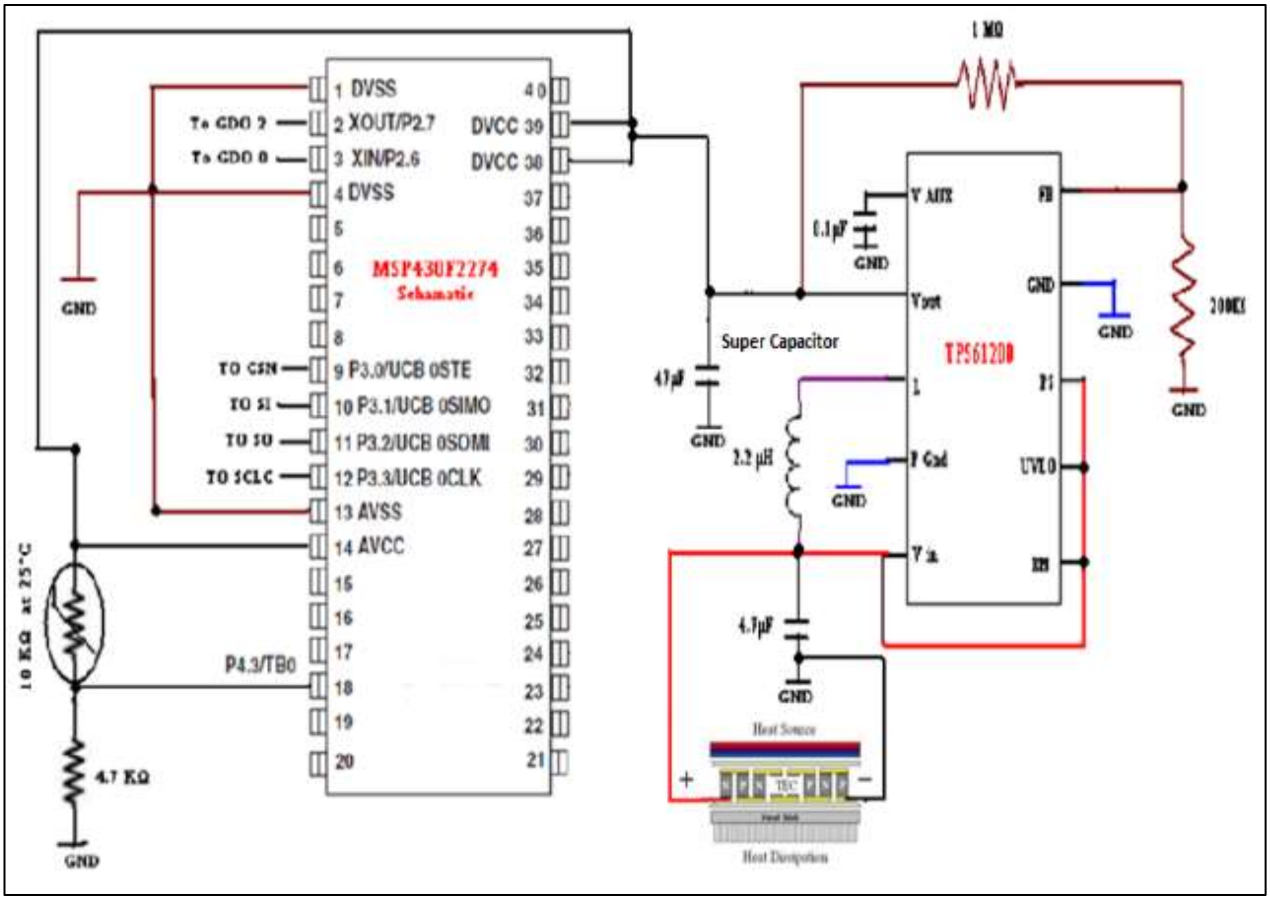

Fig. 5.1: Transmitter Schematic

A. Microcontroller-MSP430f2274

The MSP430 CPU has a 16-bit RISC architecture that is highly see-through to the application. All operations are achieved as register operations in conjunction with seven addressing modes for source operand and four addressing modes for destination operand. The CPU is integrated with 16 registers that provide reduced instruction execution time. The register-to-register operation execution time is one cycle of the CPU clock. Four of the registers, R0 to R3, are devoted as program counter, stack pointer, status register, and constant generator respectively. The remaining registers are general-purpose registers. Peripherals are connected to the CPU using data, address, and control buses, and can be handled with all instructions [12]-[14]

B. Low Power RF Transceiver using cc2500

A 50ohm chip antenna is connected at the output of transceiver. Antenna frequency range is 2400 to2500 MHz. It can transmit/receive data from 50-meter range. This chip antenna is connected for both transmitter and receiver in order to transmit and receive data through RF communication [15].

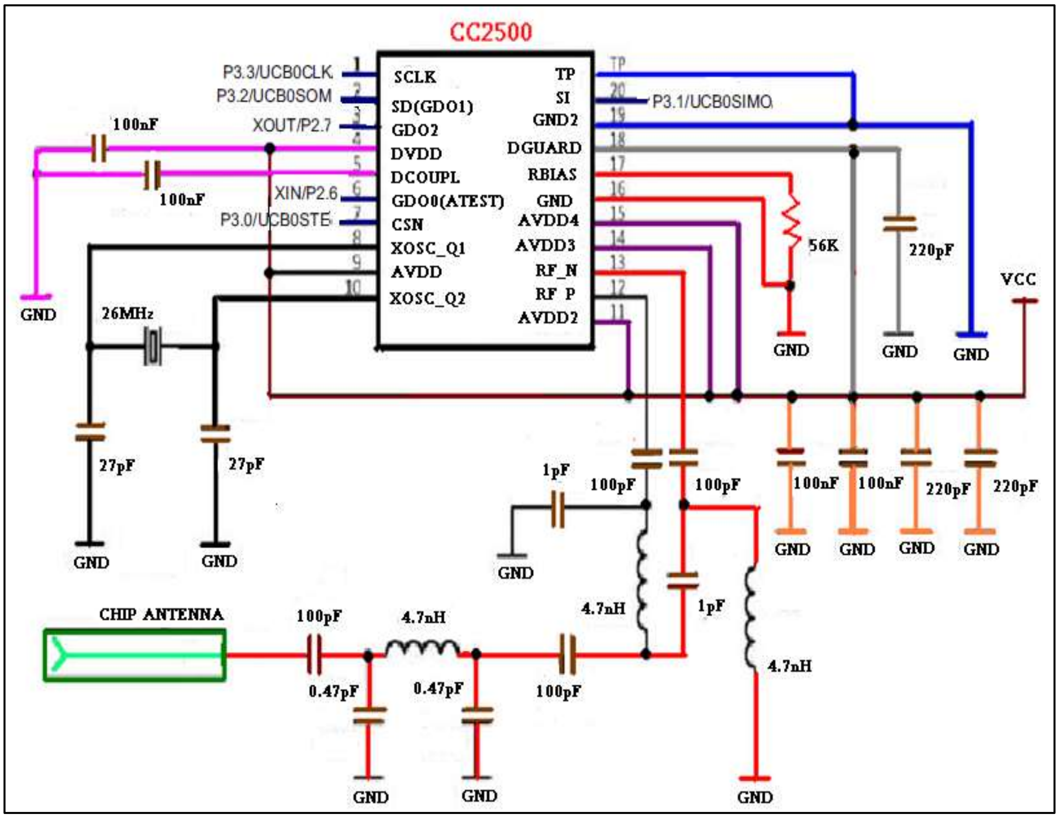

Fig. 5.2: Low Power RF Transceiver

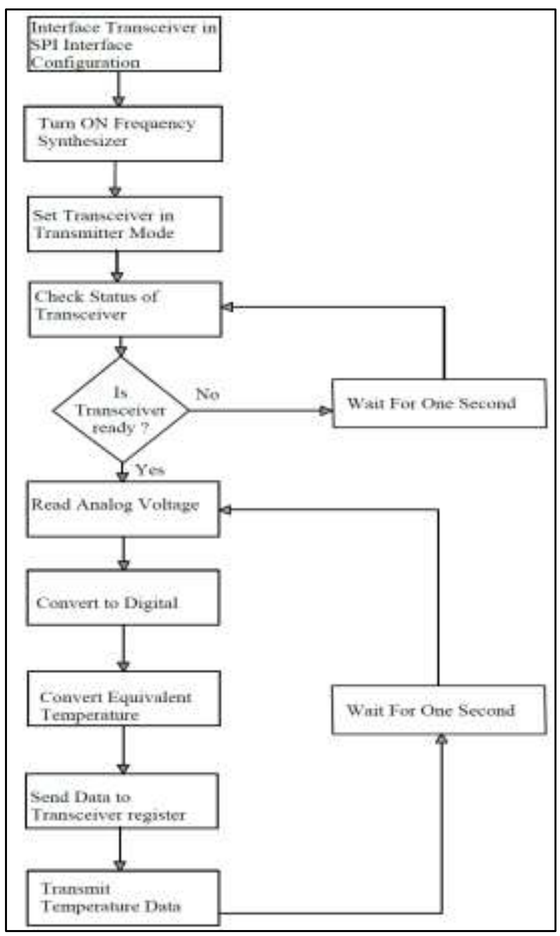

Fig. 5.3: Data Transmission Algorithm

Initially turn on frequency synthesizer so that the transceiver is ready to for the operation, at this time it will calibrate and correct the frequency for the operation. Then transceiver activate in transmitter mode by sending a particular register address from the microcontroller. An acknowledgement should be received from the transceiver, the controller checks every second to get acknowledgement from the transceiver. Once microcontroller received acknowledgement, it reads temperature in the form of voltage from data from the potential divider circuit and converts in to digital and send the data to the transceiver register. Transceiver transmits data by FIFO method. Every second once controller reads data and send to transceiver register

C. *Energy Dissipation in Transmitter*

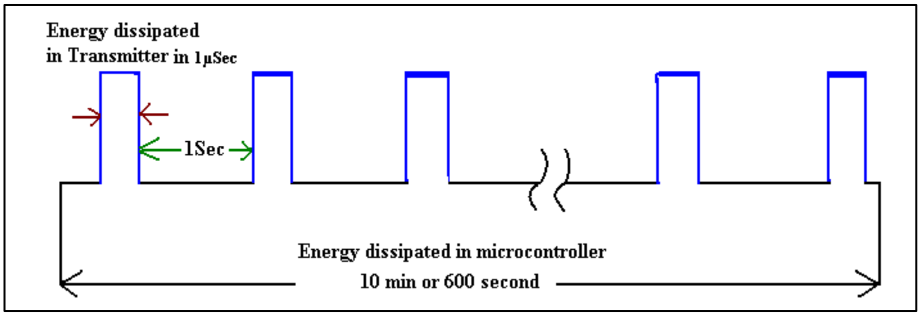

Fig. 5.4: Energy Dissipation Calculation

The transmitter module consumes only 0.99 Watt Sec energy. It is observed that energy delivered by source in worst case is 5.4-watt sec, this value almost 5 times higher than the energy consumed by transmitter module. It is concluded and verified that self-powered transmitter module can operate without any battery source.

```
35.1C,3.6,000,N#
35.6C,3.6,000,N#
35.6C,3.6,000,N#
35.6C,3.6,000,N#
35.6C,3.6,000,N#
35.6C,3.6,000,N#
35.7C,3.6,000,N#
35.8C,3.6,000,N#
35.9C,3.6,000,N#
35.9C,3.6,000,N#
35.8C,3.6,000,N#
35.7C,3.6,000,N#
35.8C,3.6,000,N#
36.0C,3.6,000,N#
36.3C,3.6,000,N#
36.9C,3.6,000,N#
37.2C,3.6,000,N#
37.6C,3.6,000,N#
38.0C,3.6,000,N#
38.4C,3.6,000,N#
39.0C,3.6,000,N#
39.6C,3.6,000,N#
40.2C,3.6,000,N#
40.9C,3.6,000,N#
41.5C,3.6,000,N#
42.3C,3.6,000,N#
43.1C,3.6,000,N#
43.9C,3.6,000,N#
44.8C,3.6,000,N#
```

Fig. 5.5: Measured Temperature Value

VI. FUTURE DEVELOPMENT

Here self-powered temperature monitoring system has been developed for single node, in future we can develop multiple node self-powered sensor network and we can monitor temperature for many places. A single receiver can receive data from many nodes; all nodes can access periodically to get data. And also increase the range of RF data communication.

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