Passive Pyroelectric Ceramic Temperature sensors

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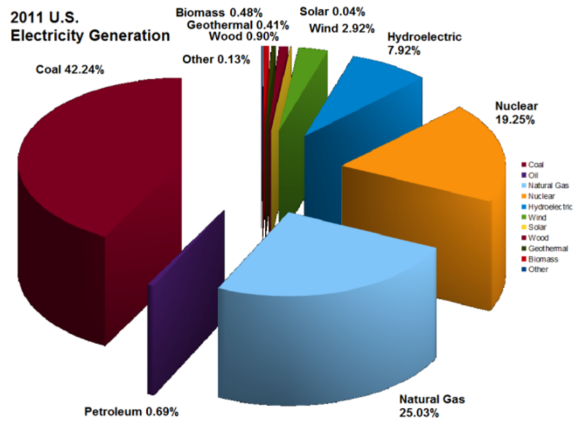
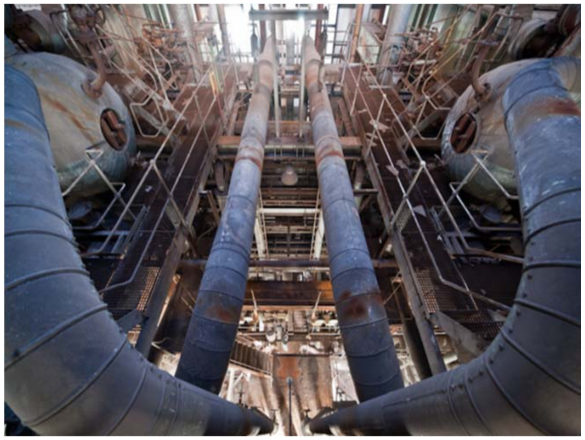
Agenda

- Introduction and Background
- Objectives
- Technical Approach
- Results
- Summary
- Future Work

Introduction

- Temperature sensing is critical in modern power plants and energy systems
  - Higher efficiencies in energy conversion
  - Lower emission for near-zero emission power plants
  - Enhanced material systems safety





Introduction

- **Project Goal**

  Design, fabricate, and demonstrate a *low cost self-powered wireless* temperature sensor for energy system applications

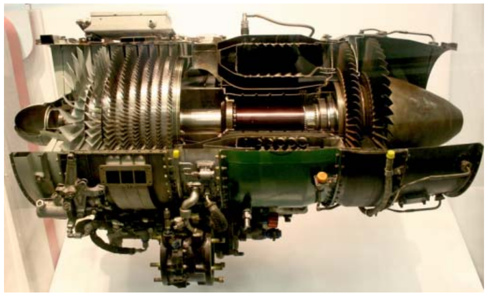
- **Expectation**

  Provide a complete set of documentation for sensor manufacturing, testing and characterization

- **Benefit**

  Energy conversion areas where continuous temperature monitoring required to achieve higher performance

Coal-Gasification Power Plant



Gas Turbine

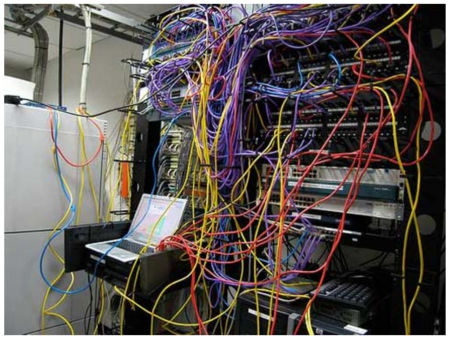
Oxy Fuel Combustion

Introduction

Overview and Rationale

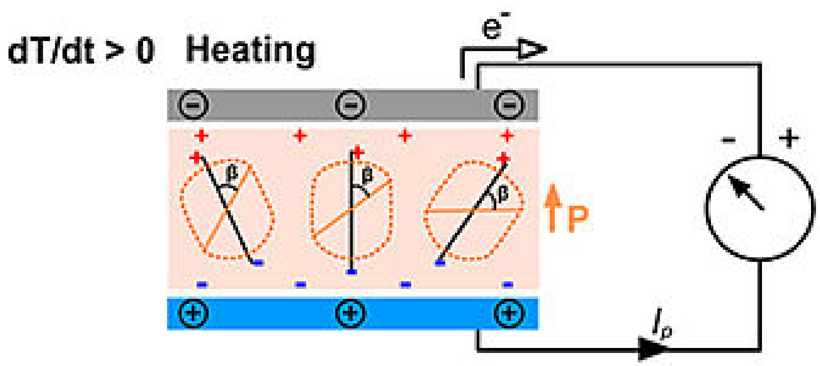
- **Wired temperature sensors**
  - High cost materials required (Sapphire, laser)
  - Complicated sensing systems lead to high cost and maintenance
  - Typically require special coupling connection

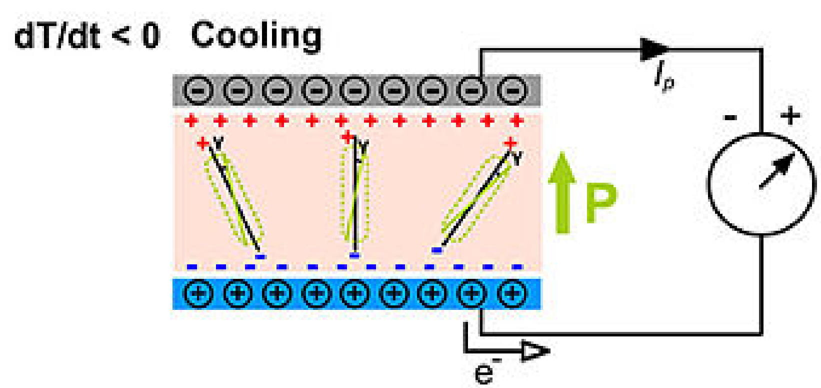
- **Wireless temperature sensors**
  - Require built-in electronics
  - High temperature limitation
  - Complicated sensor design



Background

- ❑ Pyroelectric material is heated
  - ➢ Spontaneous polarization reduced through reduction of dipole moment
  - ➢ Quantity of bound charges at the electrodes decreases
  - ➢ This subsequent redistribution of charges results current flow through the external circuit
- ❑ Pyroelectric material is cooled
  - ➢ Spontaneous polarization increased
  - ➢ Current sign is reversed



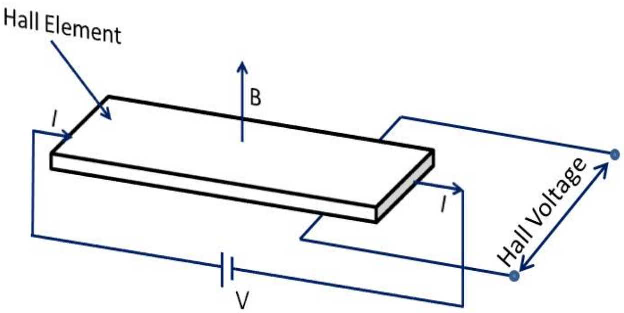


Background

Sensing of Magnetic Field

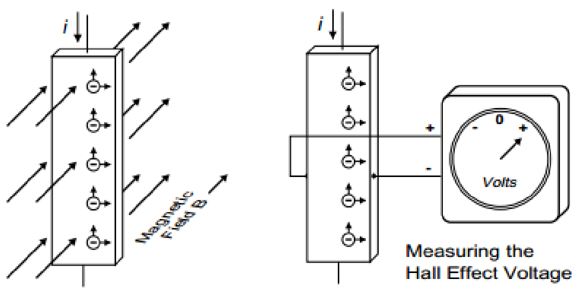
❑ Hall Sensor

- A hall effect sensor is a 3 wired sensor with reference voltage, a ground and a signal terminal



- Hall effect sensor is a transducer that varies its output voltage in presence of magnetic field

- Current flowing through a conductor in magnetic field perpendicular to the current flow would generate voltage perpendicular to both current flow and magnetic field

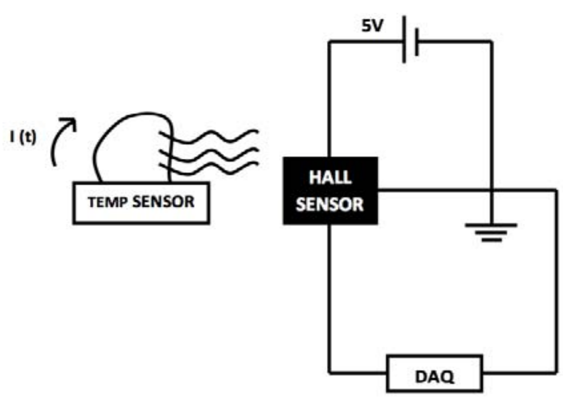


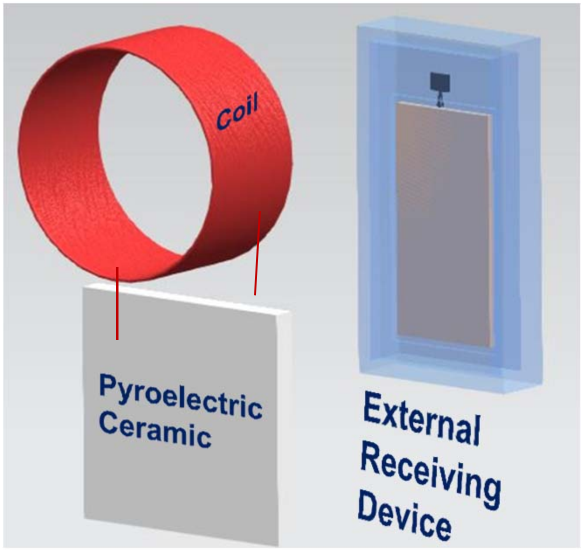
Introduction

Project Concept

- ❑ Low cost self-powered wireless temperature sensor

- ➢ Sensing mechanism is based on ***pyroelectric ceramic***
- ➢ Pyroelectric ceramic ***generates current*** upon temperature changes
- ➢ Generated current will be converted into ***magnetic flux*** by connecting the ceramic to an inductive coil and measured wirelessly by an ***external receiving device***





Technical Approach

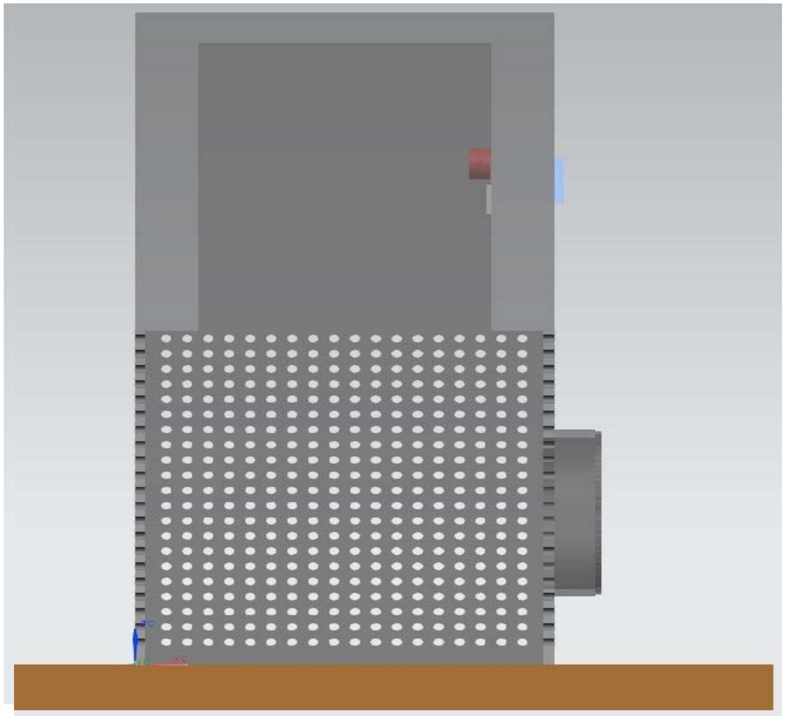
Sensing Method

- The relation between magnetic flux and current can be described as below

$$T(f) = \frac{1}{pA}\int_{t_o}^{t_f} I dt + T(0)$$

$$\varphi = \frac{\mu_0 NIA}{w}$$

- Sensing device and processing unit



- Left side: wireless signal (Current induced magnetic flux) generated by sensor
- Right side: External receiver (Hall sensor) and Data acquisition unit

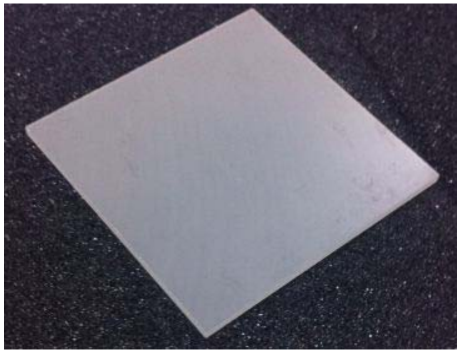
Objectives

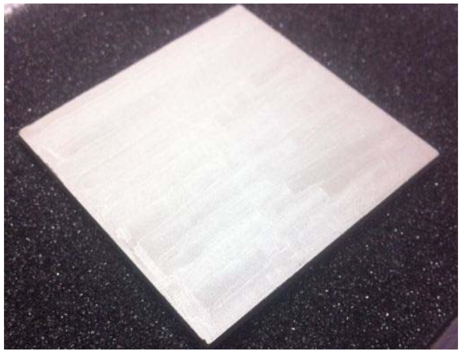
1. Determination of appropriate pyroelectric ceramics
2. Construct the wireless sensor system and demonstrate the wireless temperature sensing capability
3. Development of temperature sensor using pyroelectric properties of Lithium Niobate
4. Determine the wireless sensing performance in energy systems

Technical Approach

Objective 1: Determination of appropriate pyroelectric ceramic

- Pyroelectric materials include
  - Crystal (Lithium Tantalate)
  - Polymer (PVDF-Polyvinylidene Fluoride)
  - Ceramic (Lithium Niobate)
  - Biological materials
- Choice of pyroelectric materials depends on
  - Size & density
  - Availability and reliability
  - Maximum operation of temperature
  - Pyroelectric coefficient



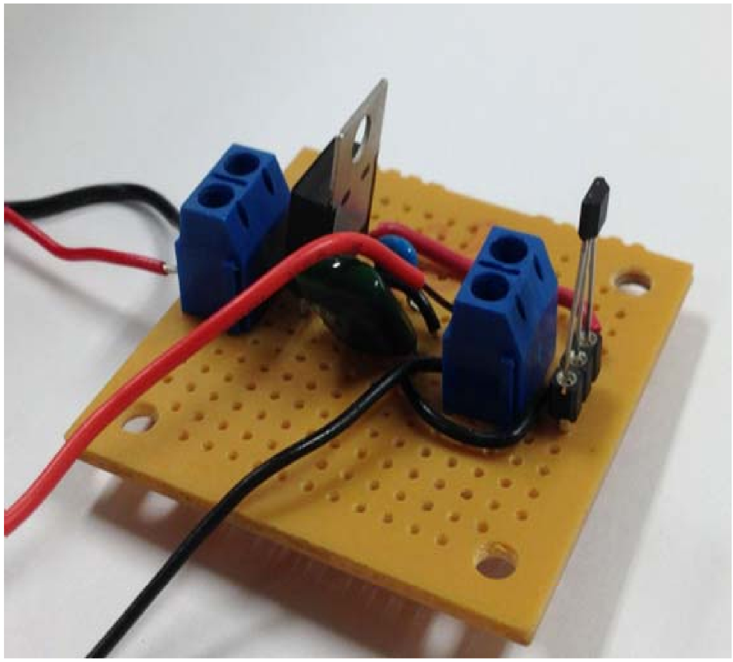


Dimension ($LiNbO_3$)	50.8×50.8 cm and 2 mm in thickness
Density	4.65 g/cm^3
Curie Temperature	1142.3±0.7º C
Dielectric Constant (@ 25º C (unclamped <500 KHz)	ε_{11} = 85, ε_{33} = 28.7
Pyroelectric Coefficient (@ 25º C)	-8.3×10^{-5} C/ºCm^2
Piezoelectric Strain Coefficients (@25ºC ×10^{-12} C/N)	d_{12}= 69.2 d_{31}=0.85 d_{22}=20.8 d_{33}=6.0
Thermal Conductivity (@ 25º C)	10^{-2} cal/cm.sec.ºC

Technical Approach

Objective 2: ***Construct the wireless sensor system*** and demonstrate the wireless temperature sensing capability

5.0 mV/Gauss ratiometric linear analog commercial Hall sensor from Alegro Micro Systems



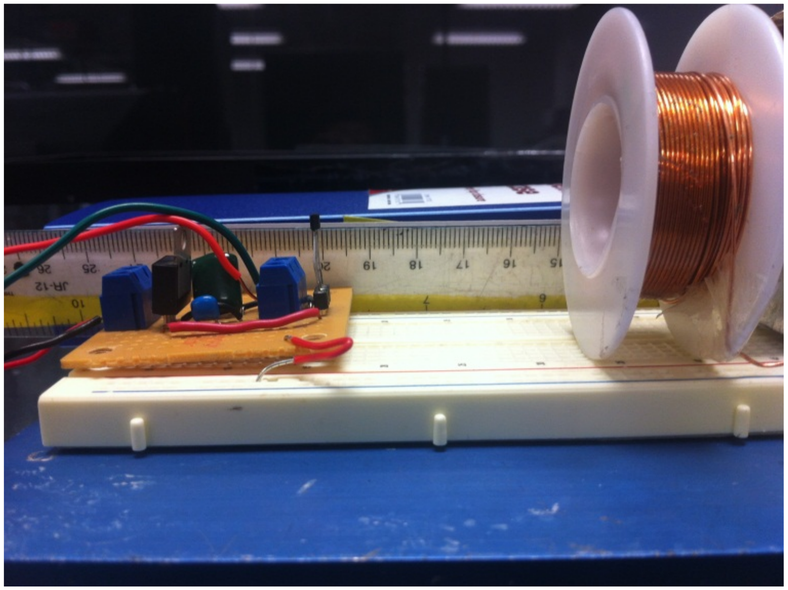
Technical Approach

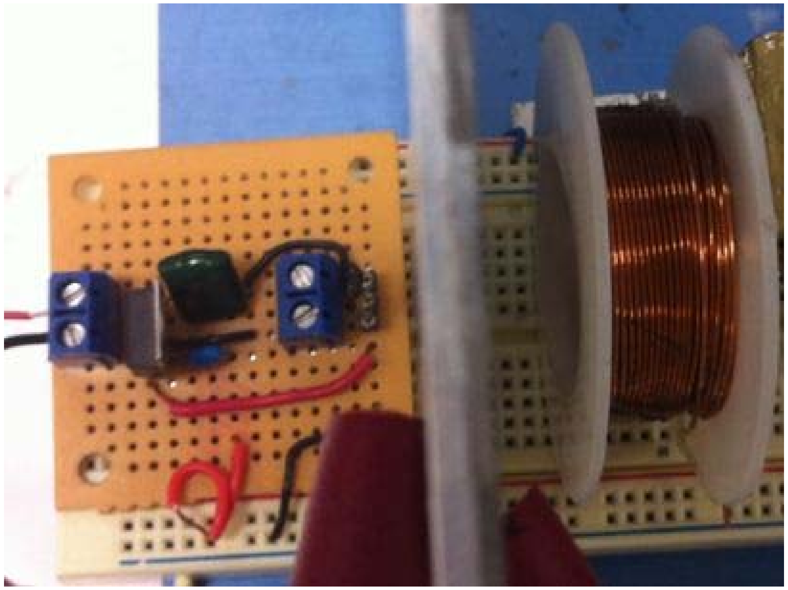
Objective 2: Construct the wireless sensor system and ***demonstrate the wireless temperature sensing capability***

❑ Task

Magnetic Field Detection by Hall Effect Sensor

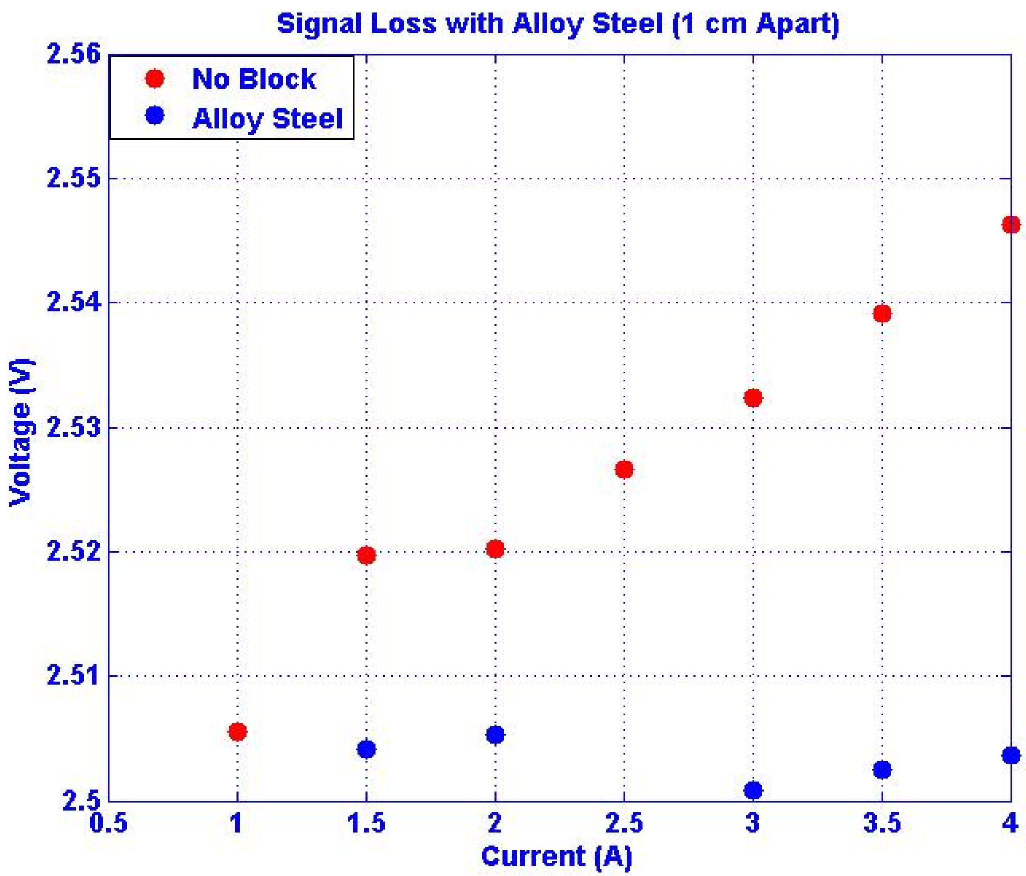
- ➢ Through Distances
- ➢ Through Material Blocks

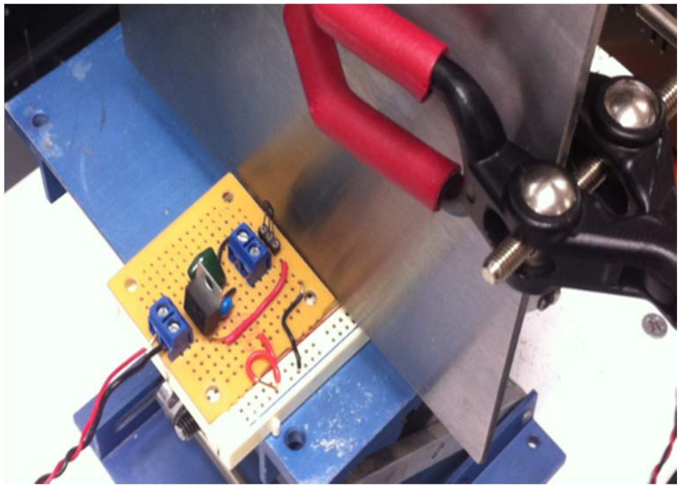


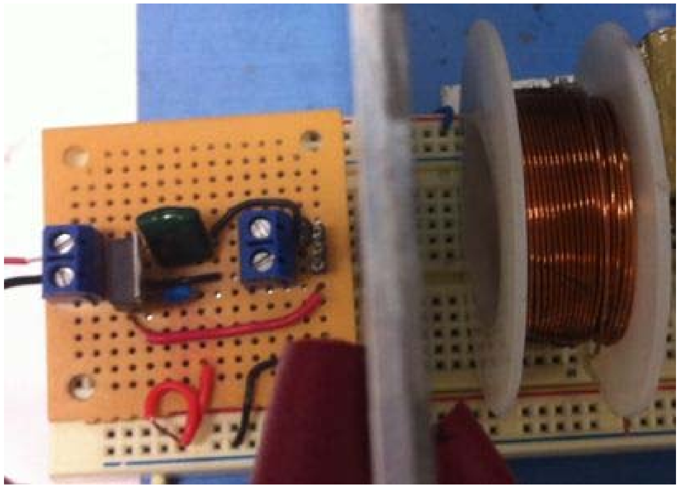


Results

Signal Loss with Various Materials



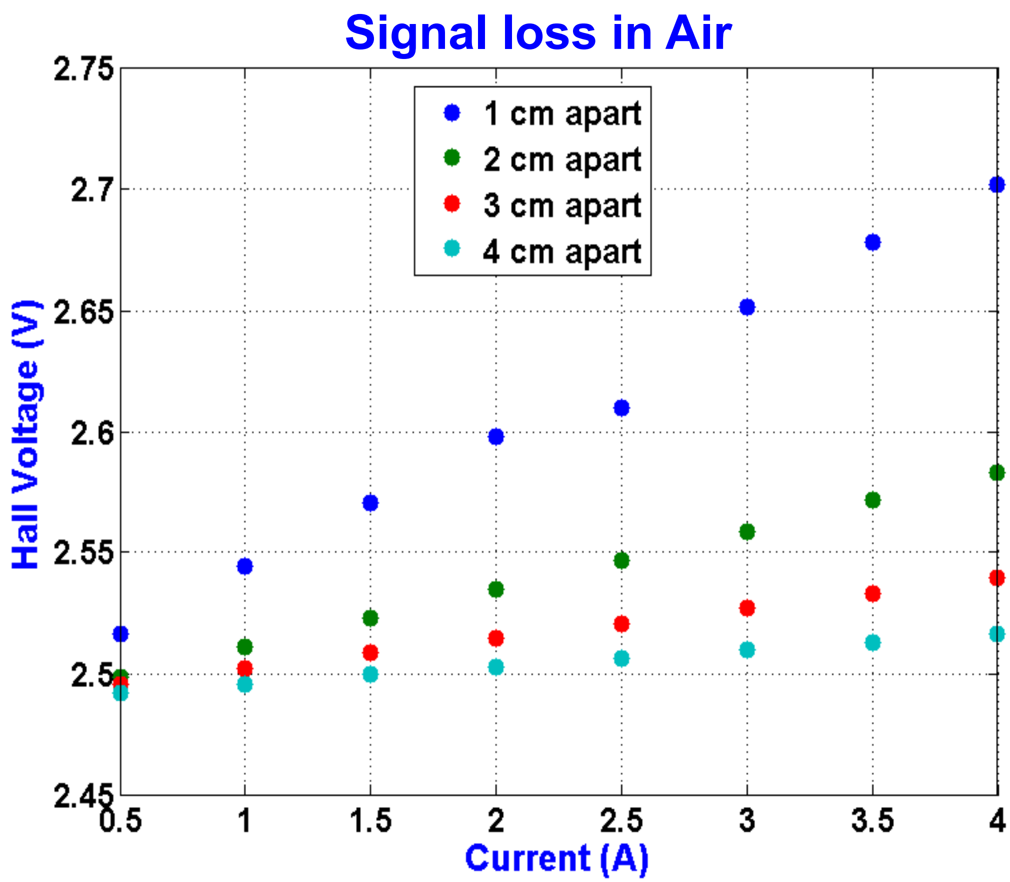


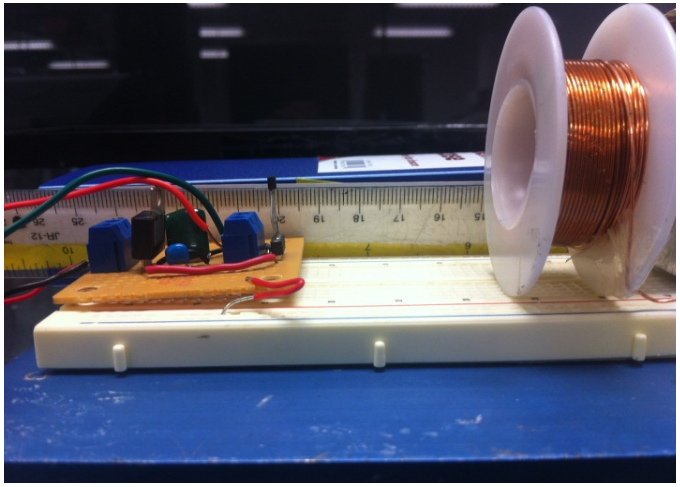


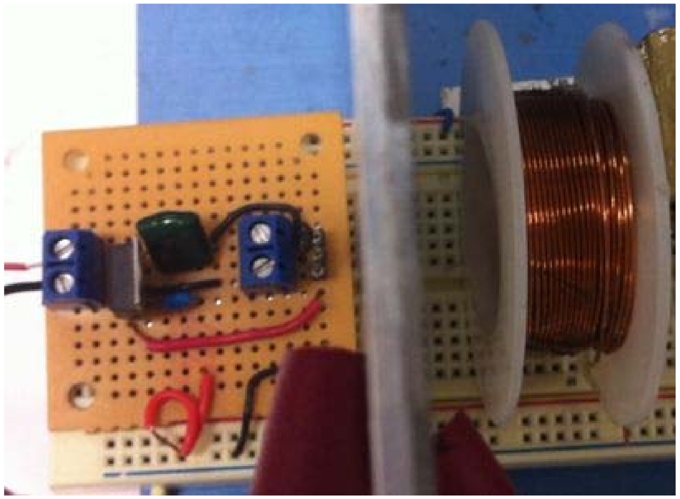
- ❑ Current supplied to winded coil from external power supply

Results

Signal Loss for Various Distances



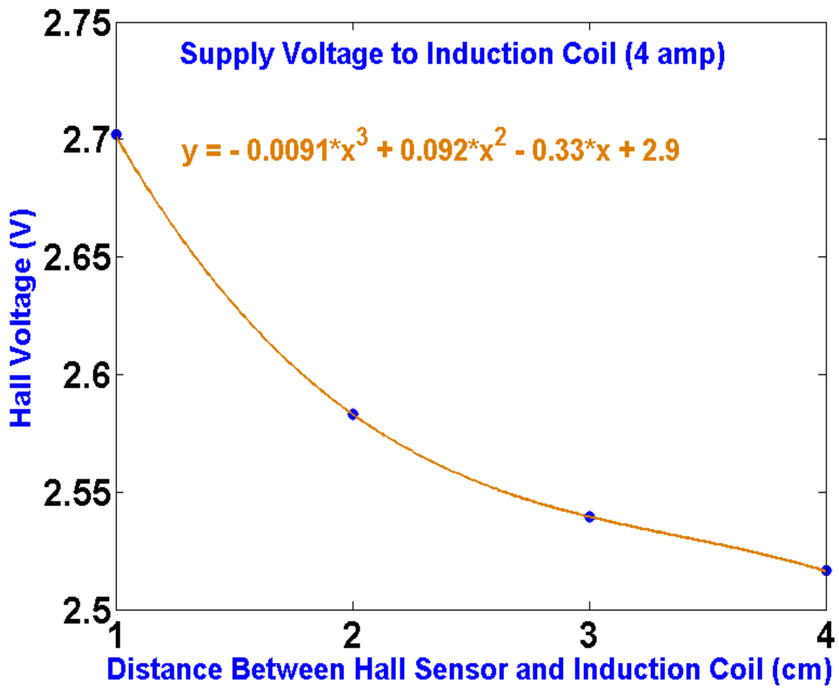




- ❑ Current supplied to winded coil from external power supply

Results

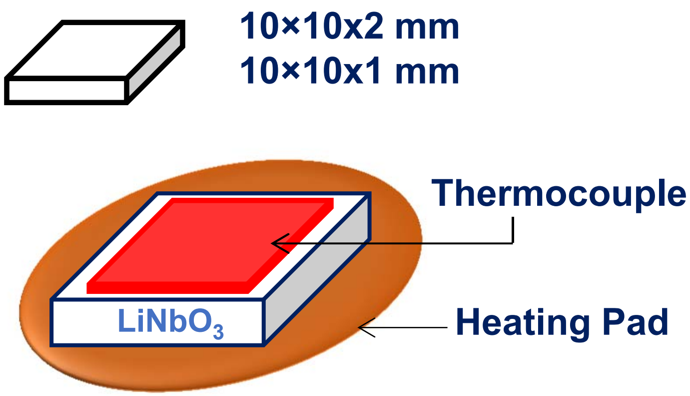
Interpolation model for Hall sensor voltage output at 4 A and varying distance



No block (Air)

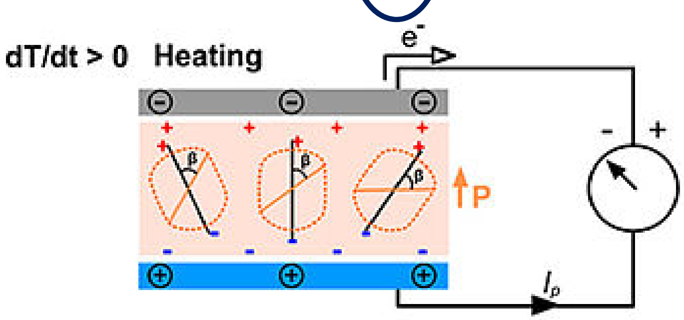
Technical Approach

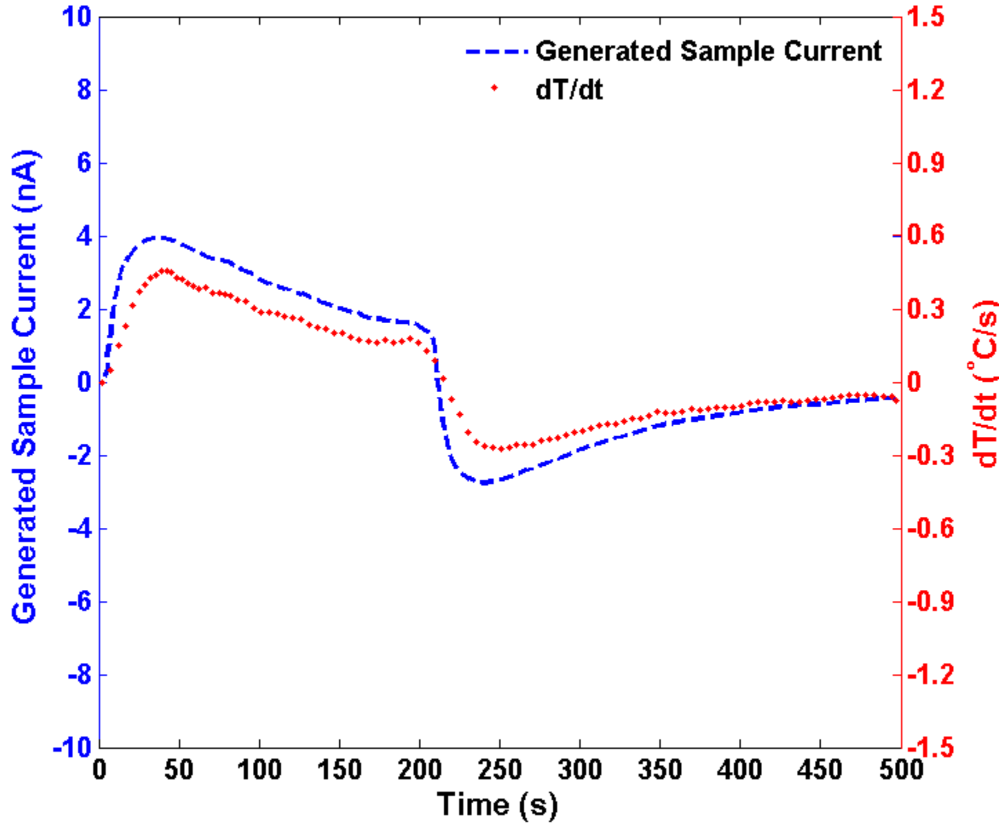
Objective 3: Development of temperature sensor using pyroelectric properties of Lithium Niobate



Pyroelectric Current

$$I = -pA\frac{dT}{dt}$$





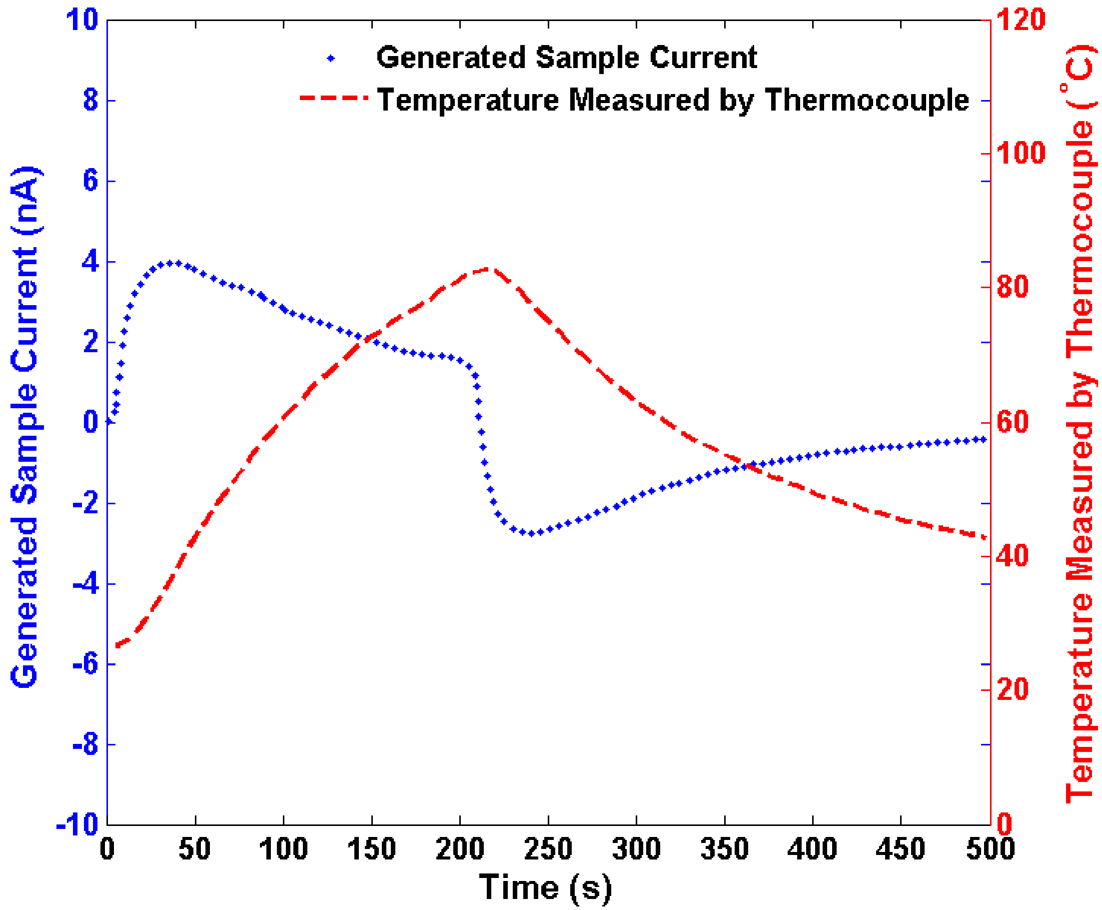
Technical Approach

Pyroelectric Current

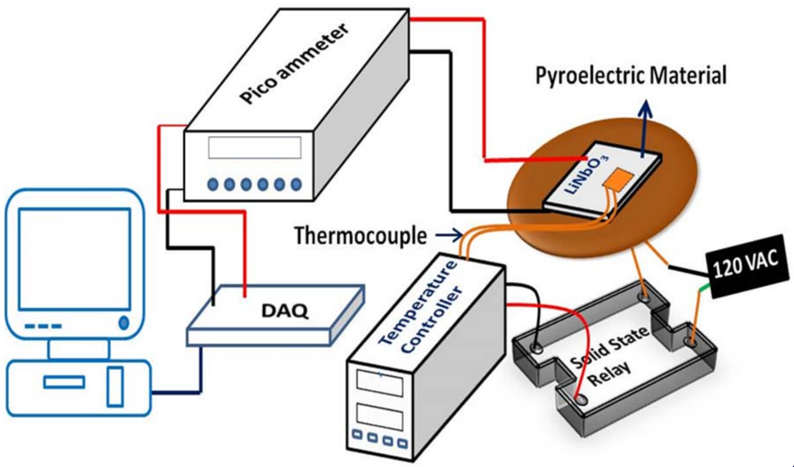
$$I = -pA\frac{dT}{dt}$$

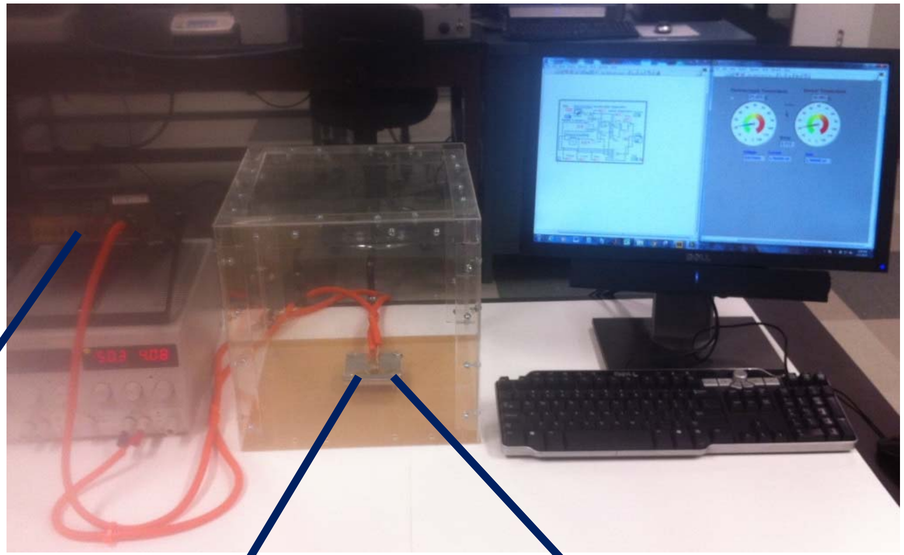
50s

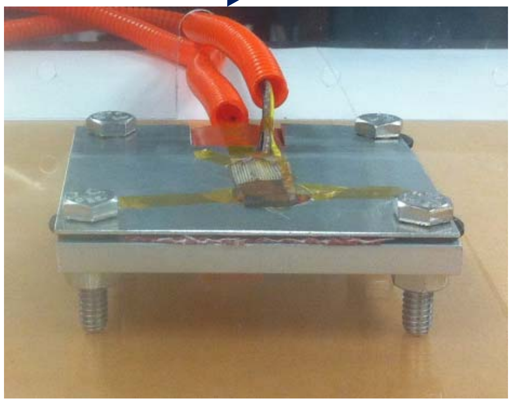
$$T_f = -\frac{1}{pA}\int_{t_i}^{t_f} I\,dt + T_i$$

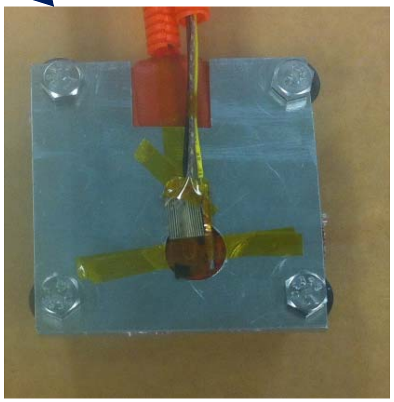


Experimental Setup

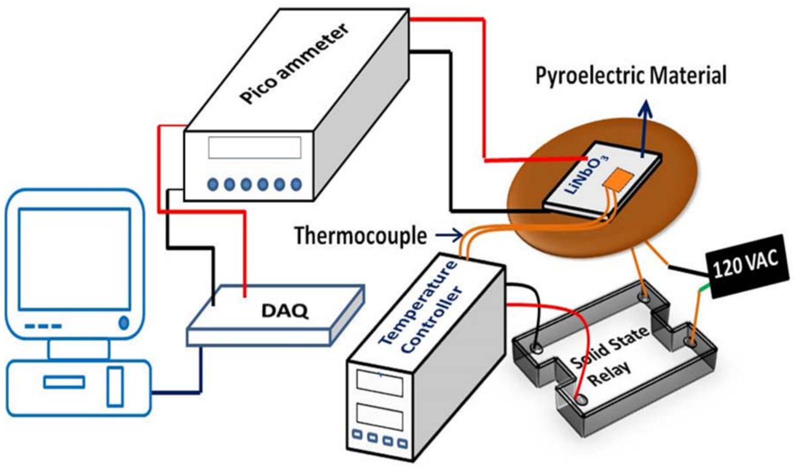


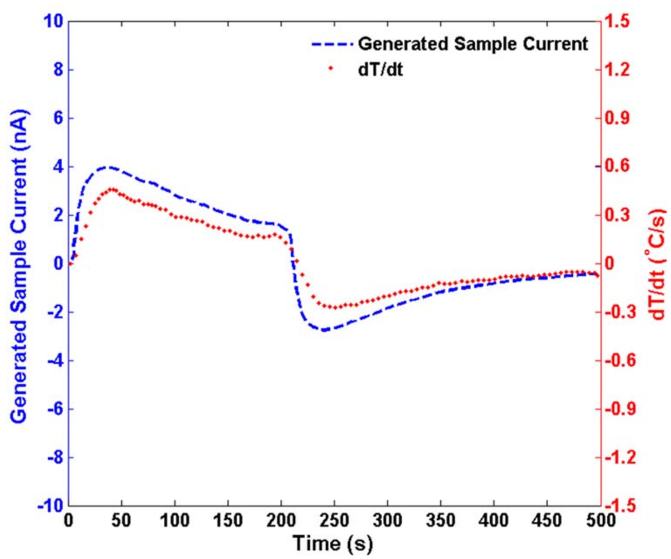




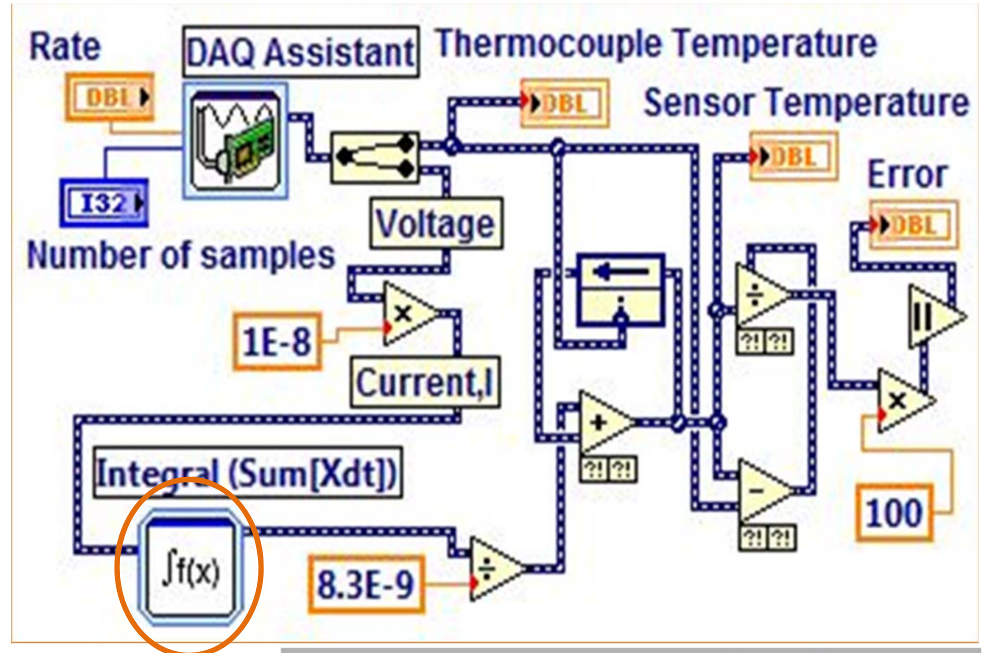


Experimental Setup

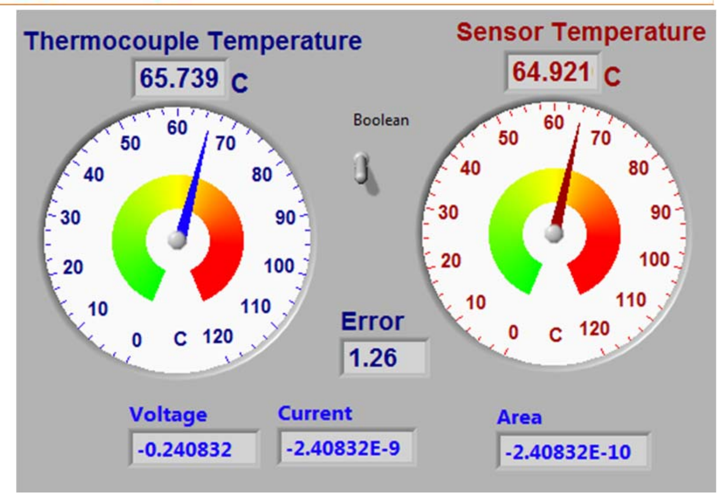




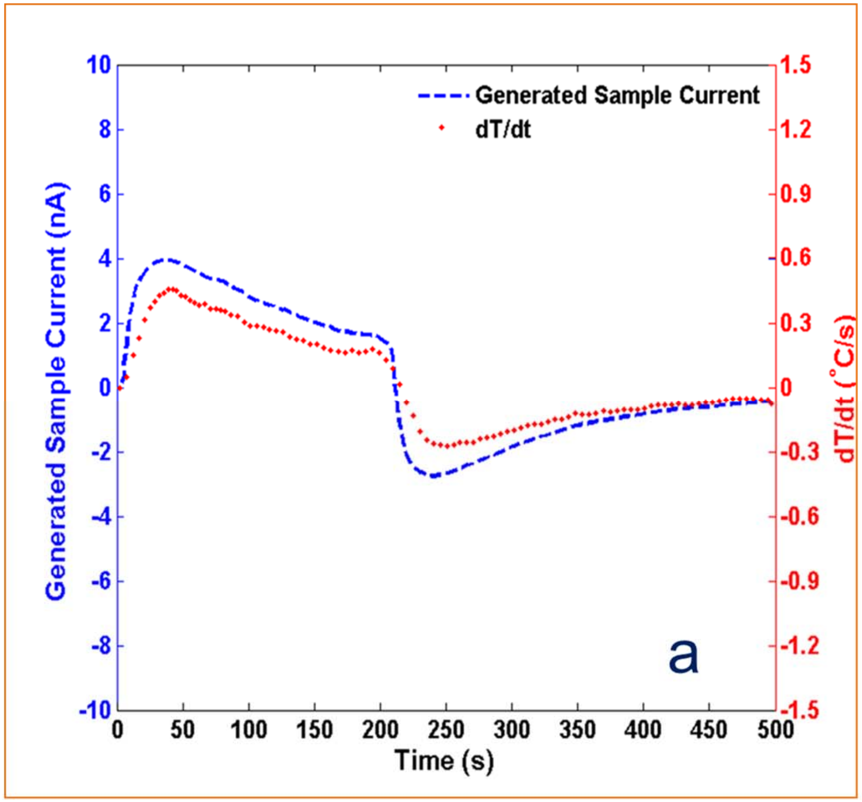
- Data Acquisition

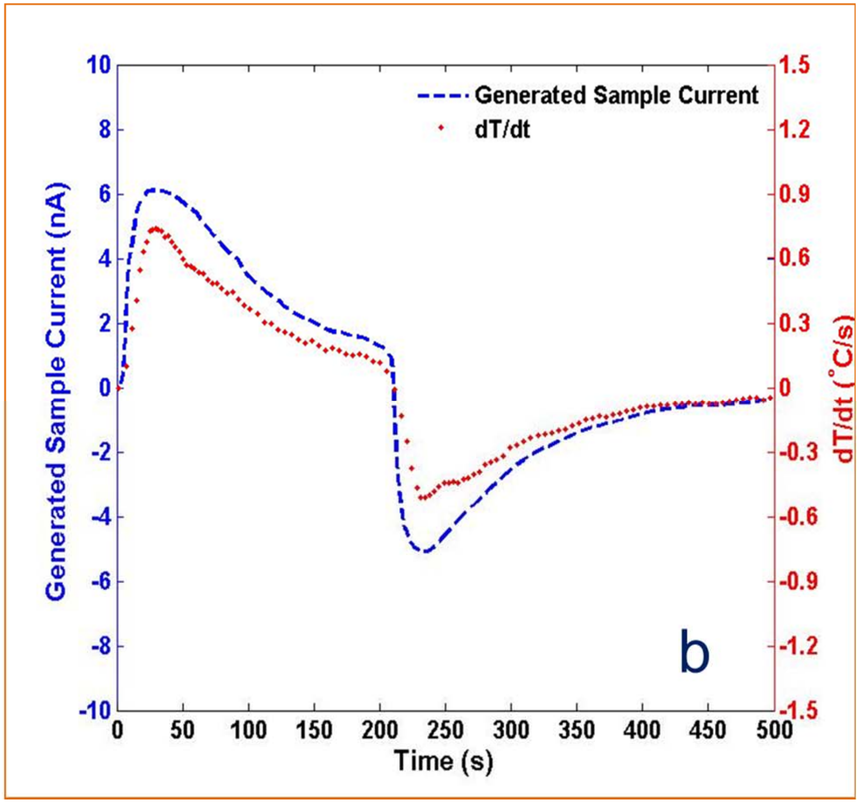


$$T_f = -\frac{1}{pA}\int_{t_i}^{t_f} I dt + T_i$$



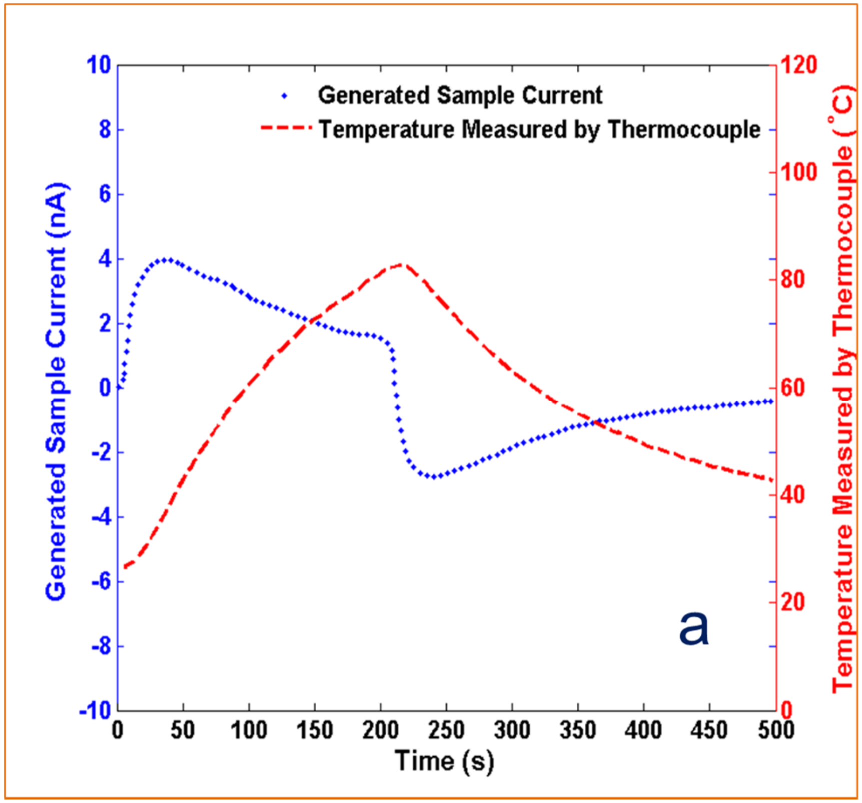
Results

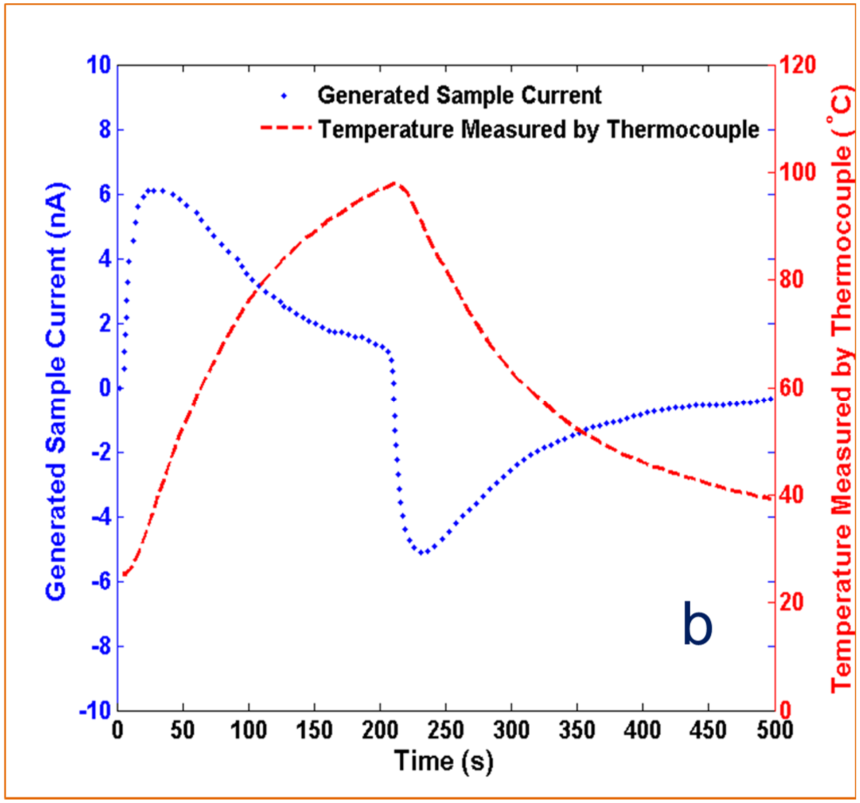




Generated current by $LiNbO_3$ and rate of temperature change of thermocouple mounted on top of (a) 2 mm and (b) 1 mm thick $LiNbO_3$

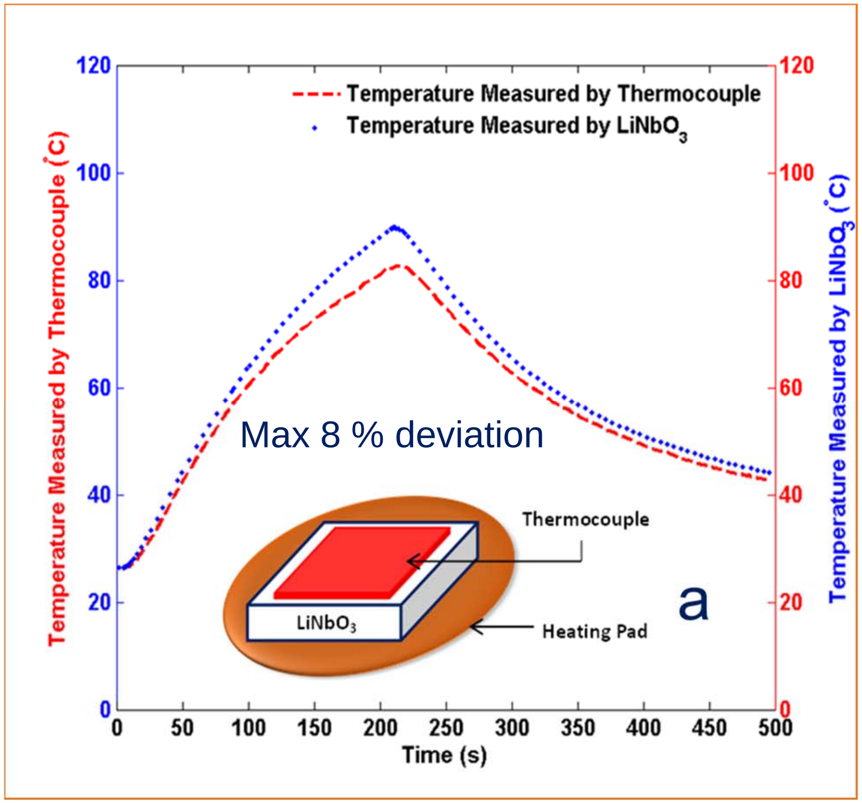
Results

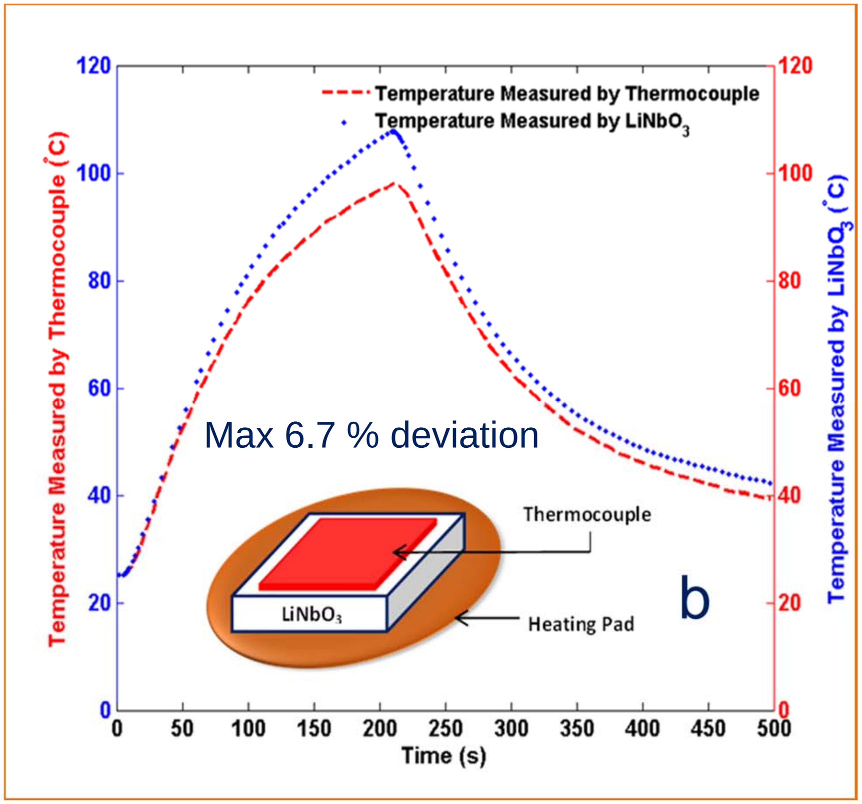




Generated current by $LiNbO_3$ and temperature of thermocouple mounted on top of (a) 2 mm thick $LiNbO_3$ and (b) 1 mm thick $LiNbO_3$

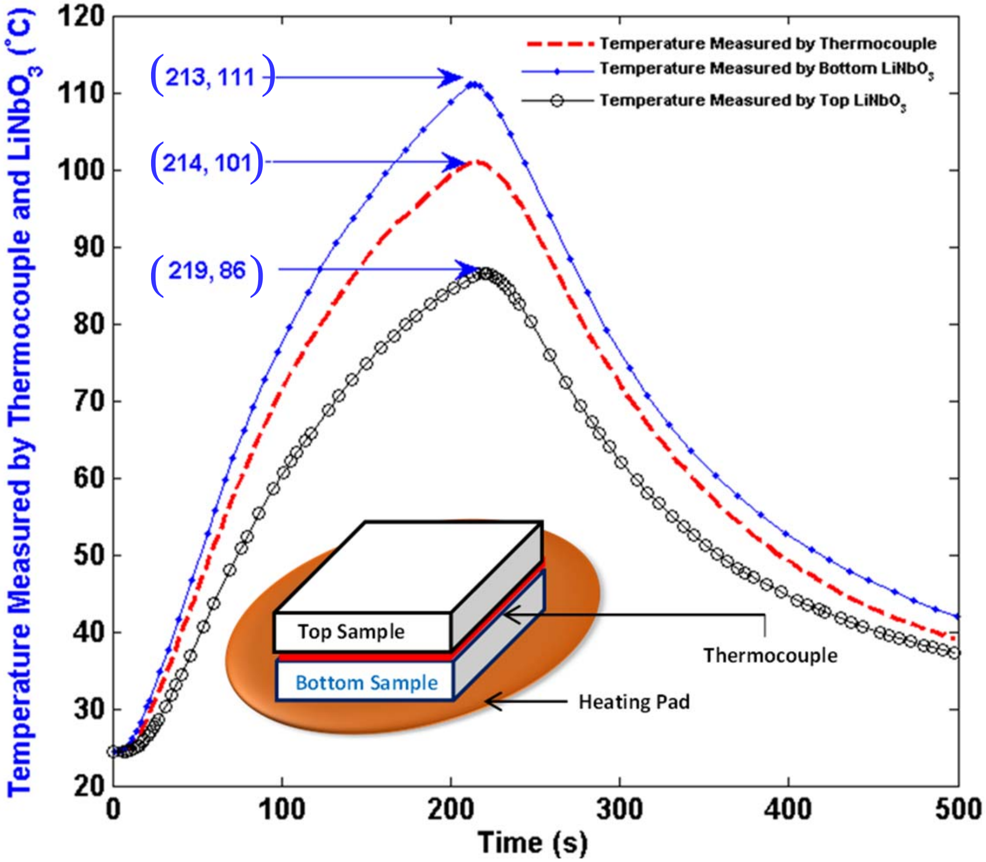
Results





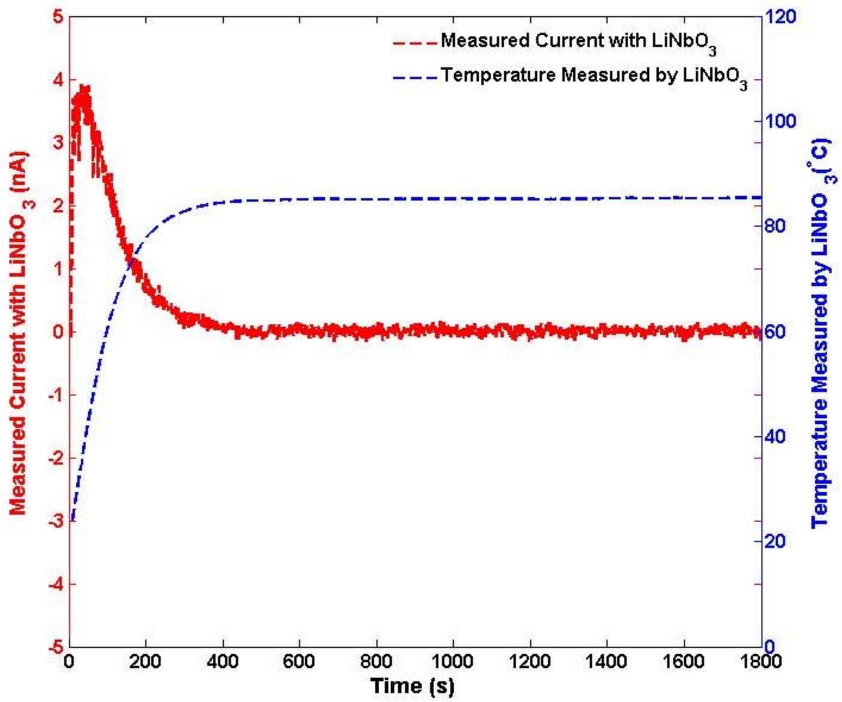
Temperature measured by thermocouple and (a) 2 mm thick and (b) 1 mm thick $LiNbO_3$

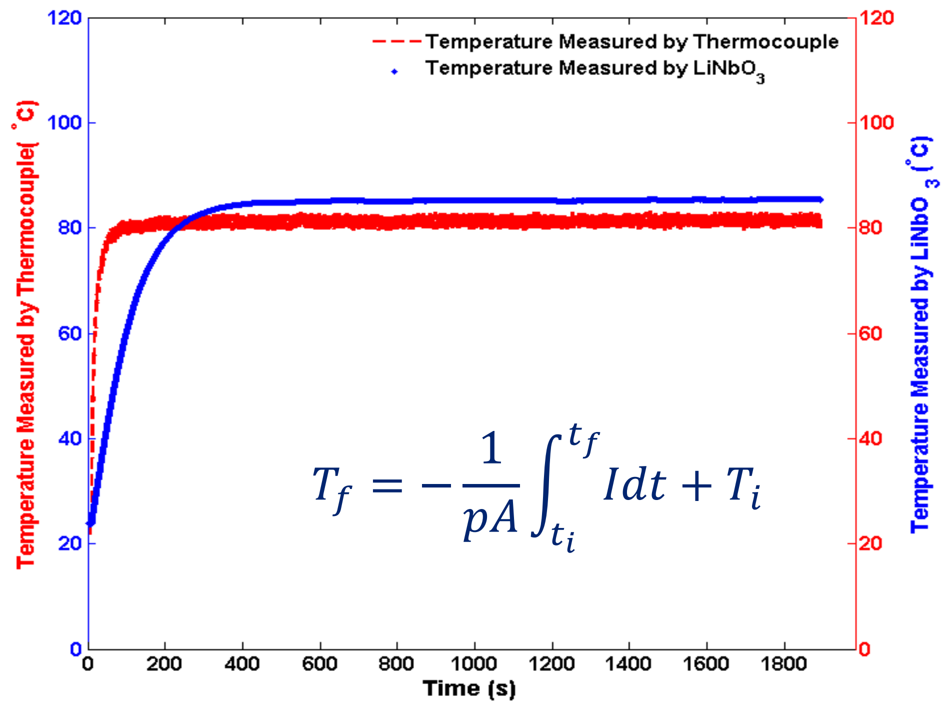
Results



Temperature measured by the thermocouple and 1 mm thick sandwich structured $LiNbO_3$

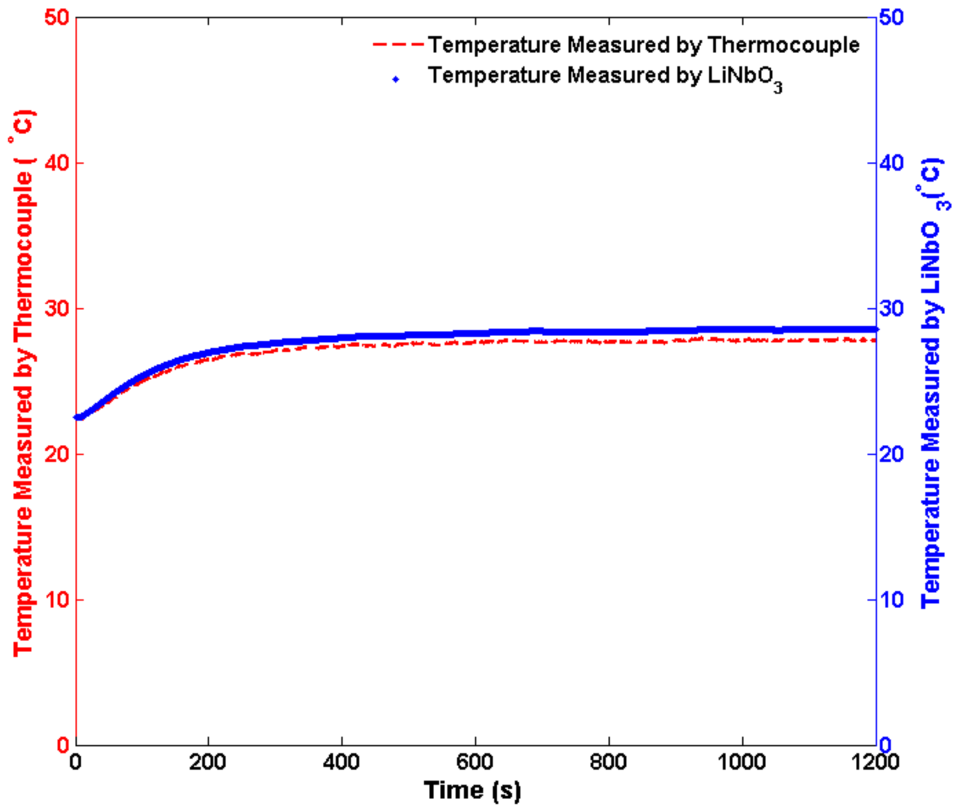
Results





Temperature measured by the thermocouple and 2mm LiNbO3
for extended time. Furnace was set at 100° C.
They were separate and place inside the furnace at same time.

Results

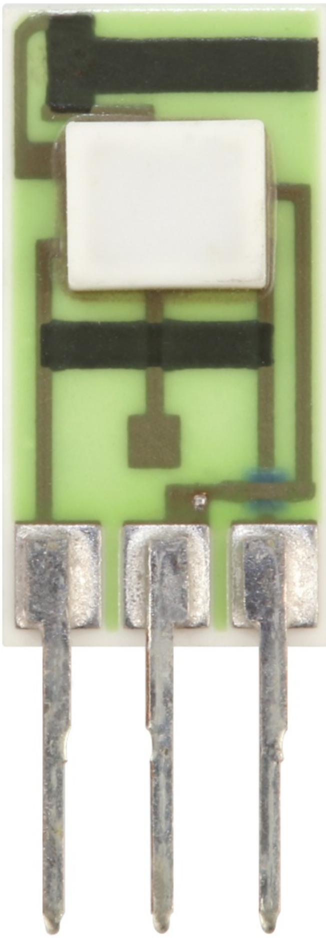


Temperature measured by the thermocouple and 2 mm thick $LiNbO_3$ for extended time with slow heating rate

Wireless Sensing Approach

- Challenges
  - Low Magnetic field generated in the inductor coil
  - High temperature material for coating, adhesive and wiring
- Probable solutions
  - Increase the current generated by having a larger sample or stacking multiple samples together
  - Design the inductor with higher number of loops, strong magnetic core to increase the magnetic field generated
  - Increase the sensitivity of the Hall sensor to detect low magnetic fields
  - Research for commercially available high temperature adhesive, coating and wire materials

Wireless Sensing Approach



Highly sensitive Hall sensor (25mv/G)

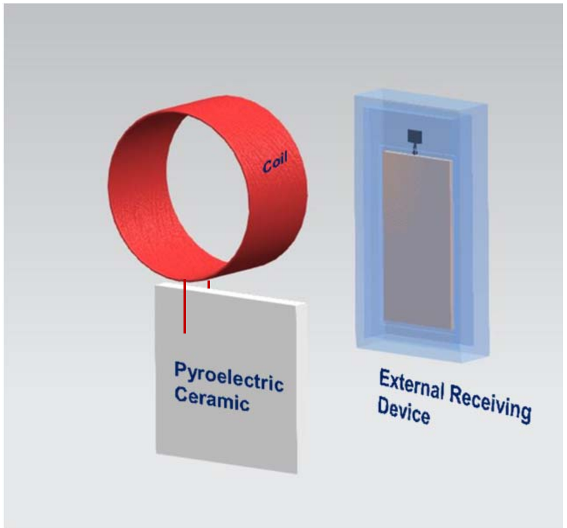
High temperature adhesive and coating from Aremco (up to 1700 °F)

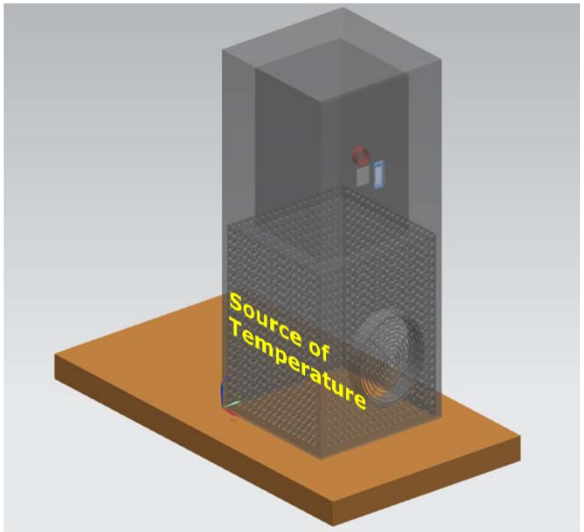
Conclusion

- A lithium niobate ceramic with high Curie temperature (1142 °C) material is selected
- Hall Effect sensor was constructed and tested to measure the magnetic flux remotely through various distances and through various materials
- 1 cm x 1 cm sample of lithium niobate material with two different thicknesses (1mm and 2 mm) were characterized in terms of current generation
- Measured current from lithium niobate is compared with the theoretical current. The comparison satisfies the definition of pyroelectricity
- Pyroelectric current from the lithium niobate ceramic material due its change of temperature is taken into consideration to calculate the sample temperature
  - maximum 8% and 6.7% differences was found for 2 mm and 1 mm thick sample respectively

Future Work

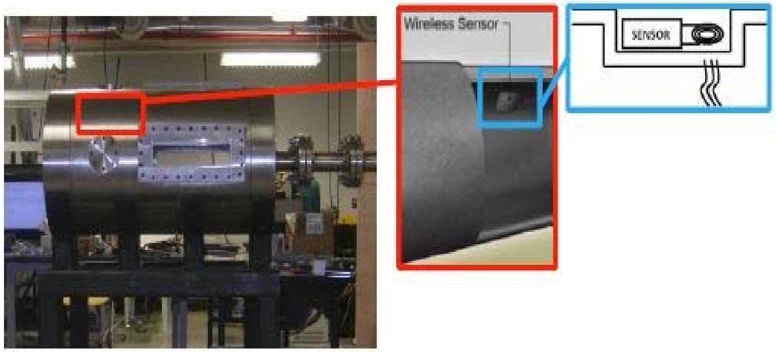
- ❑A simple inductance-Hall Sensor based wireless sensing mechanism





- ❑ Demonstrate effectiveness of wireless temperature sensing

Torch Testing



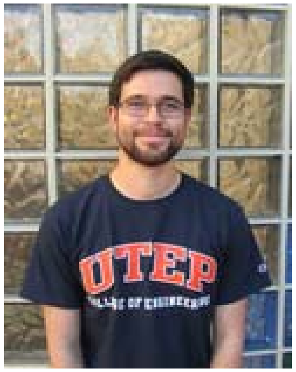
Combustion Rig

Acknowledgements

- This research was performed with the support of the U. S. Department of Energy advanced fossil resource utilization research under the HBCU/MI program with grant number of **FE0011235,** Project Manager: **Richard Dunst**

- Student Involvements




THANK YOU