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Self-powered Wireless Through-wall Data Communication for Nuclear Environments

Advanced Sensors and Instrumentation Annual Webinar

October 23, 2019

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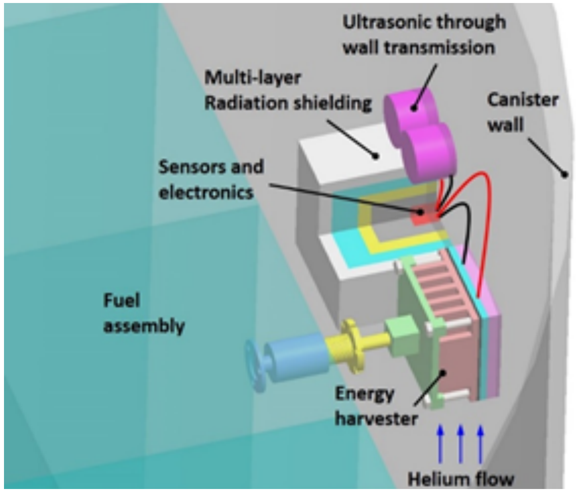
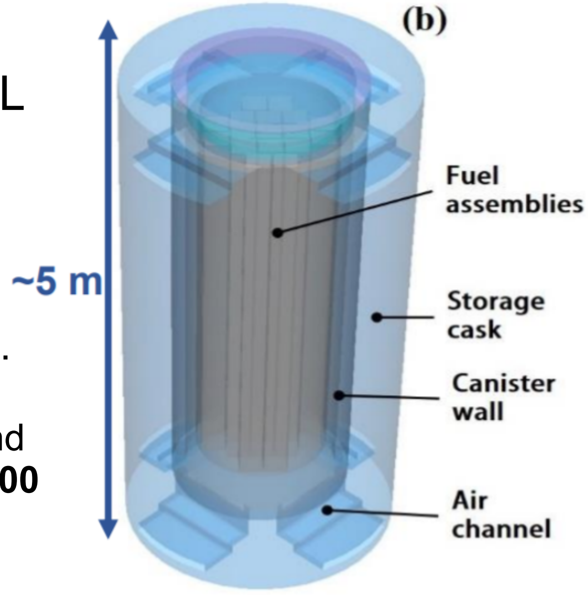
Nance Ericson, Kyle Reed, Roger Kisner, **ORNL**

Project Overview

- Goal and Objective
  - To develop and demonstrate an enabling technology for the data communications for nuclear reactors and fuel cycle facilities using radiation and thermal energy harvesters, through-wall ultrasound communication, and harsh environment electronics.
- Participants (2019)
  - Lei Zuo (PI), Y. Wu, K. Sun, F Qian, H. Jung, Virginia Tech
  - Haifeng Zhang, University of North Texas
  - Nance Ericson, Roger Kisner, Kyle Reed ,ORNL



Background: In the U.S. alone, there are more than **2,100** loaded dry casks, and the number increases by **200** each year.



Dry cask for spent fuel storage

Accomplishments

Demonstrated Energy Harvesting and Ultrasound Communication

Conducted Gamma Radiation Test and Data Analysis for:

- Thermoelectric energy harvester module
- Ultrasonic data communication module
- High-temperature radiation-hardened electronics

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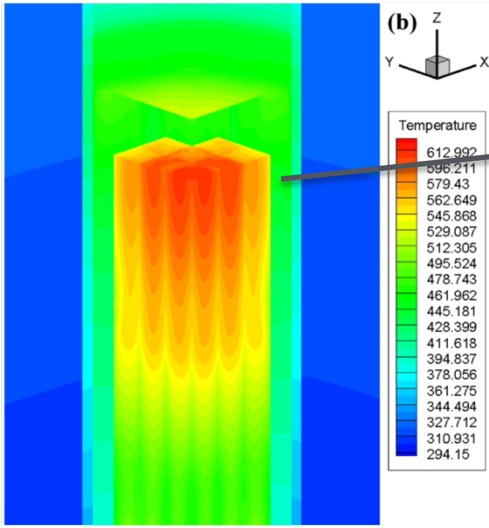
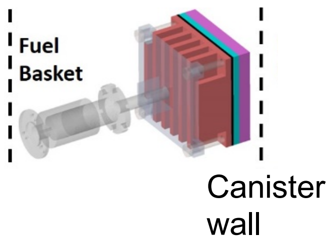
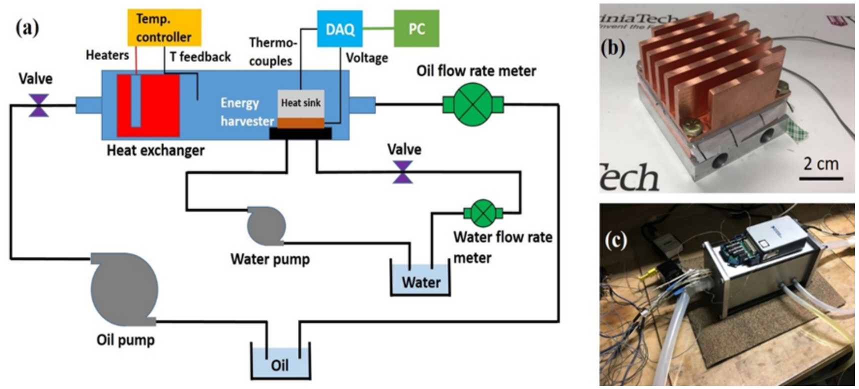
Thermoelectric energy harvester module





Temperature Profiles



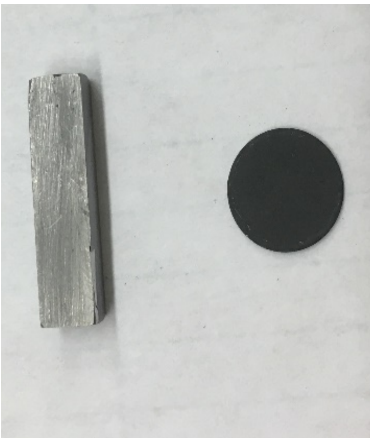
Experimental setup

The voltage and power output of one TEG

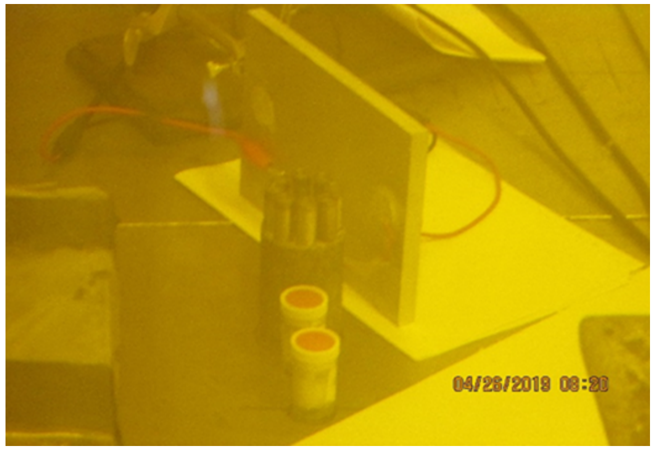
Cases	Temp. drop in TEG (K)	Simu./ Exp. Voltage (V)	Simu./ Exp. power output (mW)
Year 55	12.8	0.712/0.42	93.9/44.2
Year 50	13.7	0.757/0.49	106.1/60.0
Year 45	14.5	0.801/0.60	118.8/90.0

Achieved the Goal: Power 60mW at Y50 >= 10 mW

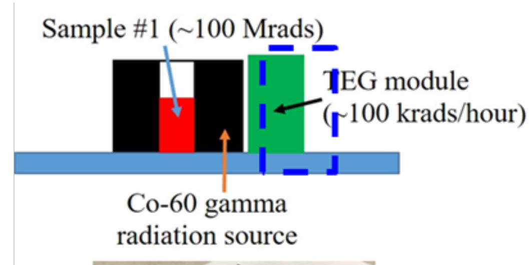
TE energy harvester: Gamma radiation tests

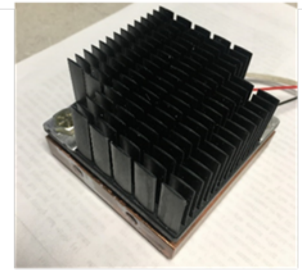


Samples



Experimental setup in the chamber



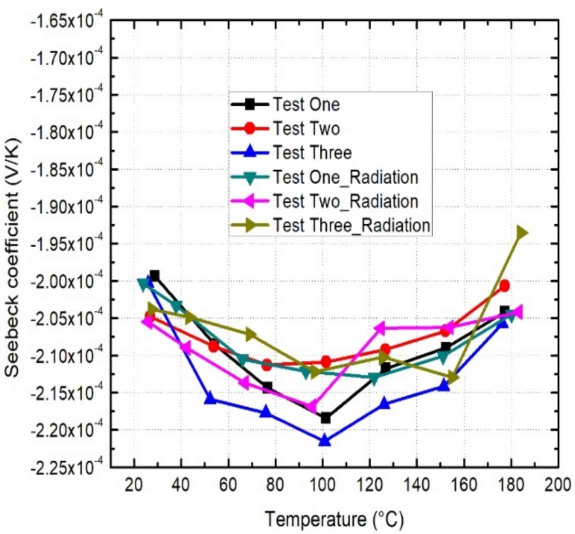


Experimental setup in the chamber

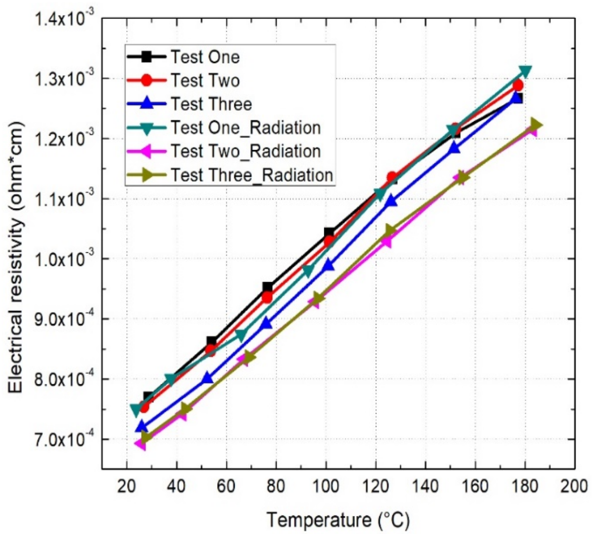
Gamma radiation test was done for all the three modules. The accumulated gamma doses were 5 Mrads and 100 Mrads.

Acknowledgement: Westinghouse

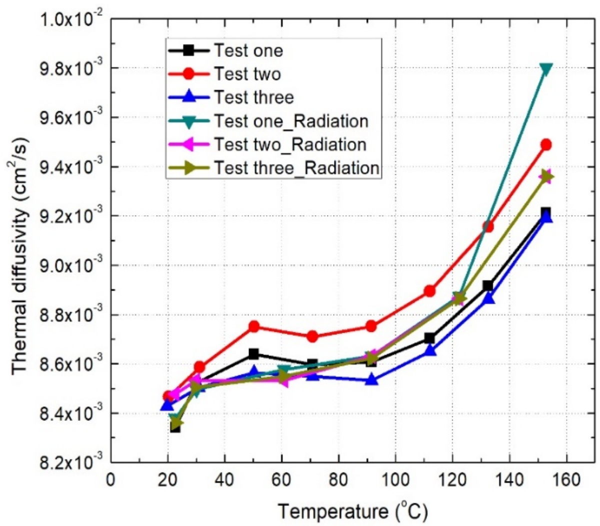
TE energy harvester: Gamma radiation tests



Seebeck coefficient

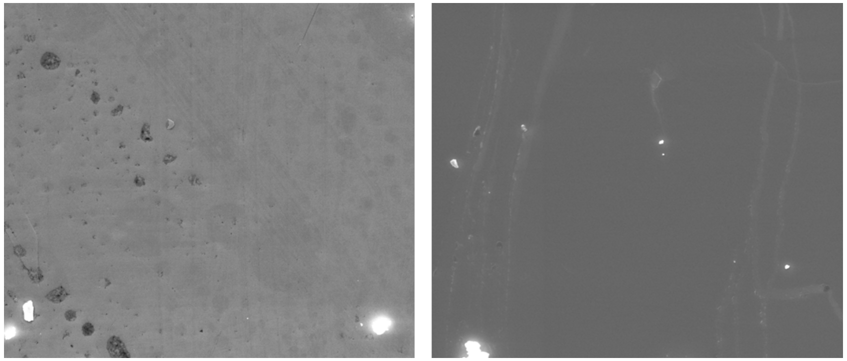


Electrical resistivity

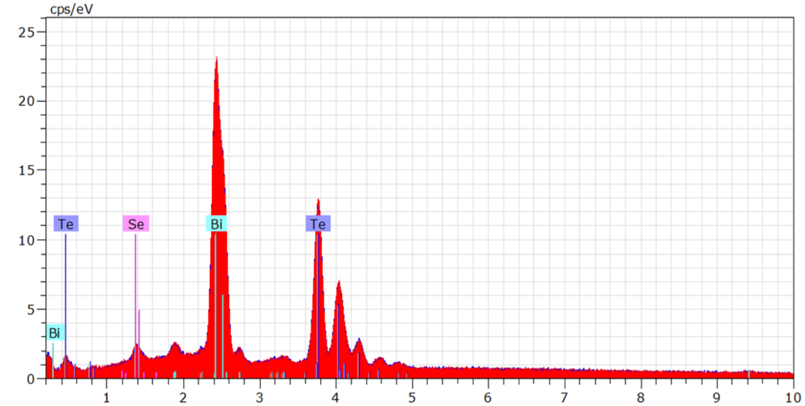


Thermal diffusivity

No obvious changes at 100M Rads



SEM images before and after test, 5000-time magnification.



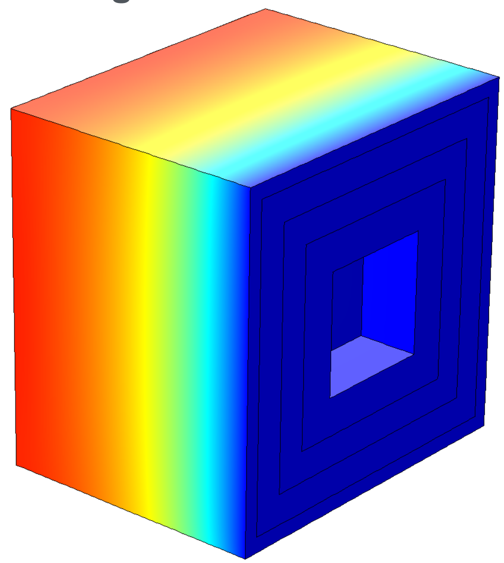
Atomic spectrum before and after test (blue and red)

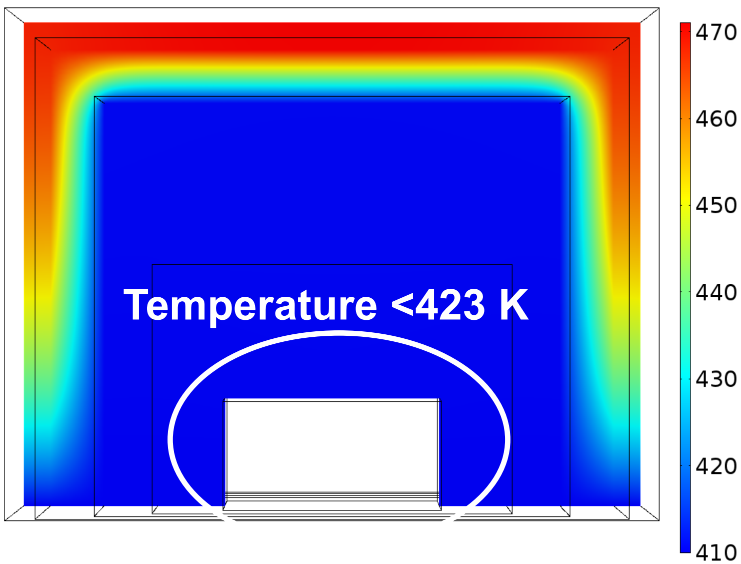
TE energy harvester: Radiation & thermal shielding

Radiation and thermal shielding for the electronics

Materials layers	Thermal conductivity (W/(m*K))	Thickness (mm)
Steel	50.2	2
Silica (removed)	1.4	5
Fiber glass	0.1	10-20
Copper	400	10
W-B4C	141.5 (Estimated by weight ratio)	25 (safe value for radiation shielding)

Boundary conditions (according to simulation results):
Ambient temperature: 480 K
Wall temperature: 410 K
Target: <150 °C at the internal surface (423 K)

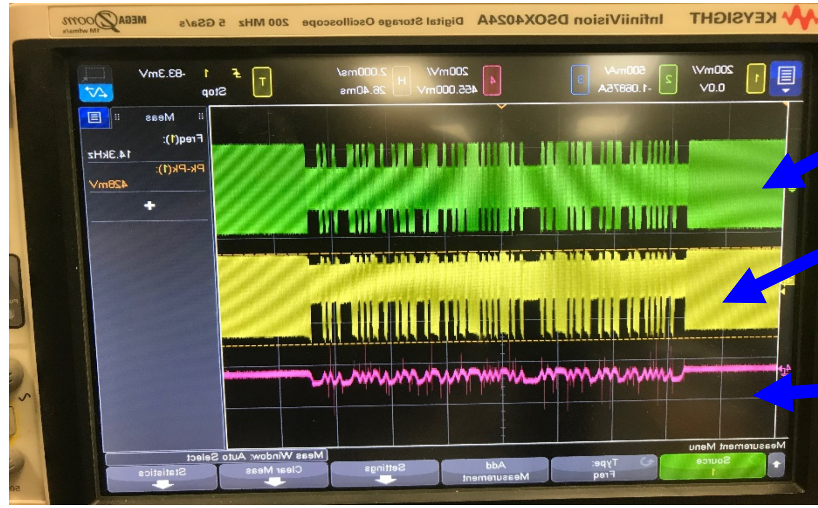




Temperature distribution in the shielding block

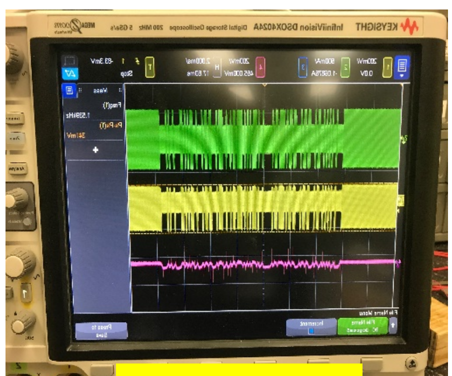
Ultrasonic Data Communication Module

Through wall communication modulus in a oven.

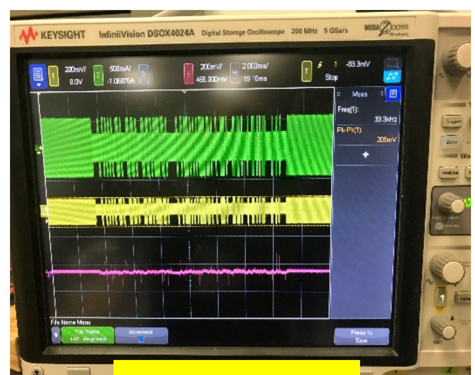


Through wall communication result (carrier wave frequency=100 kHz)

40 Deg C



100 Deg C



160 Deg C

180 Deg C

Ultrasonic Data Communication Module

- We did the experiment in a different way. In this method we did the experiment using a laser beam as an receiver. The expectation of this experiment was to receive the same input data as output without a piezo sensor as a receiver.
- In this experiment we have used a Aluminum plate with the dimension of 39in X 3 in X 0.4 in with a PZT patch attached on one side, the dimension for the PZT patch is 5 in x 3in x 0.4 in.
- The laser beam was able to receive the signal and display on the Oscilloscope..
- The experiment prove the feasibility of using laser to replace the piezo element for data communication

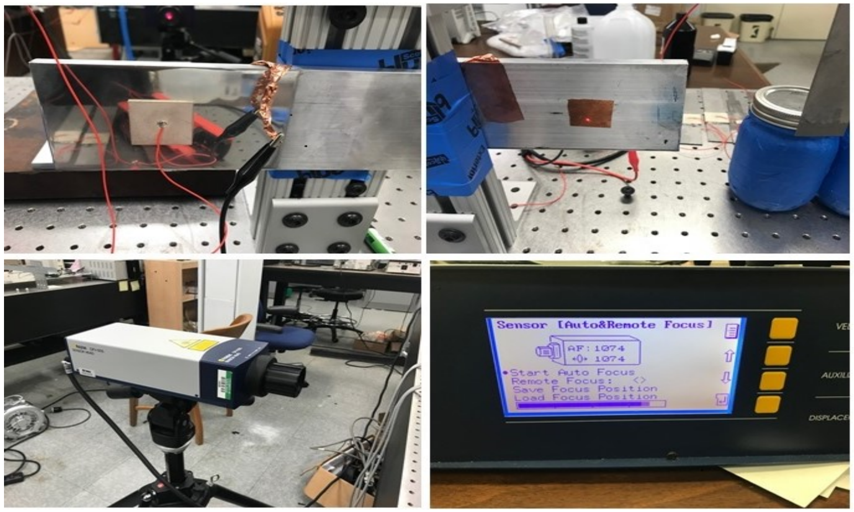
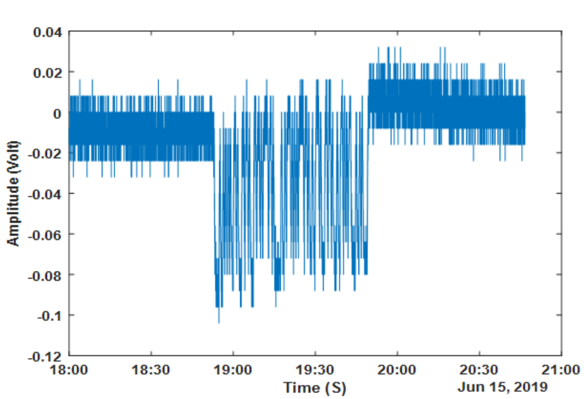


Fig. 1. Laser beam experiment setup

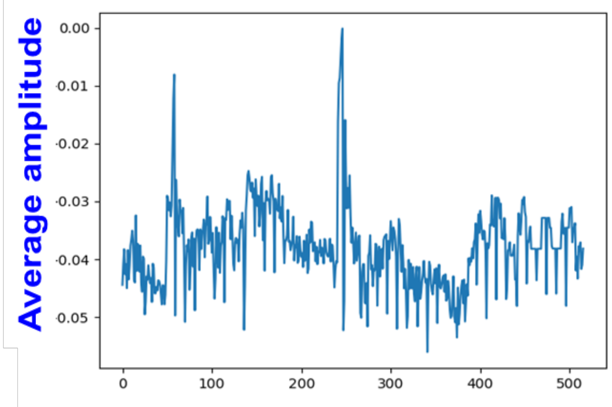
Fig. 2. The laser transmission result

Ultrasonic Data Communication: Radiation tests

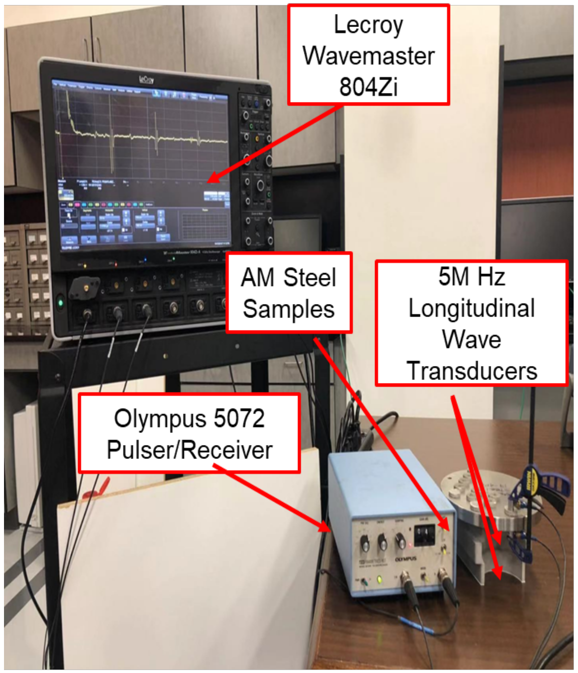
Radiation test of the ultrasonic data transmission



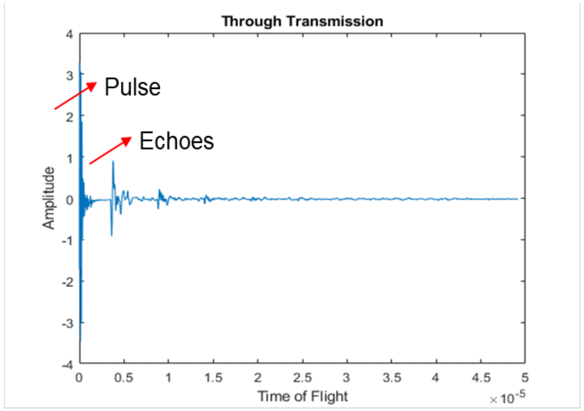
The transmitted binary data packet

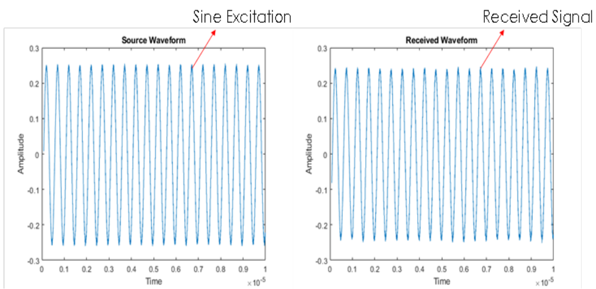


Survived after 100M Rads of Gamma Radiation



Picture of the setup





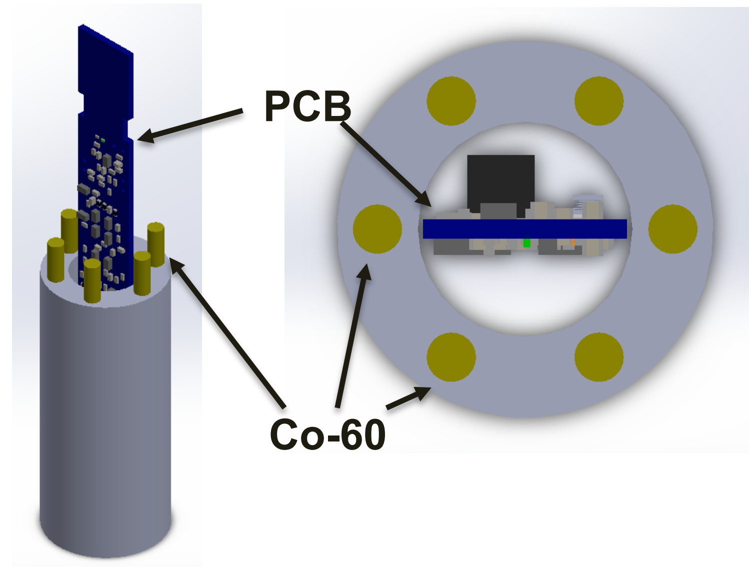
Experiment results

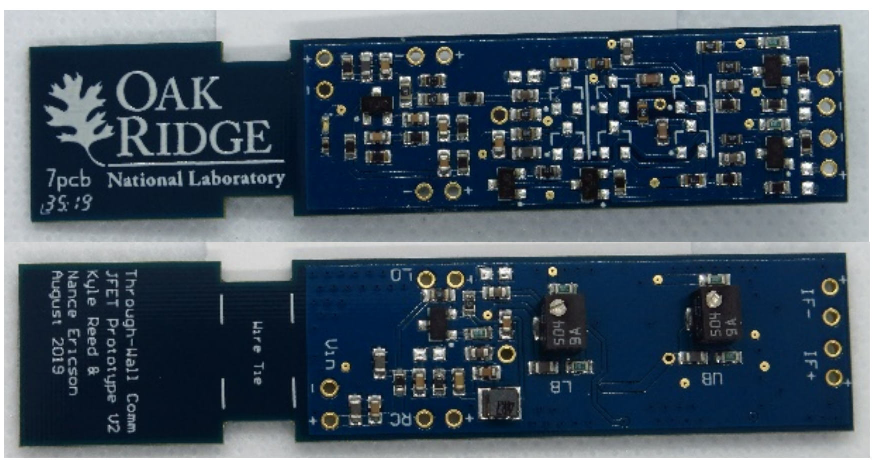
Feasibility verification of data communication through steel AM part

Acknowledgement: Westinghouse

High-temperature radiation-hardened electronics

- In FY19 (Year 3), a set of JFET boards were successfully irradiated to 2 Mrad TID at Westinghouse with a Cobalt-60 source (Pittsburgh, PA)
- The radiation dose uniformity decreases across the board as the dose rate is increased due to the initial board and source geometries
- ~500 krad/hr can be achieved if the electronics are placed inside the source cylinder (shown on right)
- Revised JFET PCBs (shown below) were designed to fit inside the Westinghouse (Pittsburgh) Cobalt-60 source

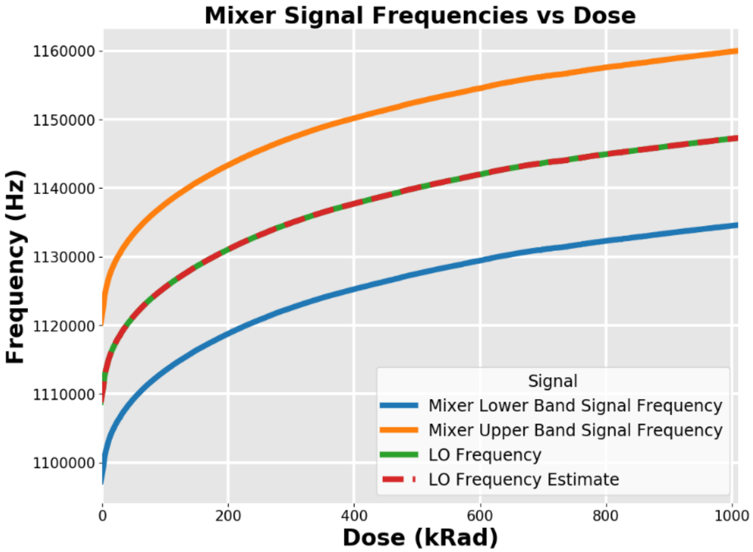




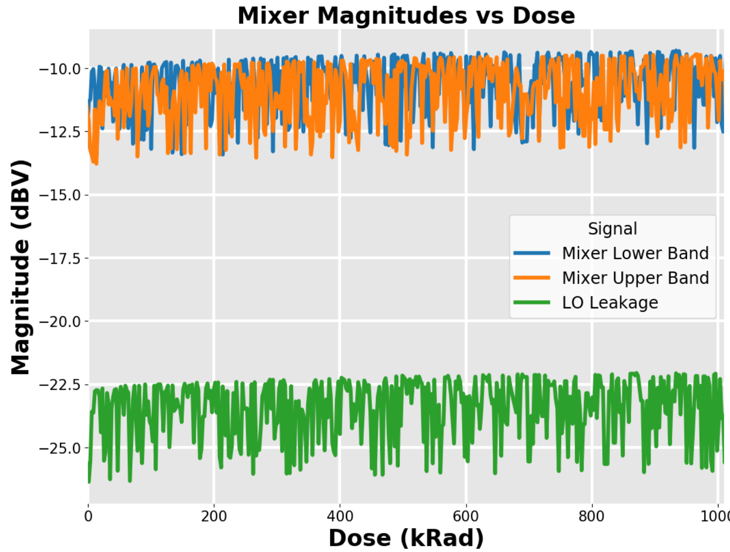
Revised JFET circuit enabling placement inside the Co-60 source for 100 MRad dose test

- The revised JFET boards will be tested inside the source cylinder to ≥100 Mrad or to failure
- Only a single sensor oscillator was placed on the board
- Other variability was removed from the design
- Connections are soldered directly to the board
- A tab was added on the board to better facilitate PCB placement and removal from the center of the source
- A notch was cut in the board to attach a cable tie for cable strain relief

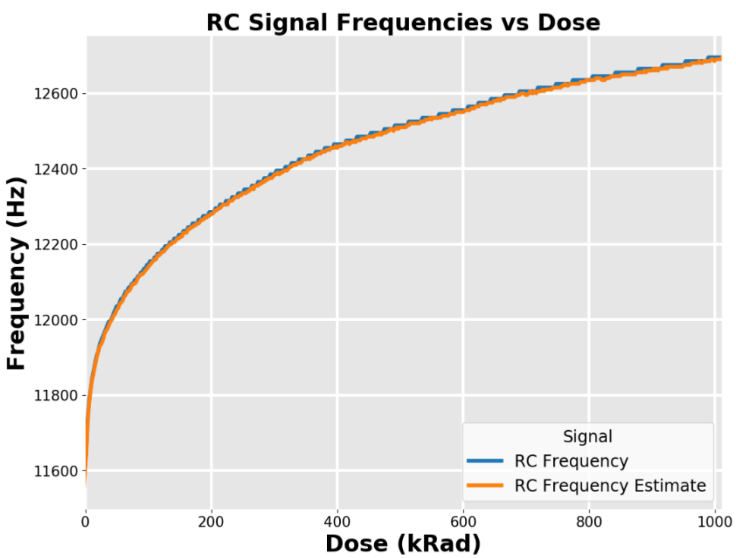
High-temperature radiation-hardened electronics



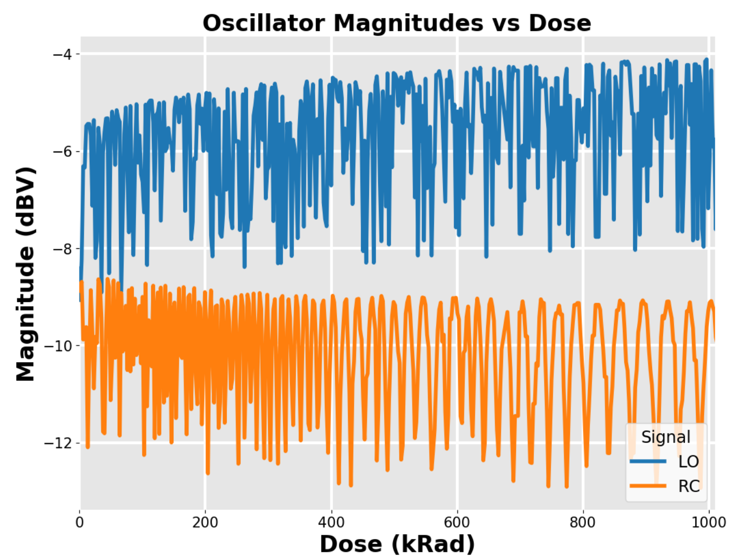
Plot of the measured and estimates of the signals in the RF frequency band of the circuit



Plots of the magnitude measurements of the output of the Gilbert Mixer



Plot of the measured and estimated RC sensor frequencies



Plots of the magnitude measurements of LO and the RC sensor

Technology Impact

The expected impacts and benefits includes,

1) Energy harvesting from nuclear radiations where no other energy sources are available;

2) Validation of the proposed electronics system incorporating energy harvesting and advanced communications through dense barriers, as is needed in nuclear environments.

3) Development of a detailed strategy for full realization of a high temperature, radiation tolerant electronics and data communication platform for nuclear environments.

Conclusion

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Conclusions

1. The TEG power module passed the gamma radiation test and proved functional in nuclear environment.

2. High-temperature audio signal & text through-wall transmission were tested and proved feasible.

3. A High-temperature and Radiation Hardened Electronics Circuit was designed and radiation test was successful.

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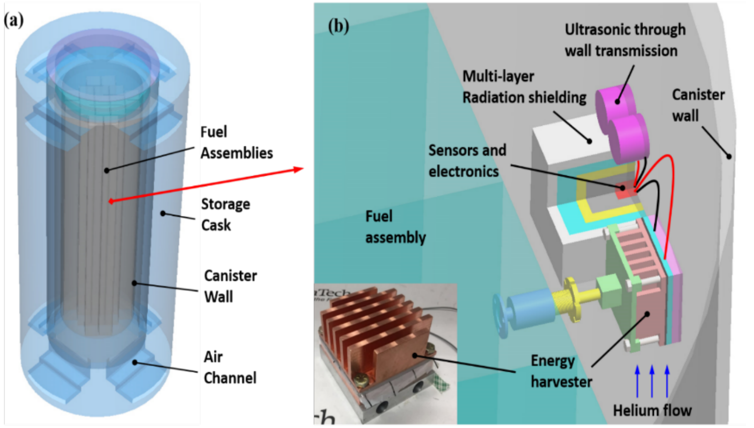

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