Ultrasonic Multipoint Temperature Sensor for Nuclear Reactor Applications

SBIR Phase I (DE-SC0022826)

Advanced Sensors and Instrumentation (ASI) Annual Program Webinar

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Project Overview

Motivation

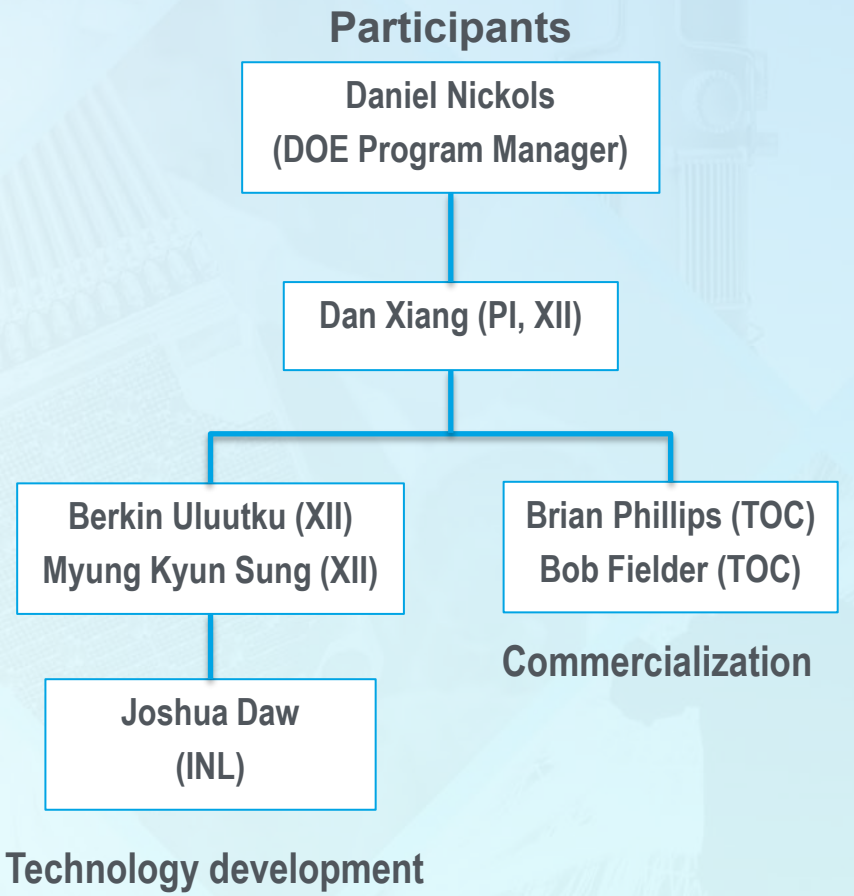
DOE seeks development of sensors and nondestructive evaluation technologies, capable of surviving in substantial radiation fields is necessary to advance nuclear plant control and monitoring systems, data analysis and other nuclear applications with demonstrated

- Accuracy
- Reliability
- Resilience
- Ease of replacement and upgrade
- Directly support existing power reactors, material test reactors and other similar systems.

Our Solution

Ultrasonic Multipoint Temperature Sensor (UMTS) that provides

- Multi point temperature profile measurements along a long waveguide
- Long operation life in nuclear harsh environments
- Cost-effective and fieldable deployment
- Experimental verification and validation
- Ease of use with the accompanying software



Technology Impact – Prior Arts

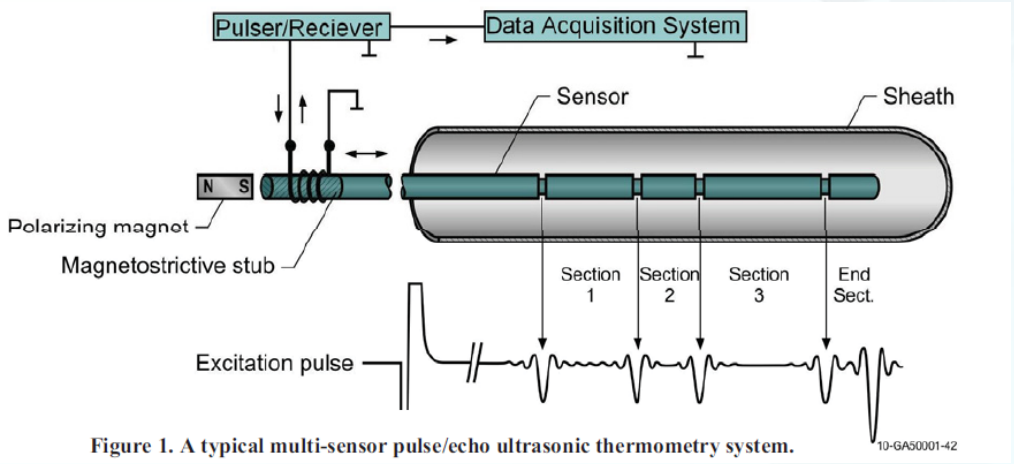
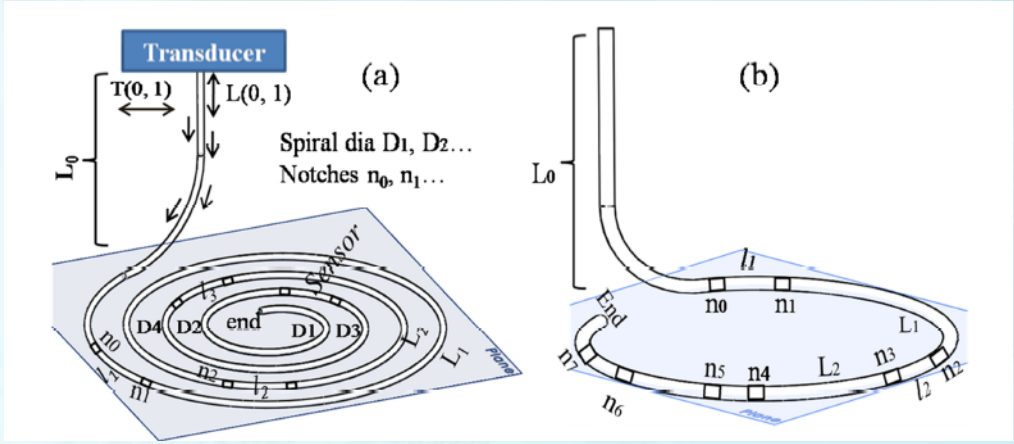
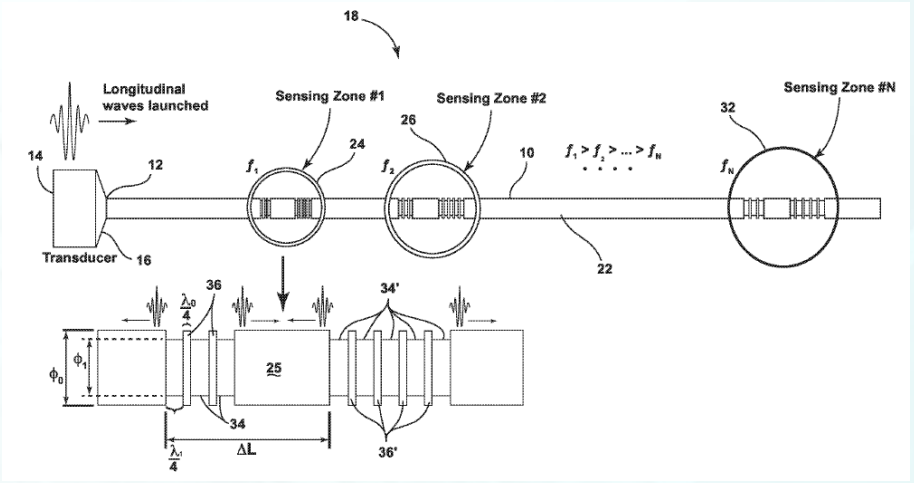


Figure 1. A typical multi-sensor pulse/echo ultrasonic thermometry system.

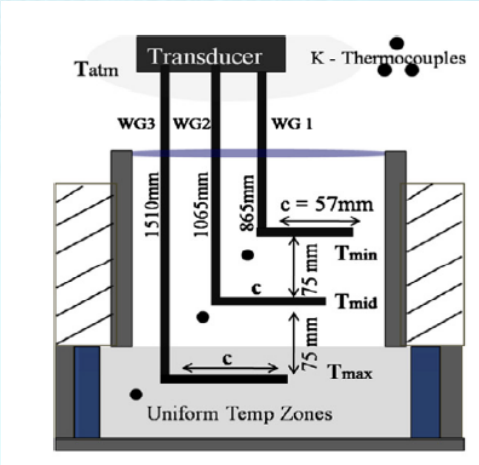
J. Daw et al, *INL/CON-11-23912*, Preprint July. 2012,



S. Periyannan et al. ,*Ultrasonics*, vol. 74, pp. 211–220, Feb. 2017,



N. Cetiner et al. ORNL, US Patent published 2021/0055167, 2021

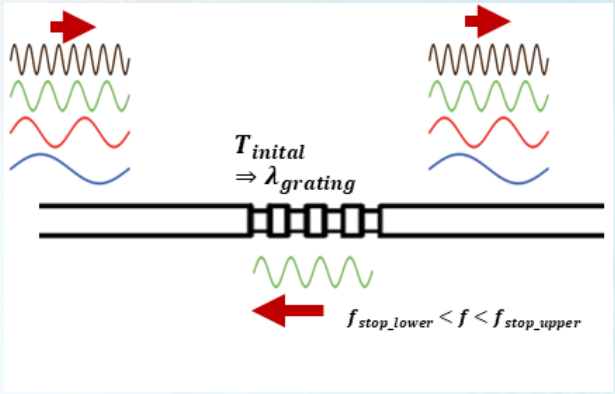


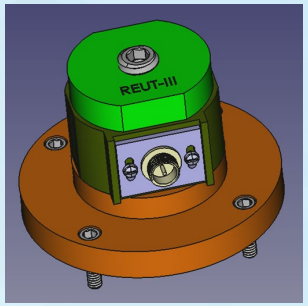
S. Periyannan et al. ,*AIP Adv.*, vol. 7, pp. 035201, Mar. 2017,

Technology Overview – UMTS

- Gratings with periodic internal structures will have wavelength selective reflectivity
- The change in temperature will alter this selective reflectivity
- Analogous to Fiber-Bragg Grating (FBG) concept

$$\lambda_{wave} = 2n_e\lambda_{\text{grating}}$$

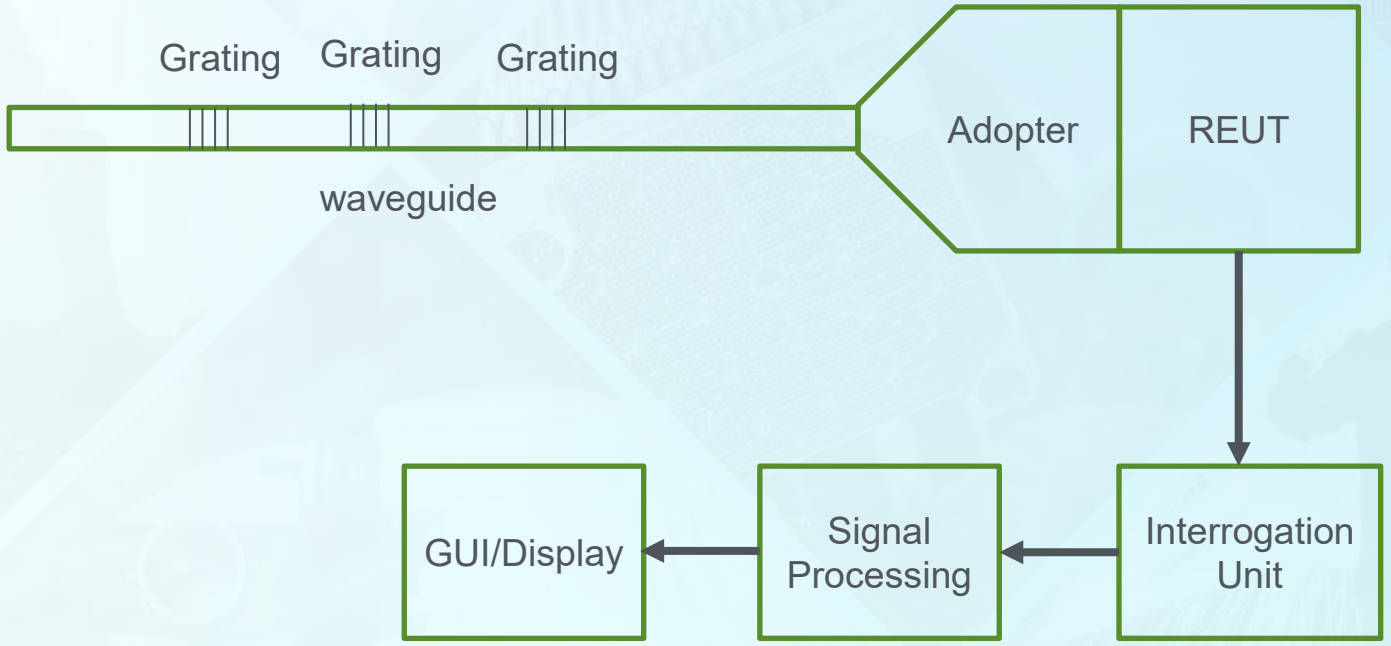




REUT sensor, US Patent 11,620,973

Applications

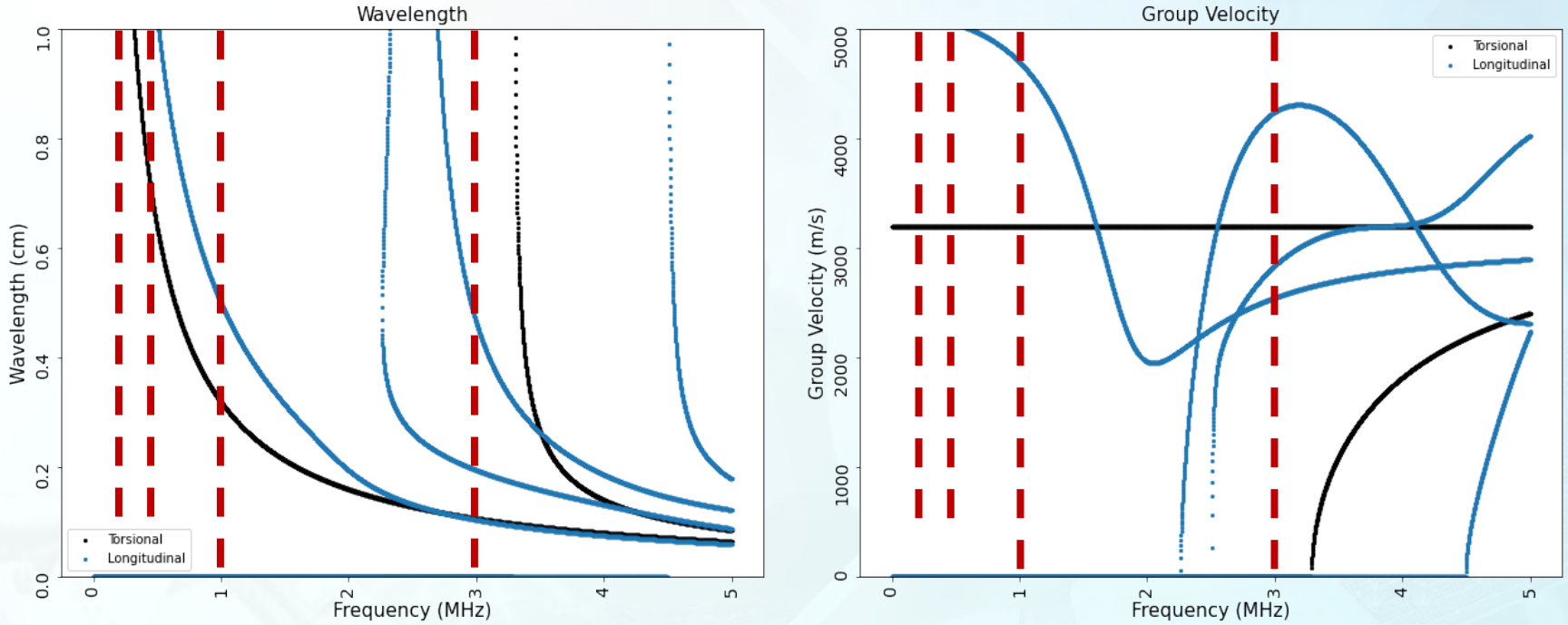
- In-pile temperature profile measurements
- Divertor diagnostics to determine strike point and X-point positions in Fission Power Plant
- Distributed temperatures, fluid levels, viscosities, etc., with limited access in reactors



Non-provisional Patent #63,462,291: ULTRASONIC WAVEGUIDE SENSOR AND APPARATUS FOR DISTRIBUTED PHYSICAL PARAMETER MEASUREMENTS

Dispersion Analysis of Waveguides

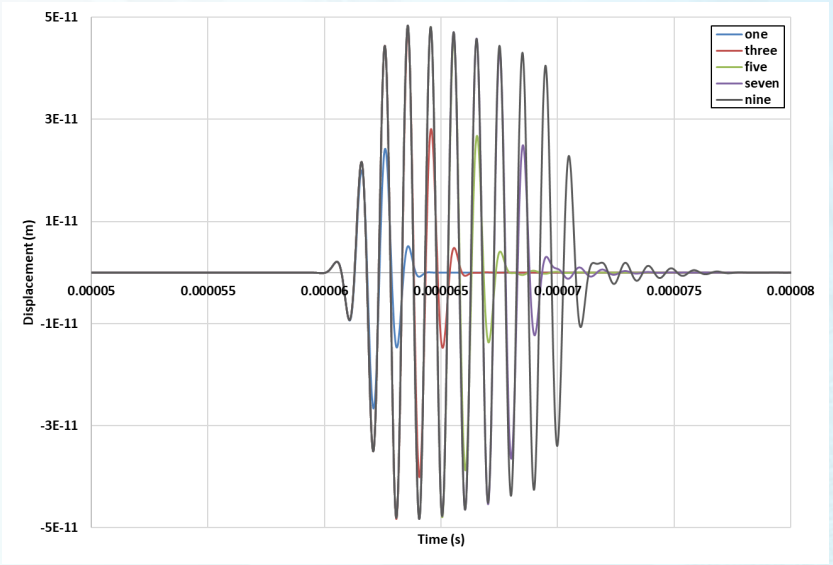
Dispersion Curve for
1/16” Diameter, Stainless Steel 316 Rod

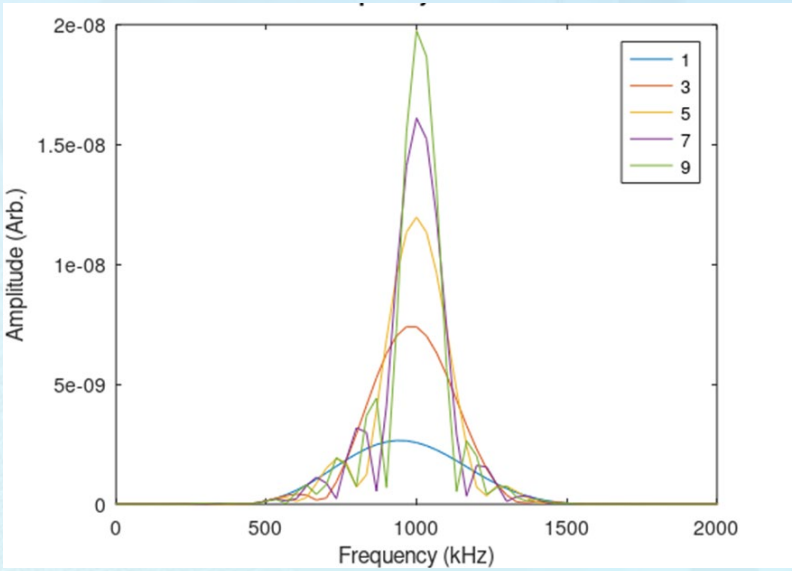


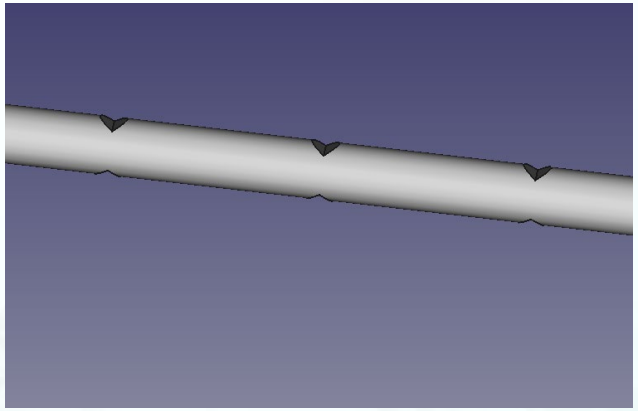
Frequency	300 kHz	500 kHz	1 MHz	3 MHz
Wavelength	18mm	12 mm	5 mm	2 mm
Half Wavelength	9 mm	6 mm	2.5 mm	1 mm

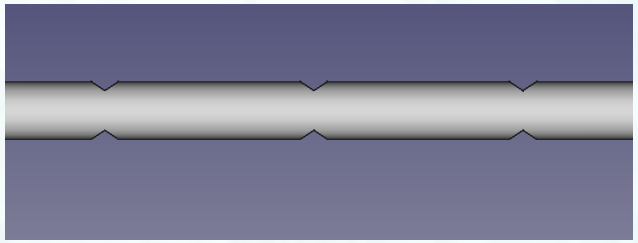
FEA Analysis of Gratings

- Small notches to build gratings
- Based on manufacturable geometries.
- Low individual perturbation



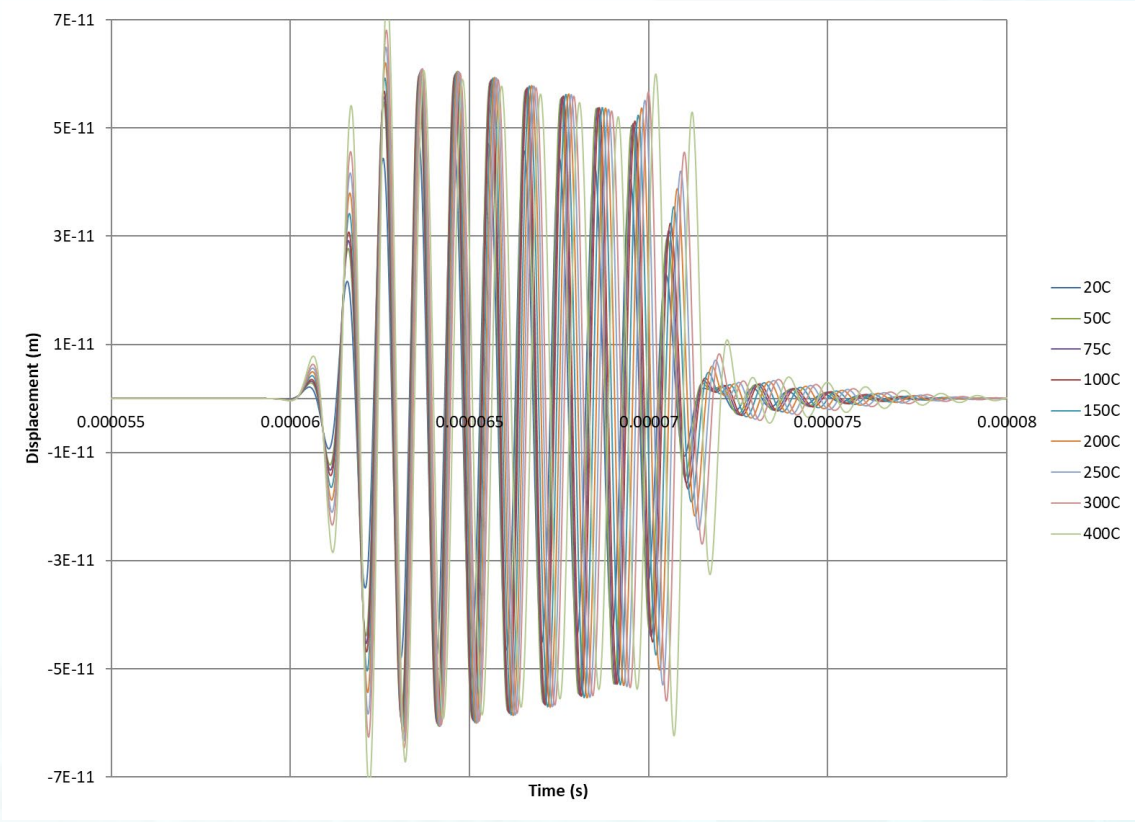


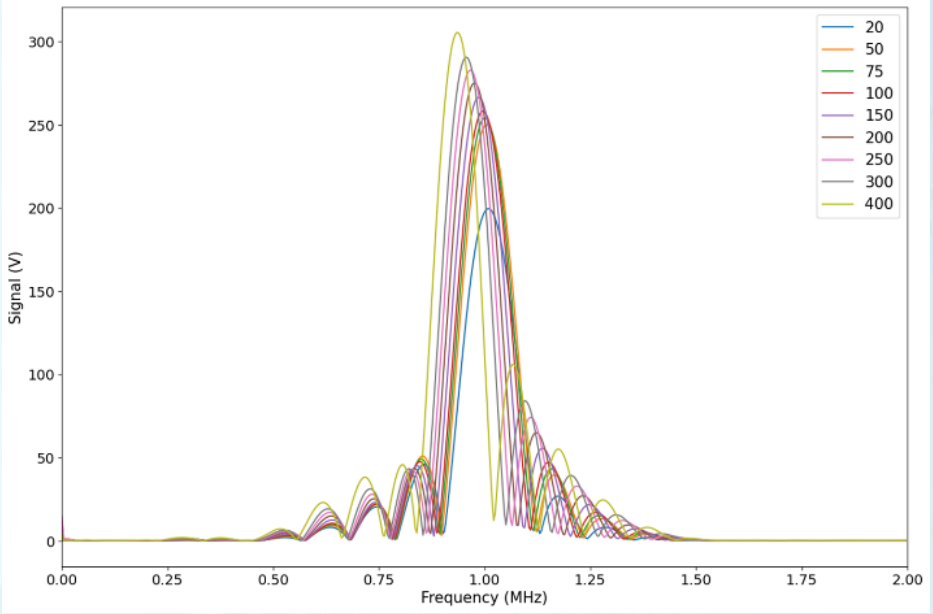




- Increasing number of notches, increases the reflection to some extent.
- Increasing number of notches widens the reflected wave packet.

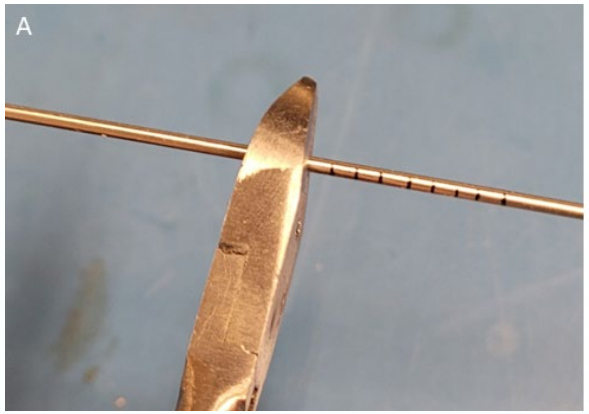
FEA Analysis of Temperature Effects

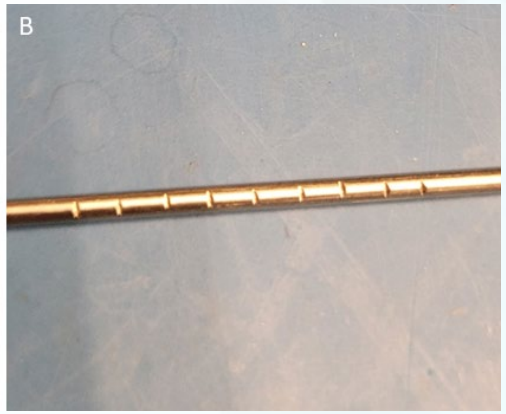


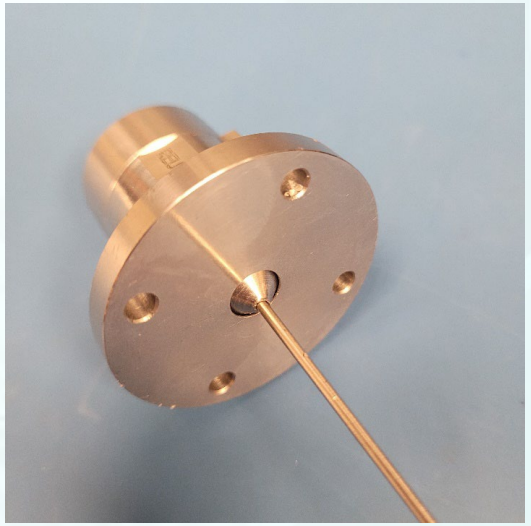


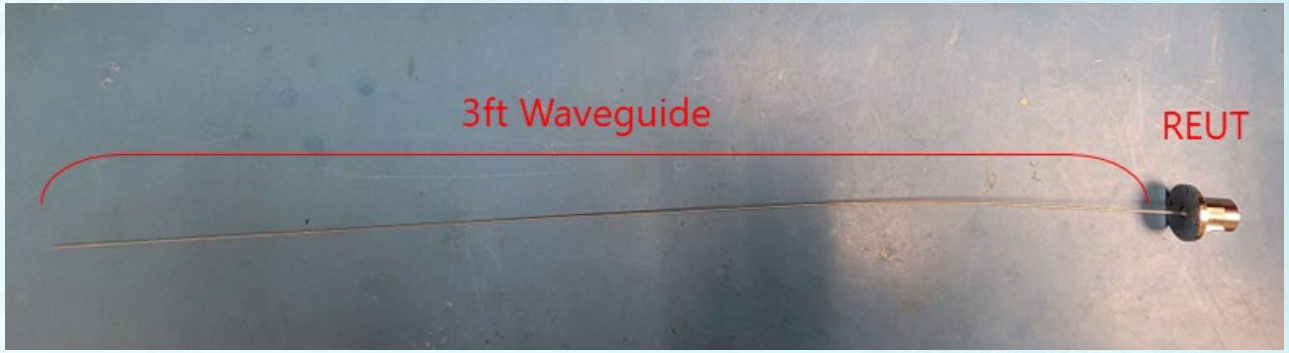
- Changes in the reflected wave packet is observed with temperature.
- The wave packet widens with the increasing temperature, due to frequency decrease.
- An amplitude increase is observed with temperature.

Prototyping

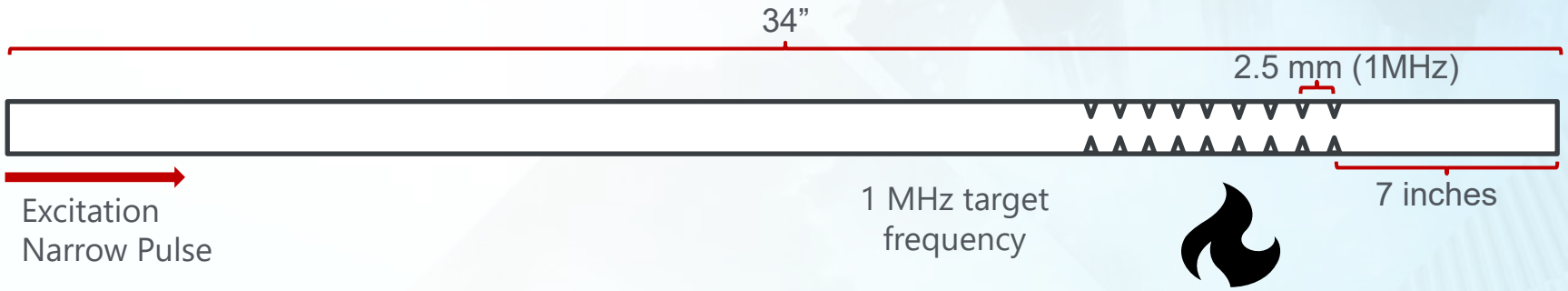


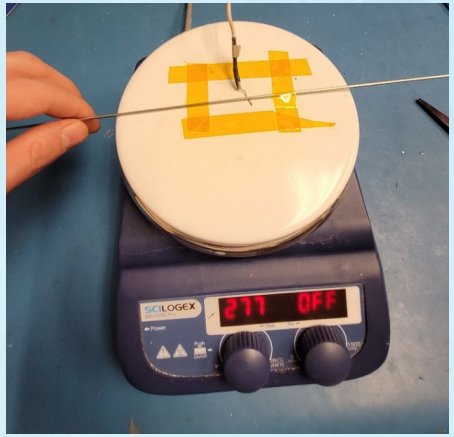


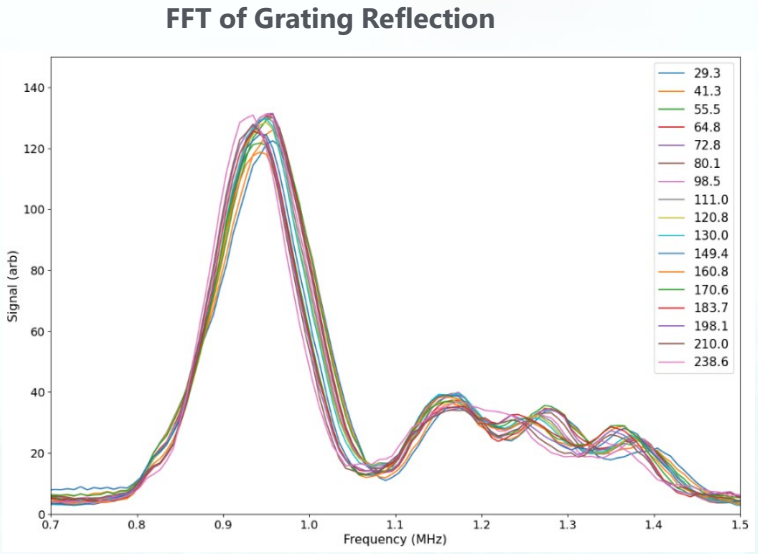


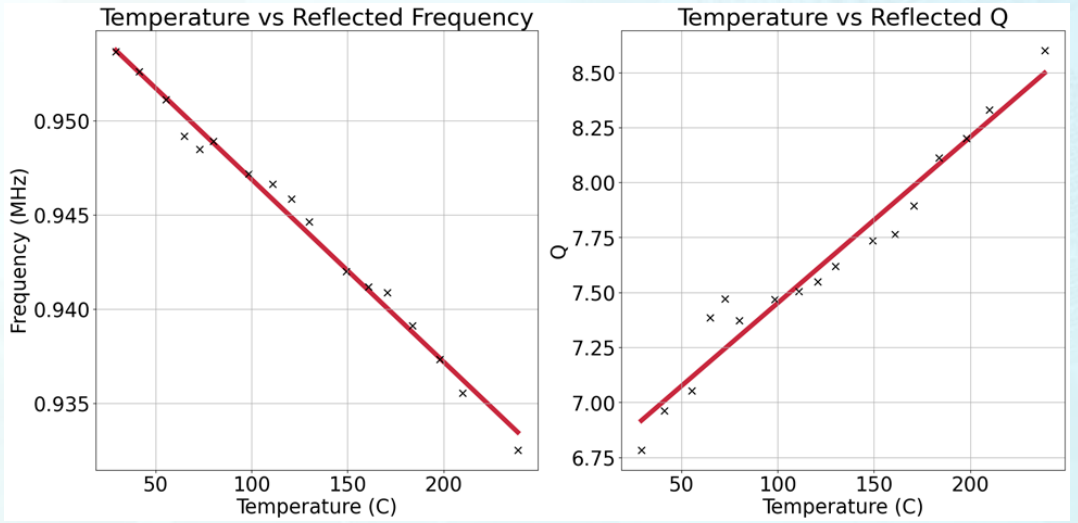


Experiment – Temperature measurement from a single grating



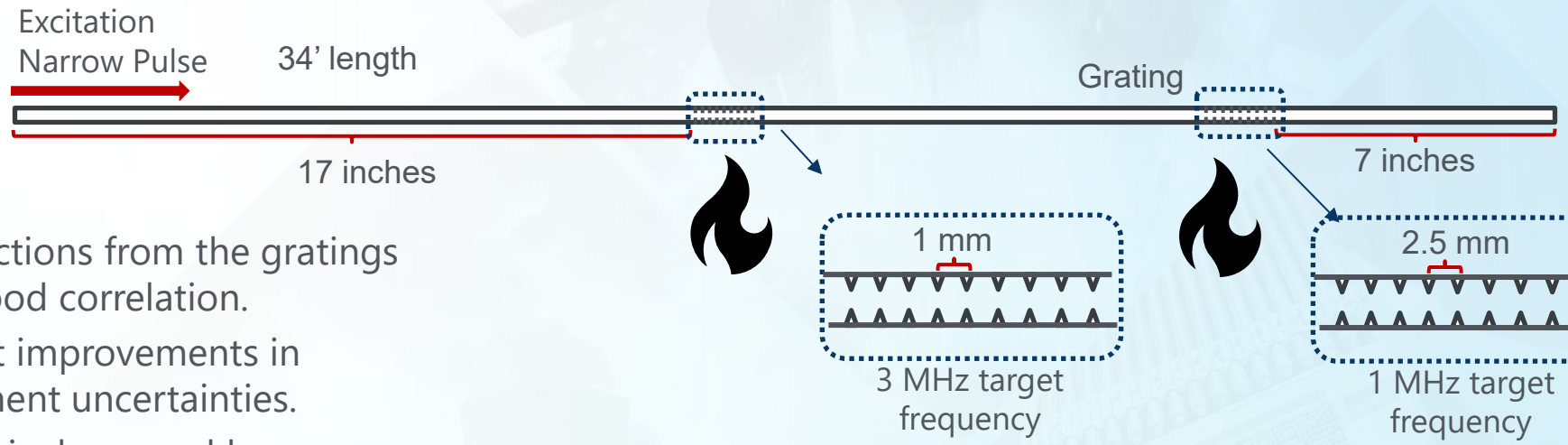






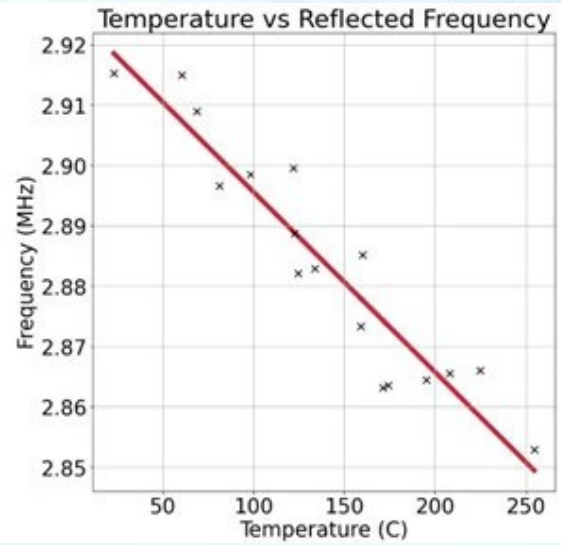
- An observable change in center frequency and bandwidth (Q) with temperature
- As expected from FEA study, a strong correlation between temperature and reflected frequency
- A good correlation between temperature and Q. which is proven unreliable in future experiments

Experiment – Temperature measurements from two gratings

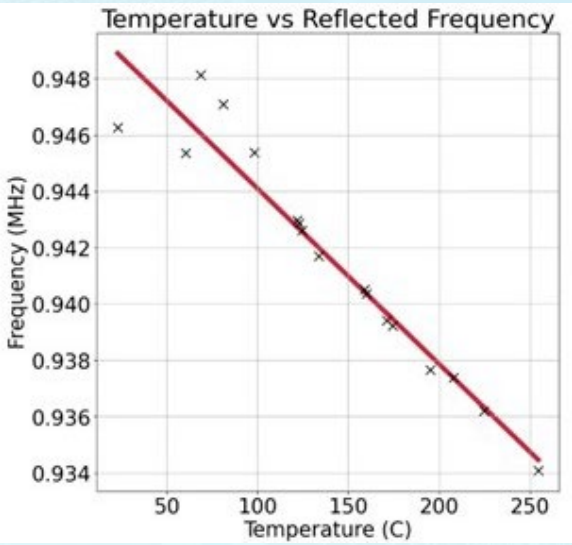


- Both reflections from the gratings show a good correlation.
- Significant improvements in measurement uncertainties.
- Cross-talk is decreased by ordering targeted frequencies high to low.

Middle Grating

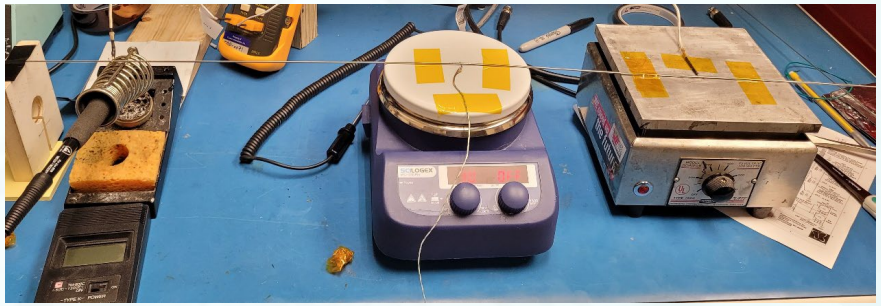


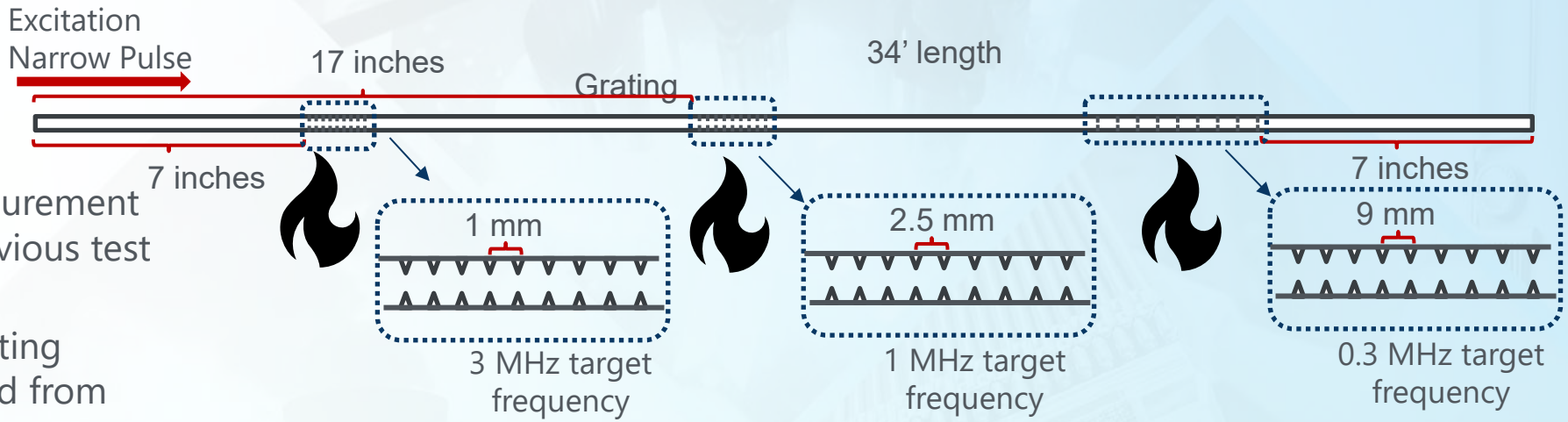
End Grating



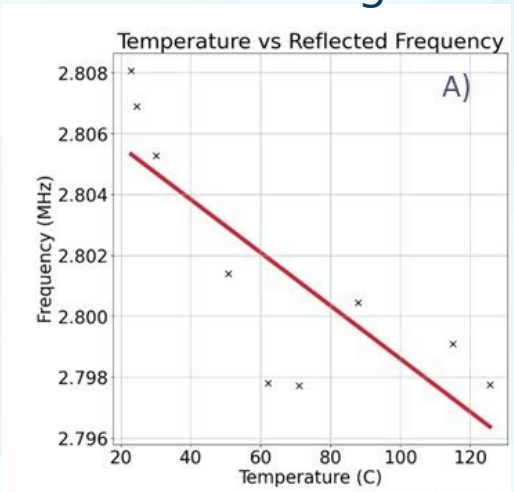
Experiment – Temperature measurements from three gratings

- 2nd and 3rd grating measurement results are similar to previous test without the 1st grating.
- Large variation in 1st grating measurements is resulted from the soldering iron heating source.
- Cross-talk is minimized by ordering targeted frequencies from high to low.

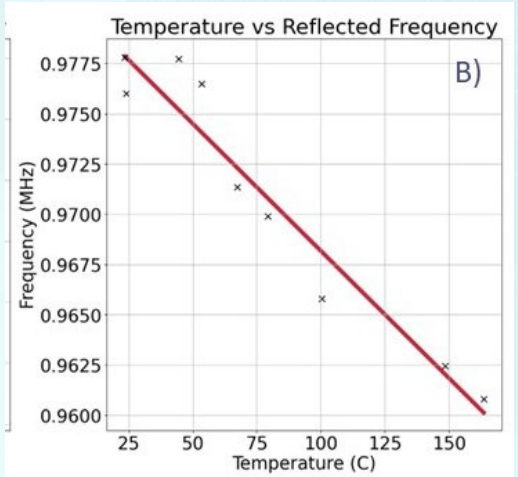




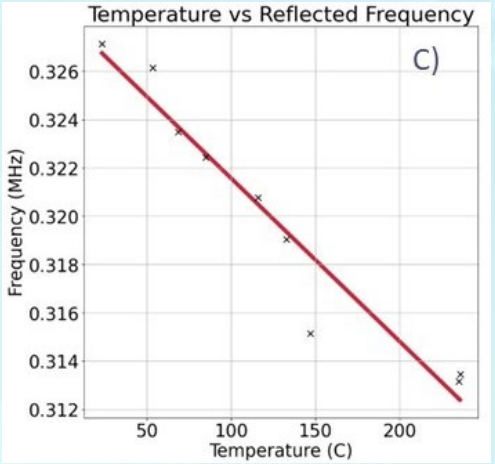
1st Grating



2nd Grating



3rd Grating



Concluding Remarks

- A novel multi-point temperature sensing method (US patent application #63,462,291) is developed and the feasibility of the concept is demonstrated.
- Waveguides utilizing periodic grating structures as frequency selective reflectors are designed and fabricated.
- Frequency of grating reflection signal is a function of the temperature, which is observed from experiments.
- This relationship can used to measure temperature at a grating point.
- Multiple grating structures are built on a single waveguide and multi-point temperature measurements are performed using a single waveguide.
- This grating waveguide design, in conjunction with the REUT sensor, may be used to sense multi-point temperatures, fluid levels, viscosities, and other physical parameters in nuclear harsh environments.

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Make state-of-the-art obsolete

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Thank You