U.S. DEPARTMENT OF ENERGY | Office of NUCLEAR ENERGY

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Transmission of Information by Acoustic Communication Along Metal Pathways in Nuclear Facilities

Advanced Sensors and Instrumentation Annual Webinar

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Project Overview

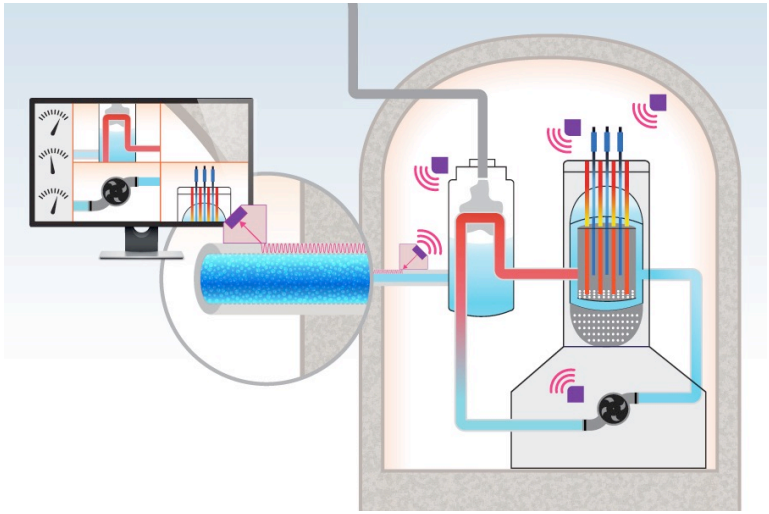
- Goal and Objective
  - Demonstrate ability to transmit information through physical boundaries at a nuclear facility
- Participants (2019)
  - Alexander Heifetz, Dmitry Shribak, Sasan Bakhtiari, Richard B. Vilim – Argonne, Xin Huang, Boyang Wang, Jafar Saniie – Illinois Tech, Andrew C. Singer - UIUC
- Schedule
  - Y1: developed system requirements and implemented ultrasonic communication setup on a pipe
  - Y2: demonstrated ultrasonic data transmission on room temperature pipe
  - Y3: demonstrated ultrasonic data transmission on elevated temperature pipe

Accomplishments

- Deliverables
  - Final Report for Transmission of Information by Acoustic Communication along Metal Pathways in Nuclear Facilities, ANL-19/42, September 30, 2019.
  - Evaluation of Acoustic Channel Capacity for Complex Piping Topology, ANL-19/28, August 30, 2019.
  - Small-Scale Demonstration of Communication LAN Prototype, August 15, 2019.
  - Tradeoffs in Parameter Values for Optimal Performance, ANL-19/11, March 29, 2019.

Accomplishments Y1

- Developed System Specification
  - Focused on acoustic transmission of information in an out of the containment building
  - Containment walls are 4 to 5 feet thick concrete with steel liner
    - Blocks RF transmission
  - Proposed acoustic communication system at a nuclear facility would transmit information on steel pipes already in place for nuclear reactor operation



Accomplishments Y1

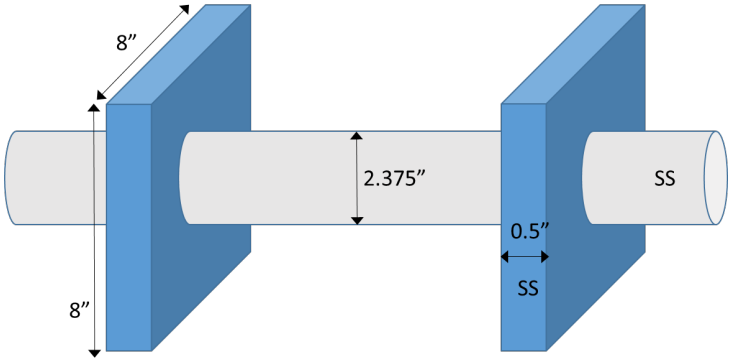
- Developed System Specification
  - Identified charging line stainless steel pipe of chemical volume control system (CVCS) as viable conduit for information transmission in and out of containment building
    - Pipe penetrates containment wall through a tunnel in concrete sealed on both ends by steel plates
  - Transducer operating conditions are specified by containment isolation function

Typical environmental stresses on containment isolation function components

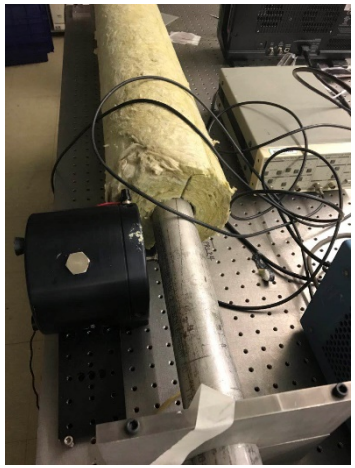
Parameter	Normal	Accident
Temperature	50-120 °F	300 °F
Pressure	atmospheric	70 psig, max
Relative Humidity	30-100 %	100 %
Radiation	50 rads/hr	150 Mrads/hr

Accomplishments Y1

- Developed test article for proof-of-principle studies
  - Schedule 160 stainless steel pipe with baffle plates to simulate mechanical constraints at actual NPP



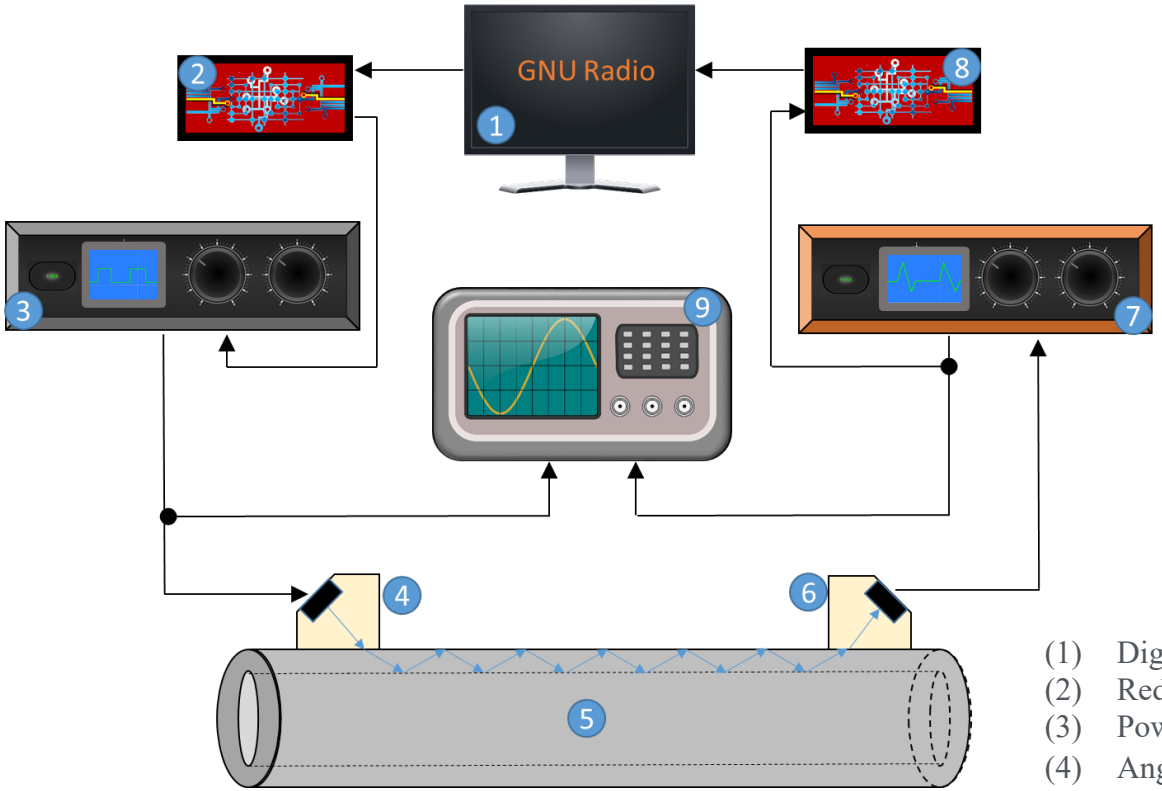
  - Demonstrated resilience of ultrasonic data transmission over pipe to low frequency noise
    - Experimentally simulated process noise with mechanical shaker vibrating a pipe
    - Vibrated pipe with 100Hz, 1KHz, 10KHz
    - Observed no interference effect on ultrasonic 2MHz shear wave information-carrying signal



Frequency-tunable mechanical shaker in contact with pipe

Accomplishments Y2

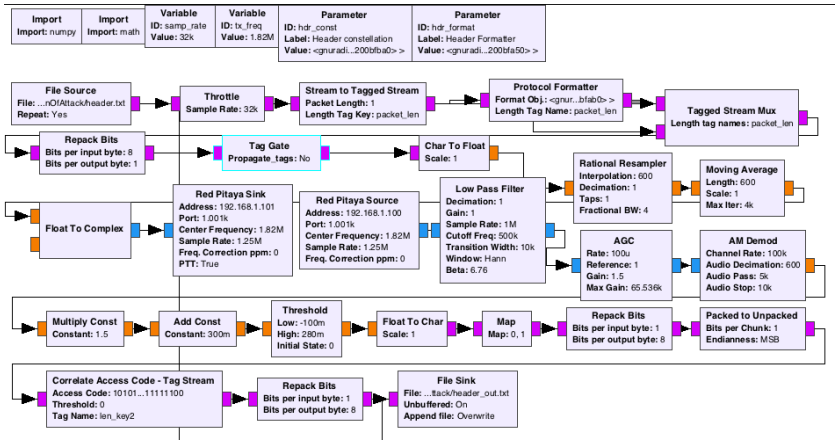
- Developed Nuclear Pipe Ultrasonic Communication System



(1) Digital computer with GNURadio software
(2) RedPitaya transmitter board
(3) Power amplifier,
(4) Angled-wedge mounted PZT transmitting refracted shear waves
(5) Stainless steel pipe
(6) Angled-wedge mounted PZT receiving shear waves
(7) Low noise amplifier
(8) RedPitaya receiver board
(9) Digital oscilloscope

Accomplishments

- Ultrasonic image transmission on a pipe at room temperature
  - Developed ASK communication protocol in GNURadio environment
    - Transducers are separated by 170cm on a pipe
    - Carrier frequency is 1.8MHz
    - 2Kbps data rate (bit pulse duration is 500 μs)
    - BER~10^{-3}



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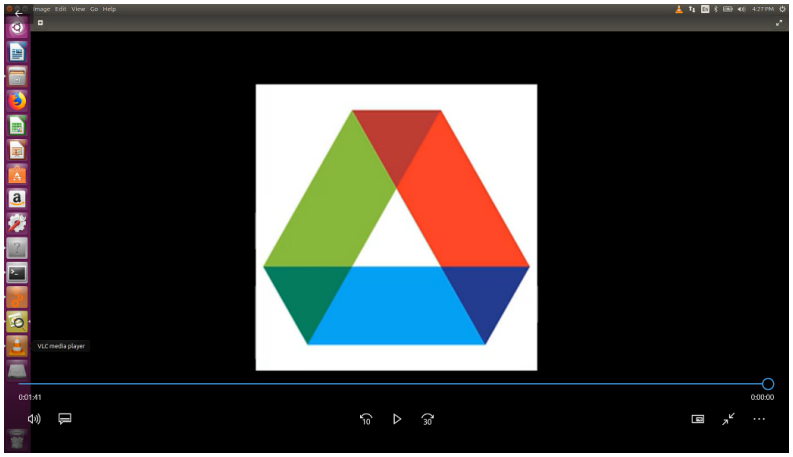
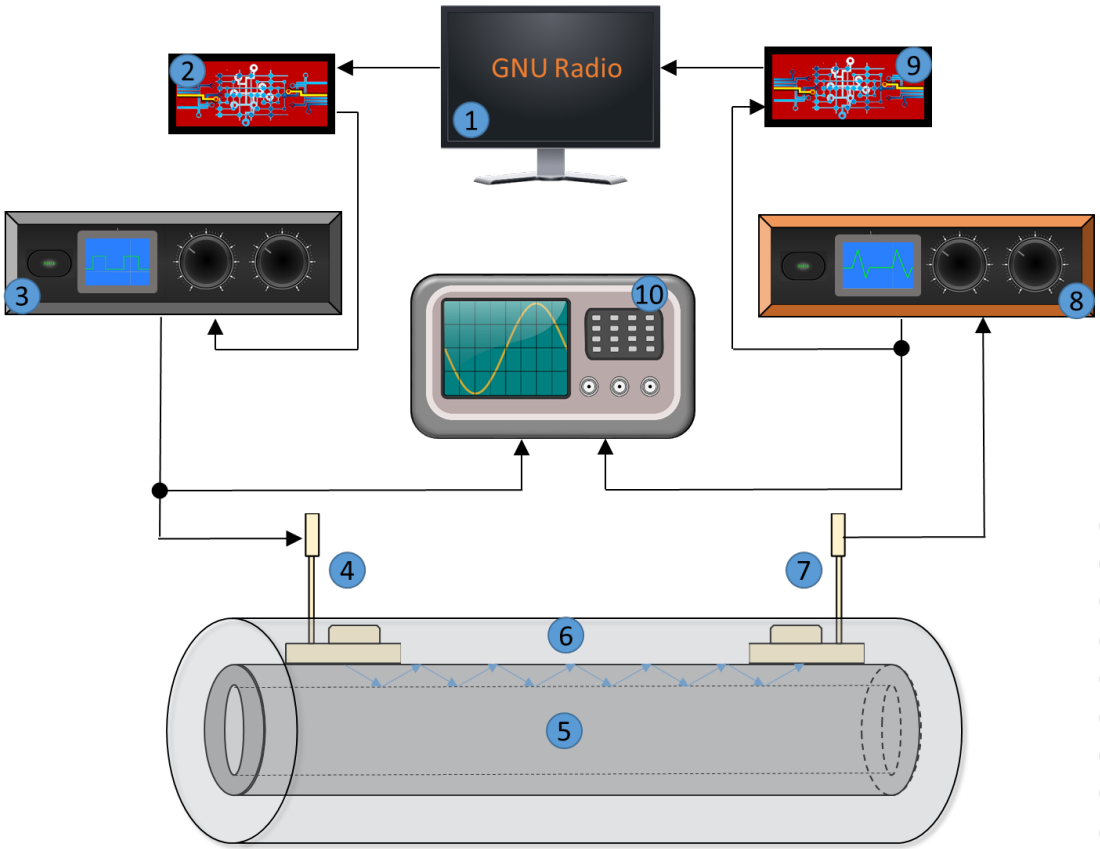


Accomplishments Y3

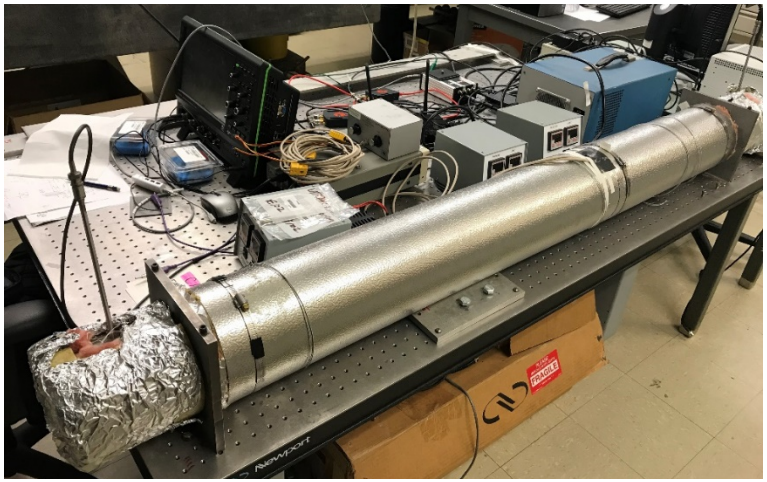
- Developed Ultrasonic Communication System on Elevated Temperature Pipes



(1) Digital computer with GNURadio software
(2) RedPitaya transmitter board
(3) Power amplifier
(4) $LiNbO_3$ ultrasonic transmitter
(5) Stainless steel pipe
(6) Thermal insulation layer
(7) $LiNbO_3$ ultrasonic receiver
(8) Low noise amplifier
(9) RedPitaya receiver board
(10) Digital oscilloscope.

Accomplishments Y3

- Ultrasonic image transmission on a heated pipe
  - Used the ASK transmission protocol implemented in GNURadio environment
    - ISI suppressed with RRC filter
    - Pipe heated to 50^{o}C and 150^{o}C
    - Transducers separated by 170cm on a pipe
    - Carrier frequency is 728 kHz
    - 10KBps data rate (bit pulse duration is 100μs)
    - BER ~10^{-3}



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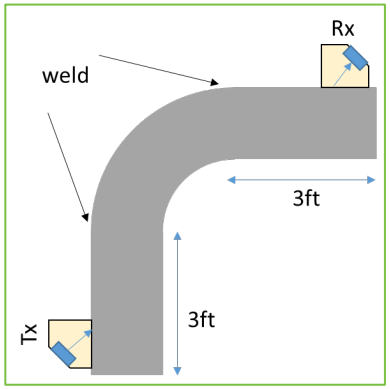
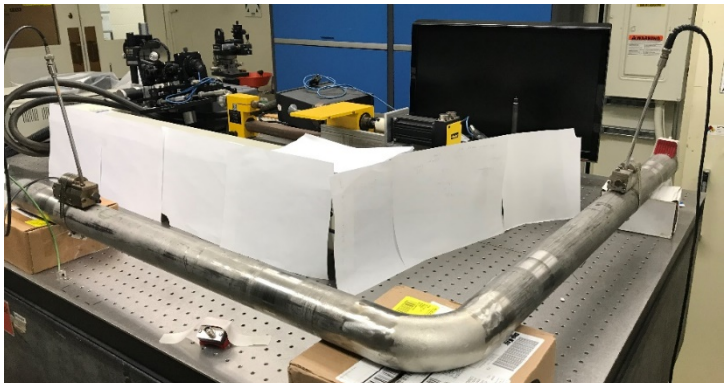
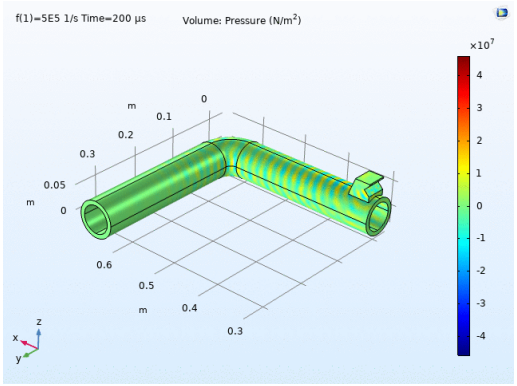
Accomplishments Y3

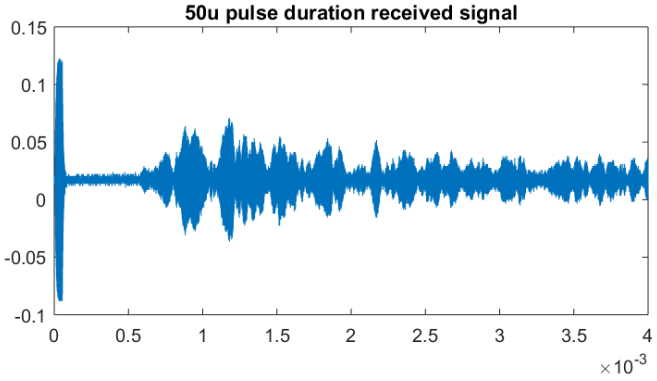
- Complex piping topology in representative environment
  - Developed bent piping test article for signal transmission evaluation

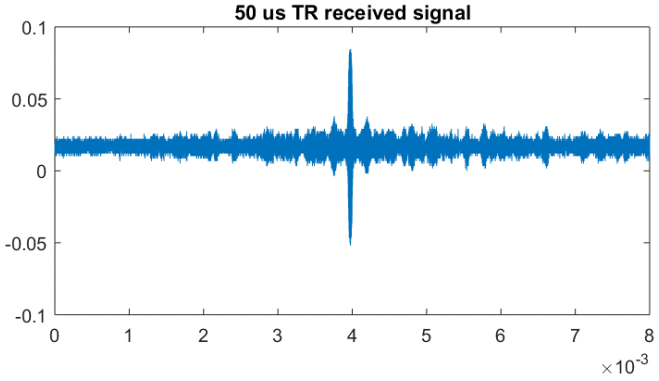






  - Demonstrated signal transmission with time-reversal modulation





Accomplishments

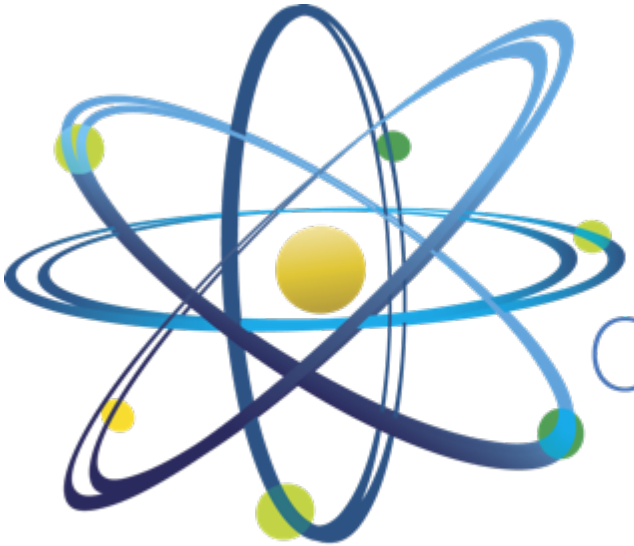
- Publications/Presentations
  - **One** paper under review in *IEEE Transactions of Ultrasonics, Ferroelectrics and Frequency Control*
  - **One** paper to be submitted to *Nuclear Technology*
  - **Four** papers in Proceedings of *IEEE International Ultrasonics Symposium* (*IUS*)
  - **Four** papers in *Proceedings of IEEE International Conference on Electro/ Information Technology* (*EIT*) (including **Best Paper Award**)
  - **One** paper in *Proceedings of Nuclear Plant Instrumentation, Control, and Human-Machine Interface Technologies* (*NPIC&HMIT*)
  - **One** paper to appear in *Transactions of ANS Winter Meeting*
  - Submitted **R&D100** application
  - Project work profiled **twice** by ANL Media Office

Technology Impact

- *Advances the state of the art for nuclear application*
  - *Provides capability to transmit information across physical barriers at a nuclear facility using in-place piping infrastructure*
- *Supports the DOE-NE research mission*
  - *Develops new means of secure and accident-resilient communication at a nuclear facility applicable to different reactor types*
- *Impacts the nuclear industry*
  - *Helps to increase safety of existing and future nuclear power plants*
- *Will be commercialized*
  - *US Patent Application 15/947,303 has been filed by A. Heifetz, R.B. Vilim, S. Bakhtiari in 2018.*

Conclusion

- *Demonstrated information transmission on nuclear grade stainless steel pipe using ultrasonic transducers*
  - *Demonstrated high-bitrate ultrasonic transmission of images on a pipe at simulated normal and post-accident conditions*
  - *Conducted preliminary studies for ultrasonic communication over piping manifolds*
- *Contact Information*
  - *aheifetz@anl.gov*
  - *630-252-4429*



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