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

Advanced Sensors and Instrumentation Annual Webinar

October 31 – November 1, 2018

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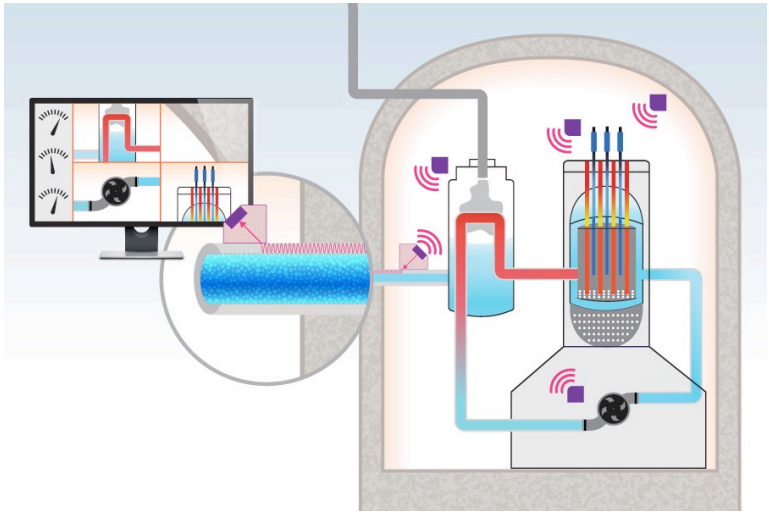
Argonne National Laboratory

Project Overview

- Goal and Objective
  - Demonstrate ability to transmit information through physical boundaries at a nuclear facility
- Participants (2018)
  - Alexander Heifetz, Xin Huang (ANL/IIT), Roberto Ponciroli, Jacey Young (SULI, St Norbert College), Dmitry Shribak (SULI, U Chicago), Sasan Bakhtiari, Jafar Saniie (IIT), Richard B. Vilim
- Schedule
  - Y1: developed system requirements and implemented ultrasonic communication setup
  - Y2: demonstrated sound, text, and image transmission using low-temperature PZT and EMAT
  - Y3: working towards power-efficient data transmission using high-temperature ultrasonic transducers

Accomplishments

- 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

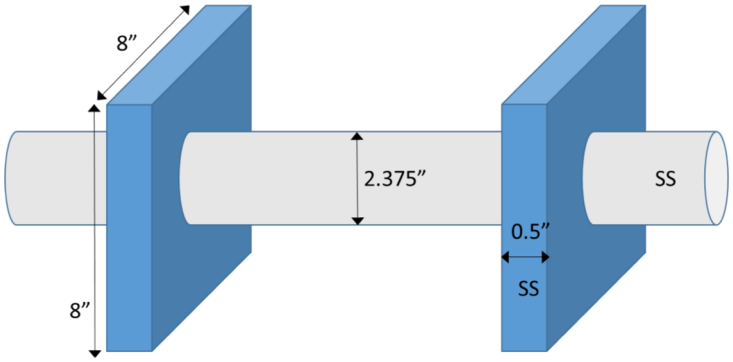
- Developed System Specification
  - Identified charging line stainless steel pipe of chemical volume control system (CVCS) as viable conduit for information transmission in and out of containment building
    - Pipe penetrates containment wall through a tunnel in concrete sealed on both ends by steel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

Typical environmental stresses on containment isolation function components

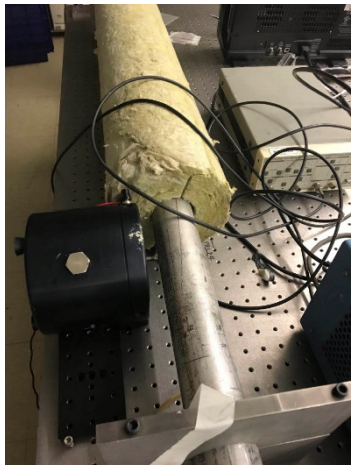
Parameter	Normal	Accident
Temperature	50-120 °F	300 °F
Pressure	atmospheric	70 psig, max
Relative Humidity	30-100 %	100 %
Radiation	50 rads/hr	150 Mrads/hr

Accomplishments

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



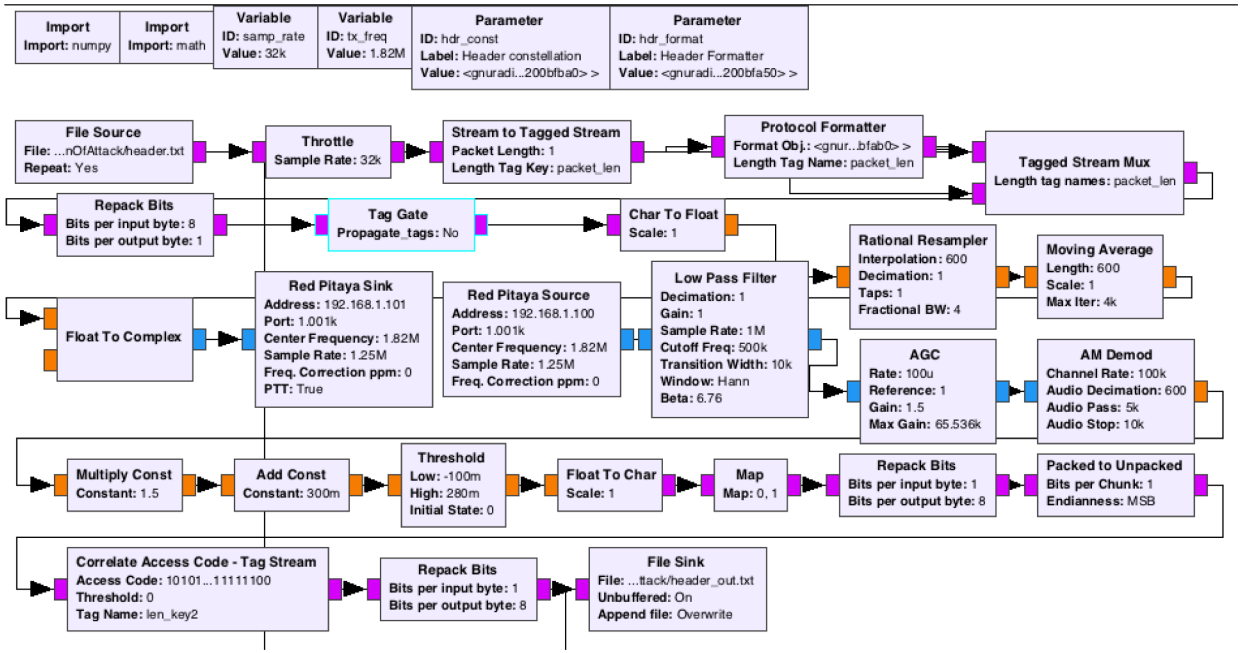
  - Demonstrated resilience of ultrasonic data transmission over pipe to low frequency noise
    - Experimentally simulated process noise with mechanical shaker vibrating a pipe
    - Vibrated pipe with 100Hz, 1KHz, 10KHz
    - Observed no interference effect on ultrasonic 2MHz shear wave information-carrying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



Frequency-tunable mechanical shaker in contact with pipe

Accomplishments

- Demonstrated information tramsmission
  - Developed amplitude shift keying (ASK) communication protocol using GNURadio software defined radio environment

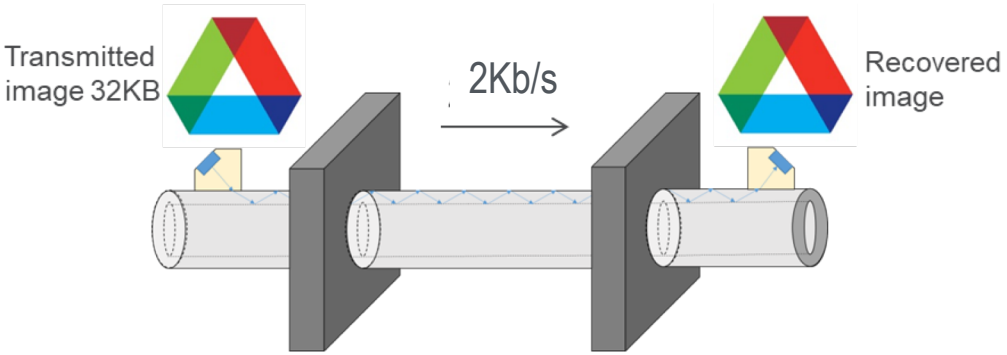


ASK communication protocol flowchart

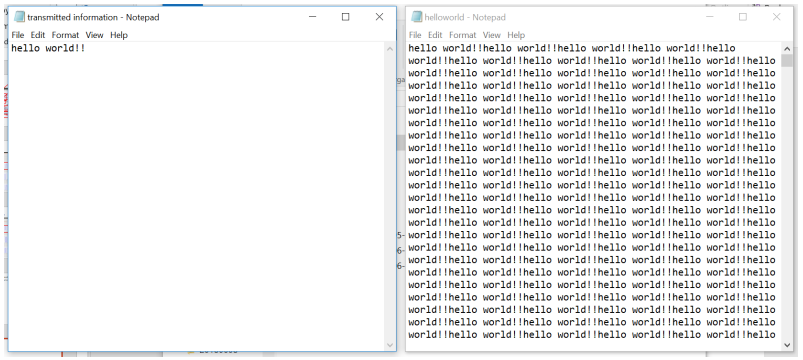
Accomplishments

- Demonstrated information transmission
  - Demonstrated image and text file transmission with 1.8MHz frequency shear wave at 2Kb/s data rate across 5 foot-long pipe
    - Demo performed during Digital Environment for Advanced Reactors Workshop at ANL on June 5

Schematics of communication system setup for image transmission on a pipe



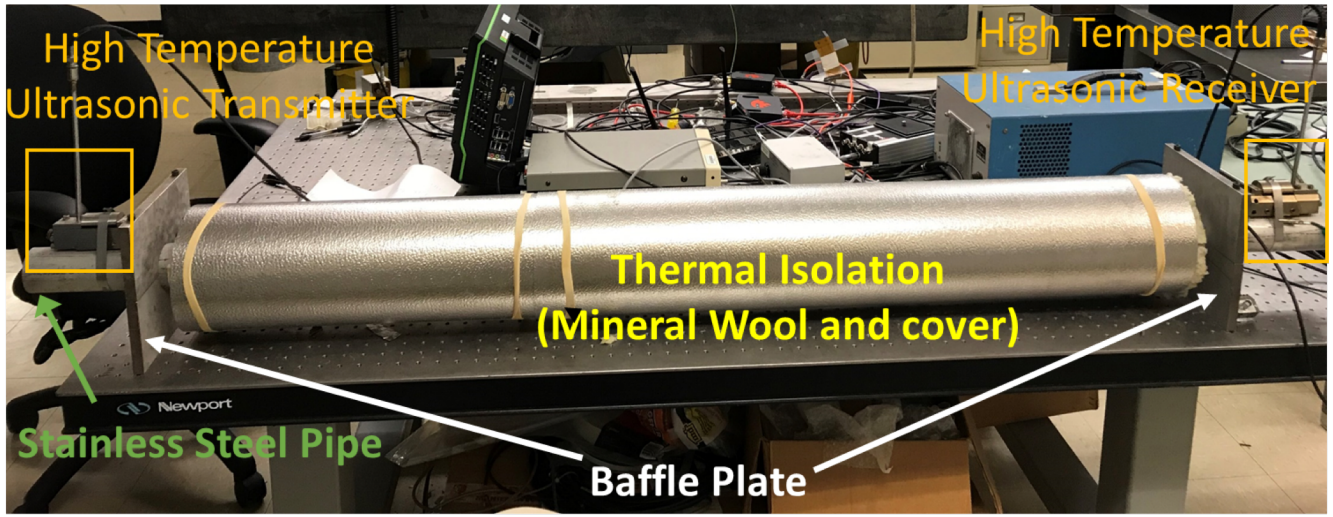
Text file transmission

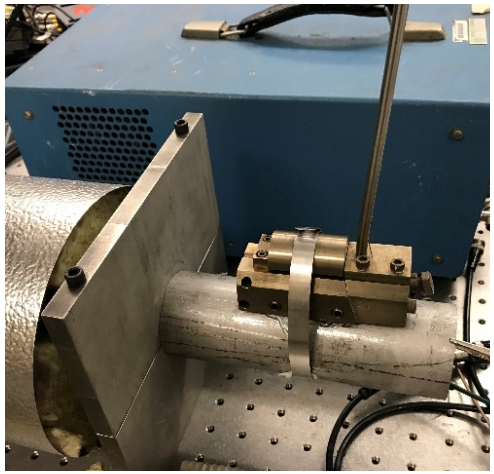


Transmitted file Received file

Accomplishments

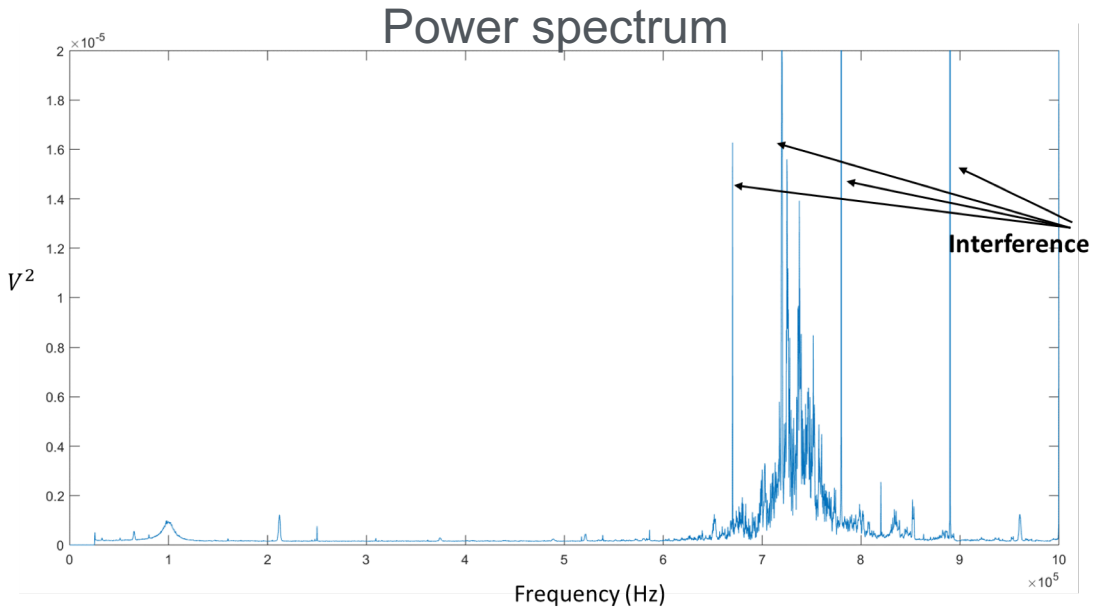
- Transition to high-temperature ultrasonic transducers
  - Shear wave ultrasonic transducers originally developed at Argonne for EBRII liquid sodium flow metering applications
  - $LiNbO_3$ high-temperature crystal in stainless steel case
  - Couples to metallic pipe with copper foil





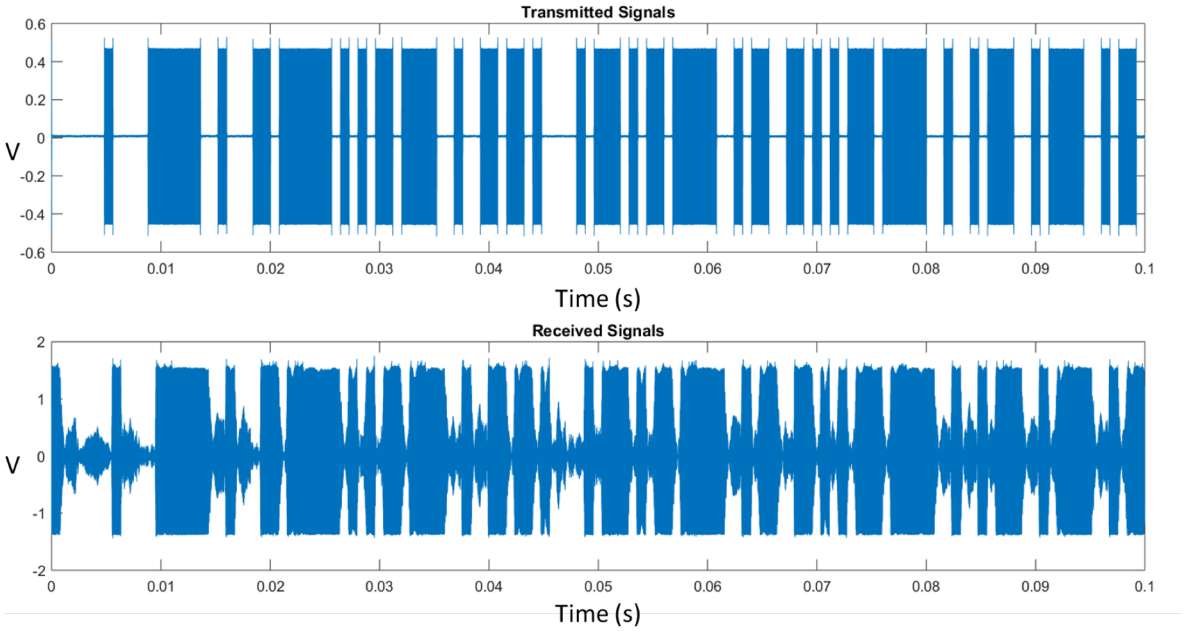
Accomplishments

- Information transmission with high-temperature transducers
  - Evaluated frequency response of transducers separated by 170cm on a pipe
  - Maximum frequency response is around 750KHz
  - Spikes are likely caused by electromagnetic interferences



Accomplishments

- Information transmission with high-temperature transducers
  - Evaluated on off keying (OOK) modulation signal transmission
    - Transducers separated by 170cm on a pipe
    - Carrier frequency is 728 kHz
    - Bit pulse duration is 200 μs



Accomplishments

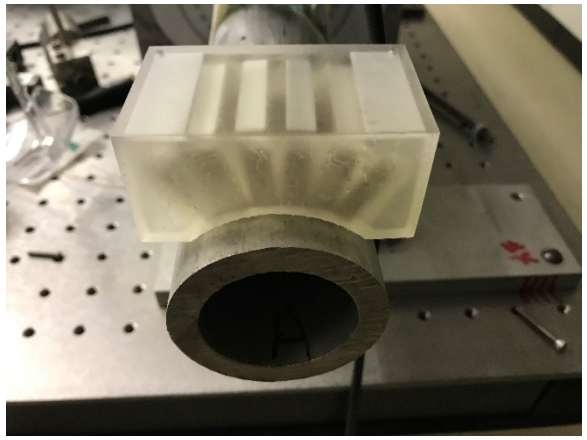
- Image transmission results
  - Used the ASK transmission protocol in GNURadio environment
    - Transducers separated by 170cm on a pipe
    - Carrier frequency is 728KHz
    - Bit pulse duration is 400μs (2.5Kb/s data rate)
  - Errors in approximately 10% of bits

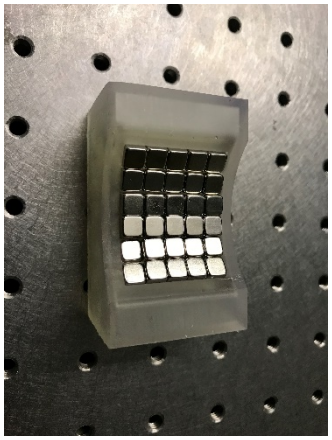
Transmitted 90KB Image

Received Image

Accomplishments

- Next steps
  - Improvement of communication protocol to reduce error rate
  - Power-efficient transmission of data
    - Without power amplifier on the transmitter side
    - Low noise amplifier used on the receiver side
  - Transmission of data on heated pipe
  - Development of custom EMAT with contoured surface for better signal coupling





Accomplishments

- Deliverables
  - A. Heifetz, X. Huang, R. Ponciroli, J. Young, D. Shribak, S. Bakhtiari, J. Saniie, R.B. Vilim, “Second Annual Progress Report on Transmission of Information by Acoustic Communication along Metal Pathways in Nuclear Facilities,” ANL-18/35, September 30, 2018.
  - A. Heifetz, X. Huang, D. Shribak, S. Bakhtiari, J. Saniie, R.B. Vilim, “Analysis of Achievable Rates of Communication,” ANL-18/27, August 31, 2018.
  - A. Heifetz, J. Young, X. Huang, S. Bakhtiari, J. Saniie, R.B. Vilim, “Acoustic Channel Link Models for Digital Communication Protocols,” ANL-18/25, August 15, 2018.
  - A. Heifetz, R. Ponciroli, X. Huang, B. Wang, J. Saniie, S. Bakhtiari, R.B. Vilim, “Ultrasonic Link Model Development,” ANL/NE-18/7, March 30, 2018.(List description of milestones, deliverables, outcomes for FY18)

Accomplishments

- Publications/Presentations
  - A. Heifetz, X. Huang, R. Ponciroli, S. Bakhtiari, J. Saniie, R.B. Vilim, “Acoustic Communication Over Metal Pipes in Nuclear Facilities,” submitted to ANS 111th Nuclear Plant Instrumentation, Control and Human-Machine Interface Technologies (NPIC&HMIT), 2019.
  - A. Heifetz, R. Vilim, S. Bakhtiari, “Transmission of Information by Acoustic Communication along Metal Pathways in Nuclear Facilities,” to be presented at International Mechanical Engineering Congress and Exposition (IMECE), Pittsburgh, PA, November 2018.
  - B. Wang, J. Saniie, S. Bakhtiari, A. Heifetz, “Software Defined Ultrasonic System for Communication through Solids,” presented at 17th IEEE International Conference on Electro Information Technology, Rochester, MI, May 2018.
  - X. Huang, J. Saniie, S. Bakhtiari, A. Heifetz, “Application of EMAT to Ultrasonic Communication Through Steel Plates and Pipes,” presented at 17th IEEE International Conference on Electro Information Technology, Rochester, MI, May 2018.

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*
  - *Developed communication protocol using GNURadio environment*
  - *Demonstrated transmission of 32KB images at 2Kb/s data rate*
  - *Present efforts are aimed at demonstrating power-efficient data transmission using high-temperature ultrasonic transducers*
- *Contact Information*
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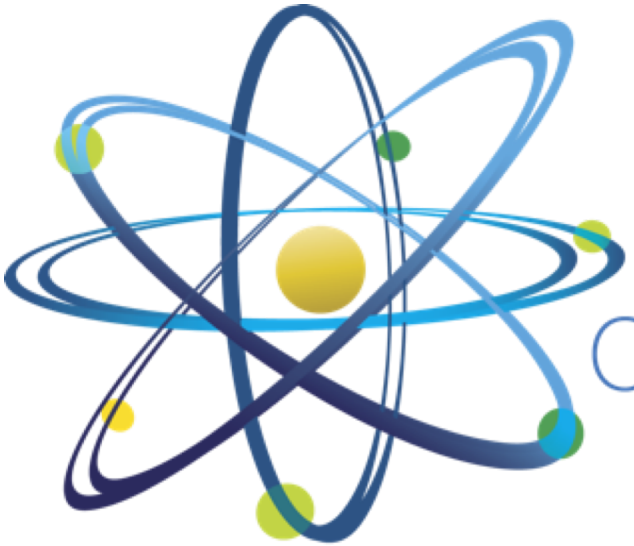
  - *630-252-4429*



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