

Advanced Monitoring System for Health Assessment of Overhead Transmission Lines

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Acknowledgement

This project has been supported by:

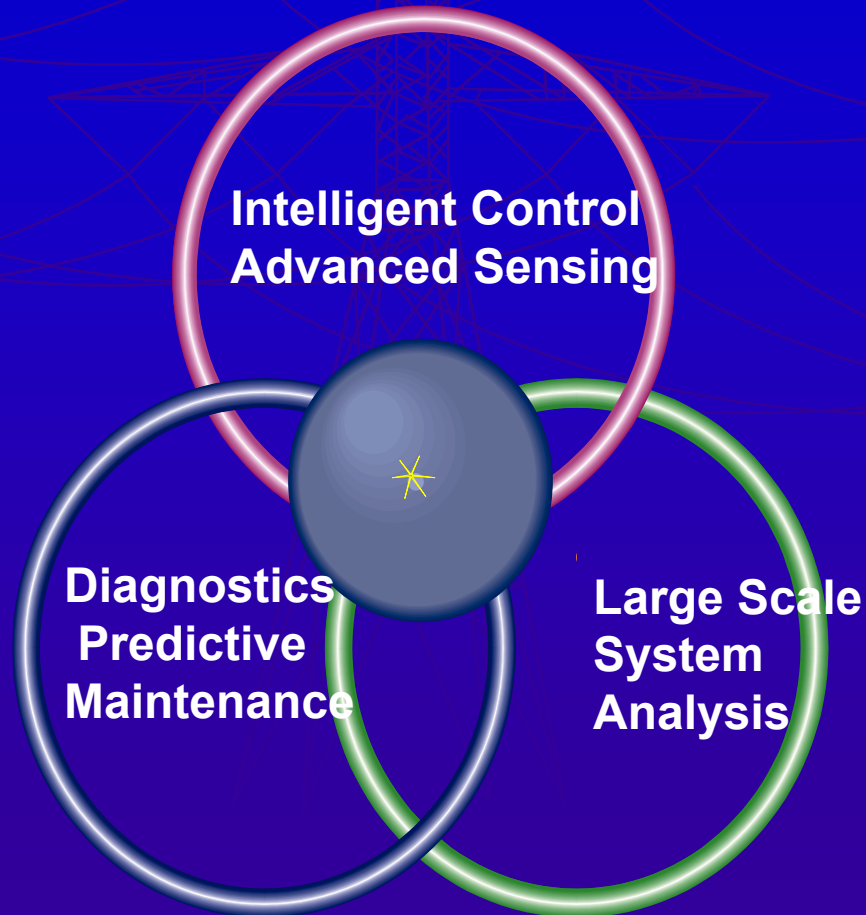
- Electric Power Research Institute
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 - David Wolff
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 - Art Mander
- Western Area Power Administration
 - Paulette Kaptain



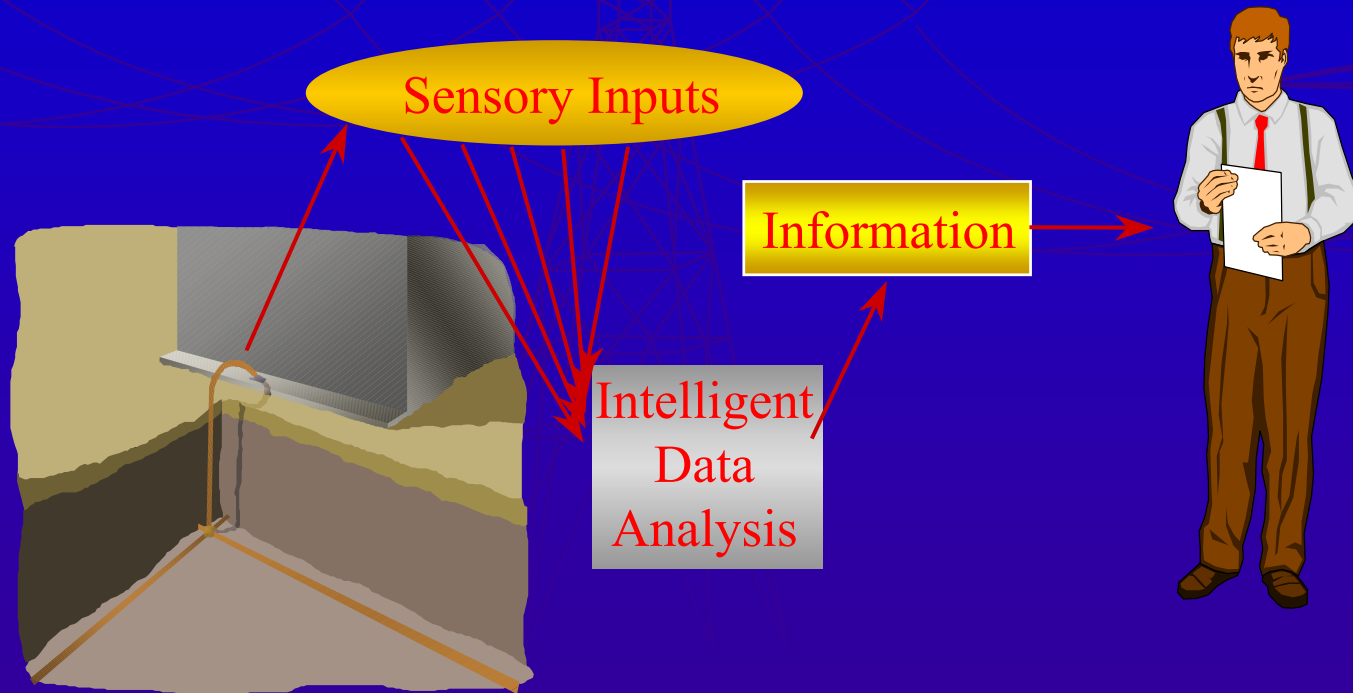
“SENSORS”

**Essential Elements For
Enhancing System Intelligence**

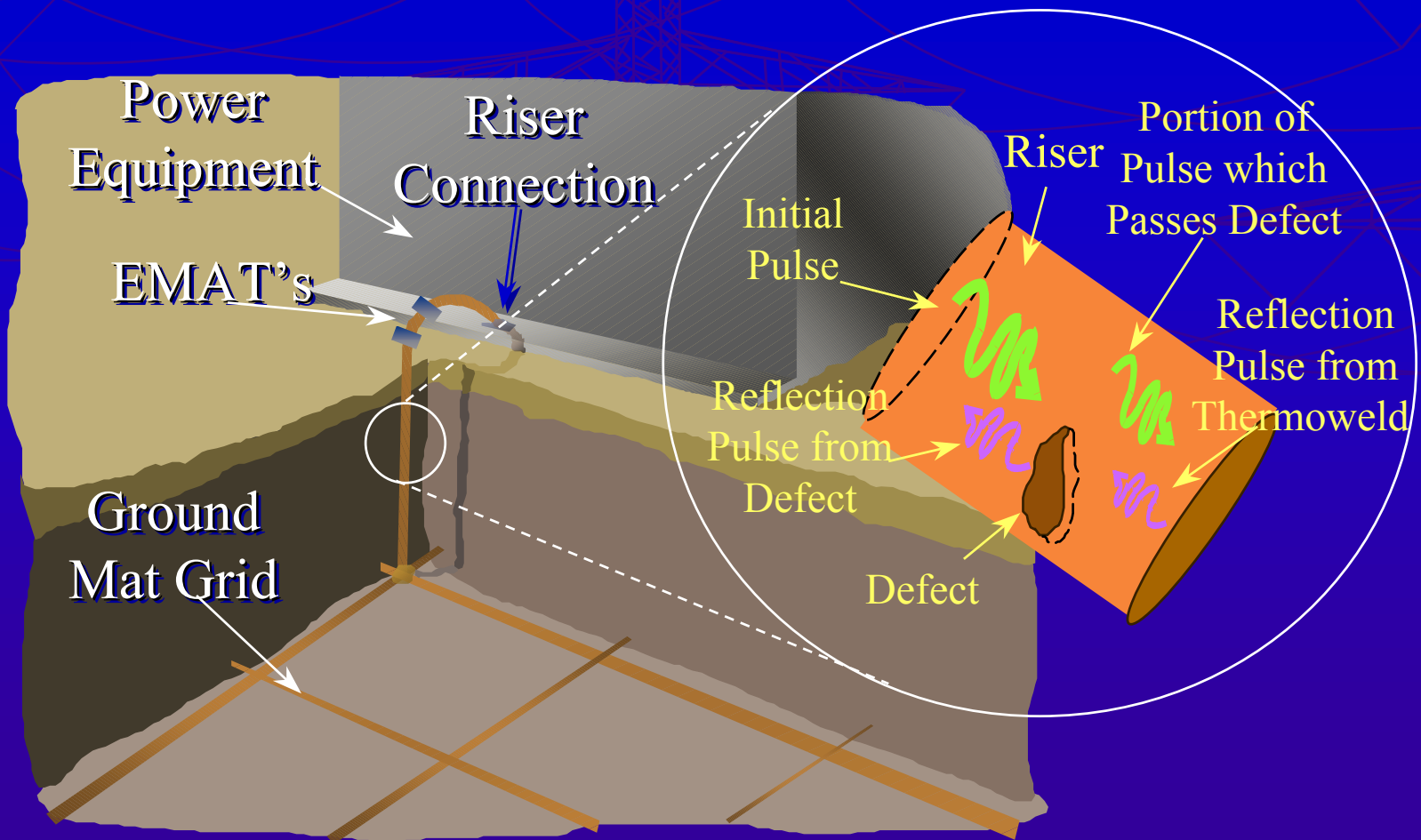
PSERC Research Thrusts at CSM



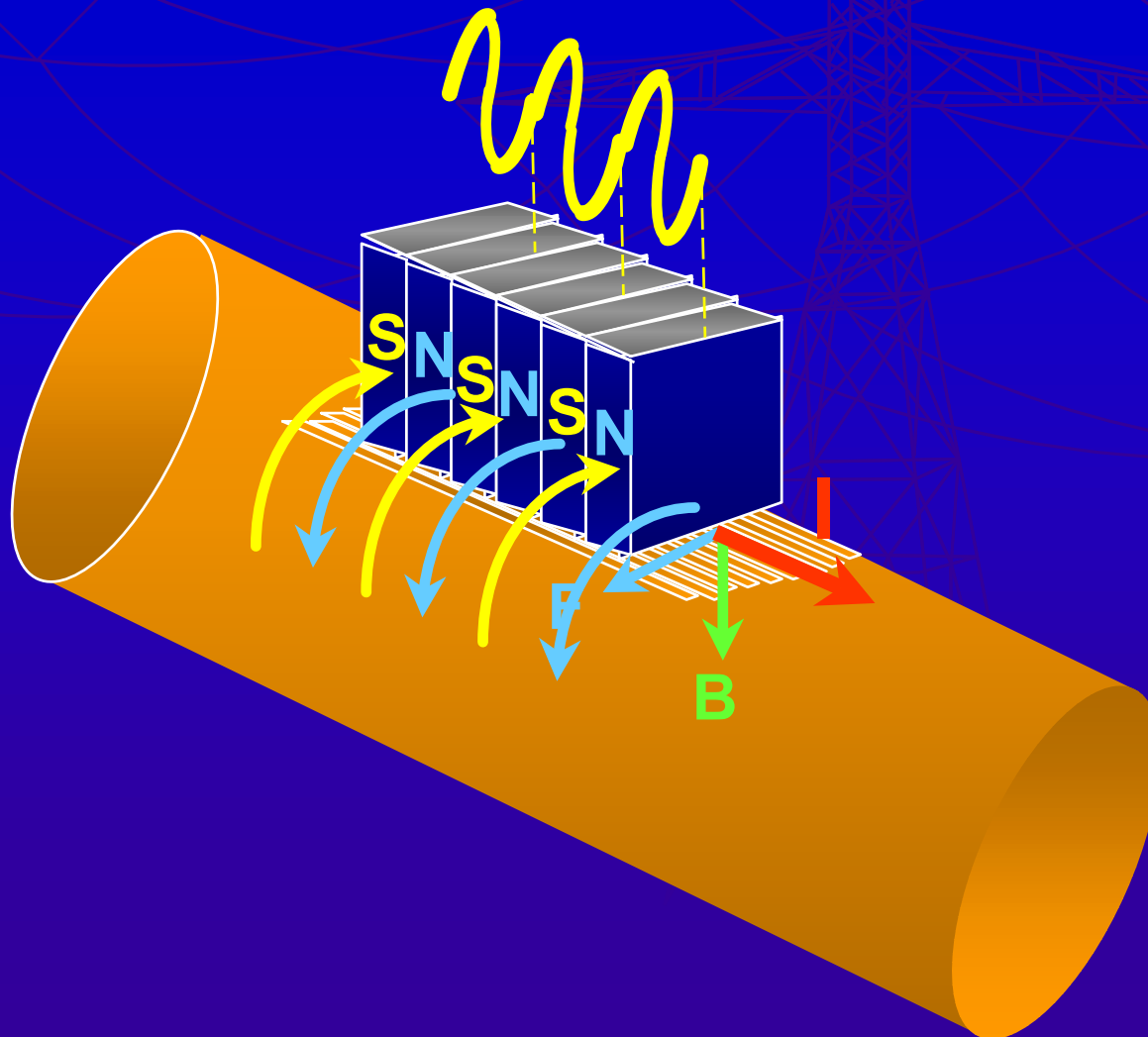
Initial Problem: Integrity of Ground Risers



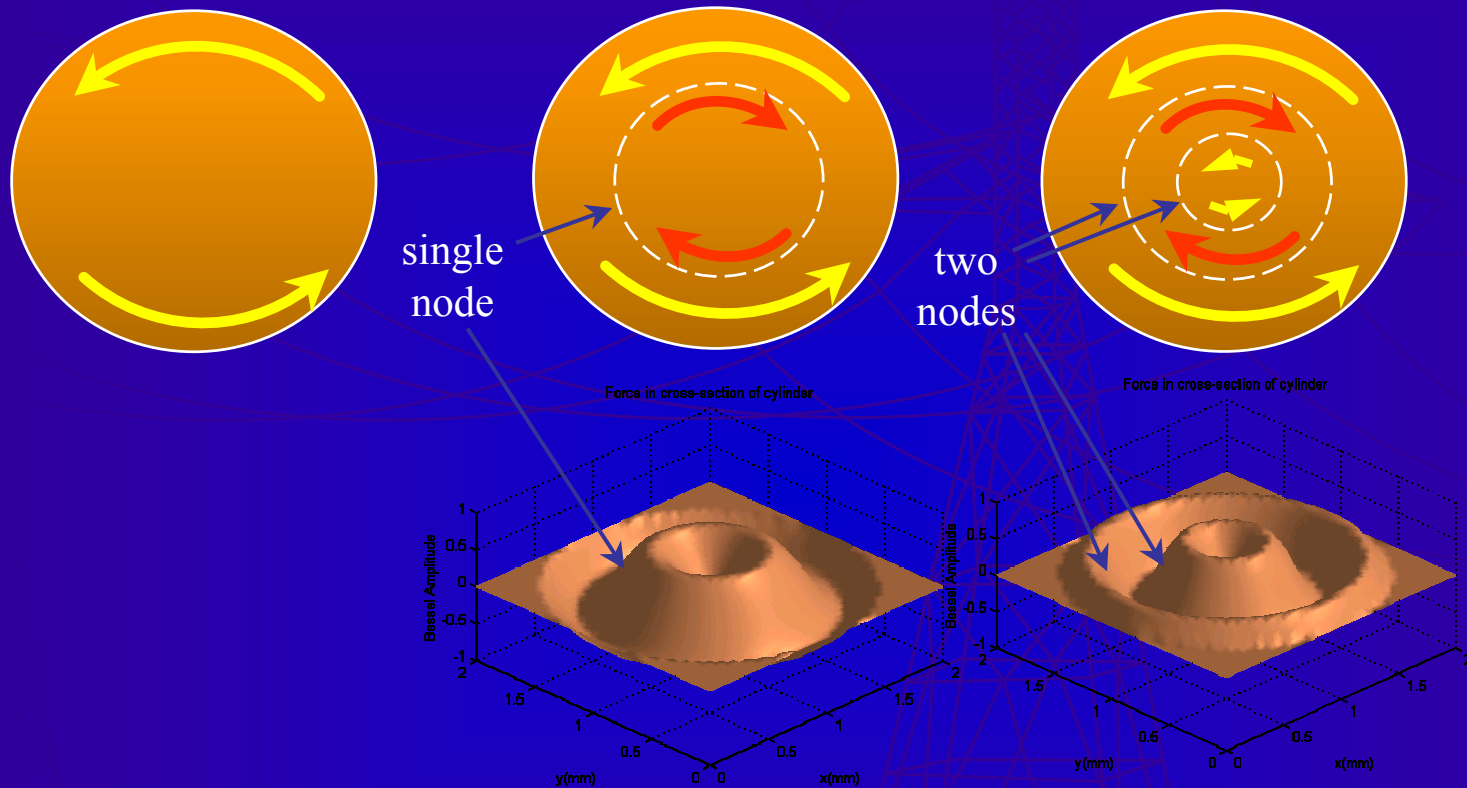
EMAT Transducer Concept



Torsional Mode in Cylinders



Torsional Modes



Zero Order

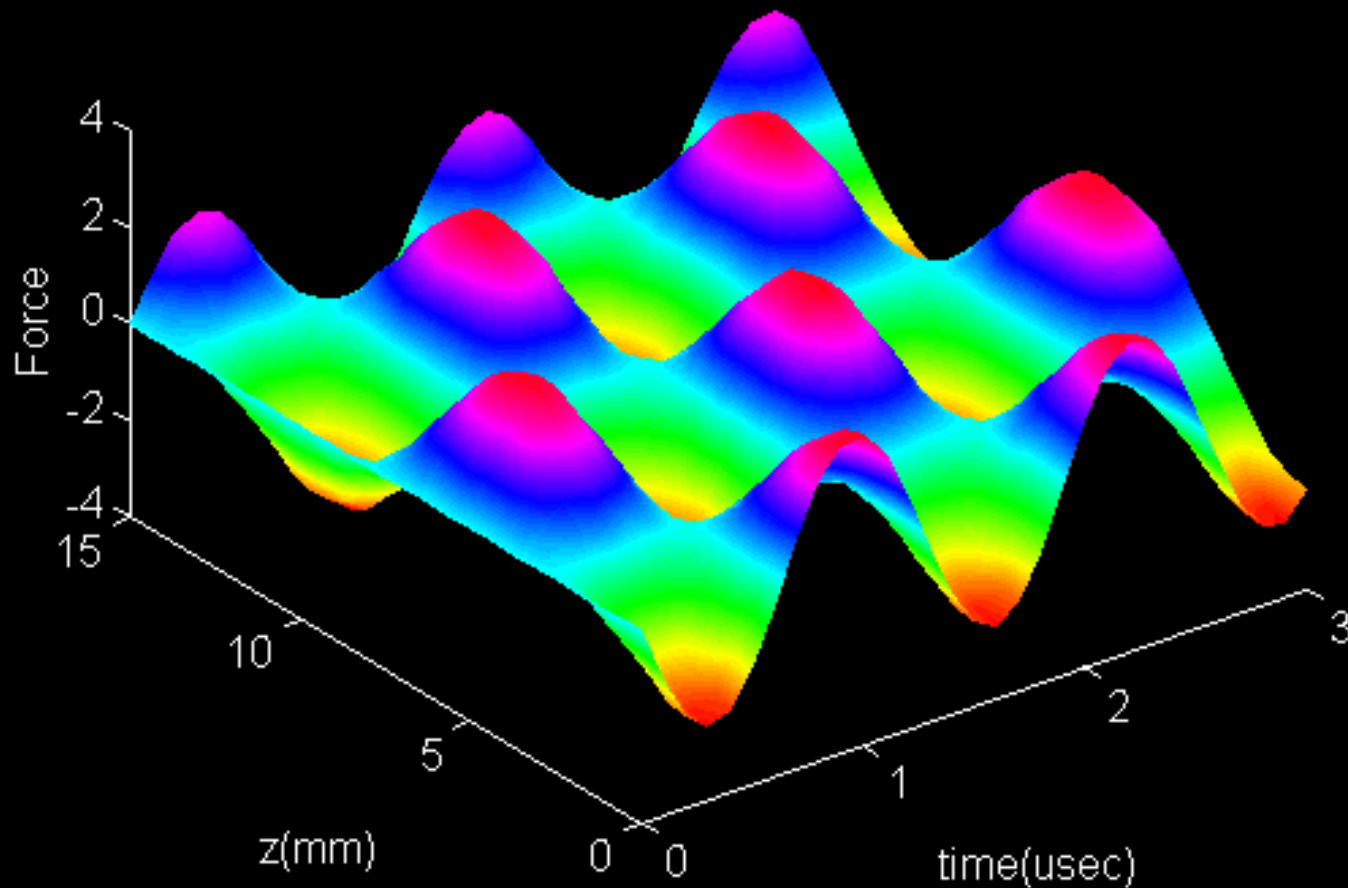
First Order

Second Order

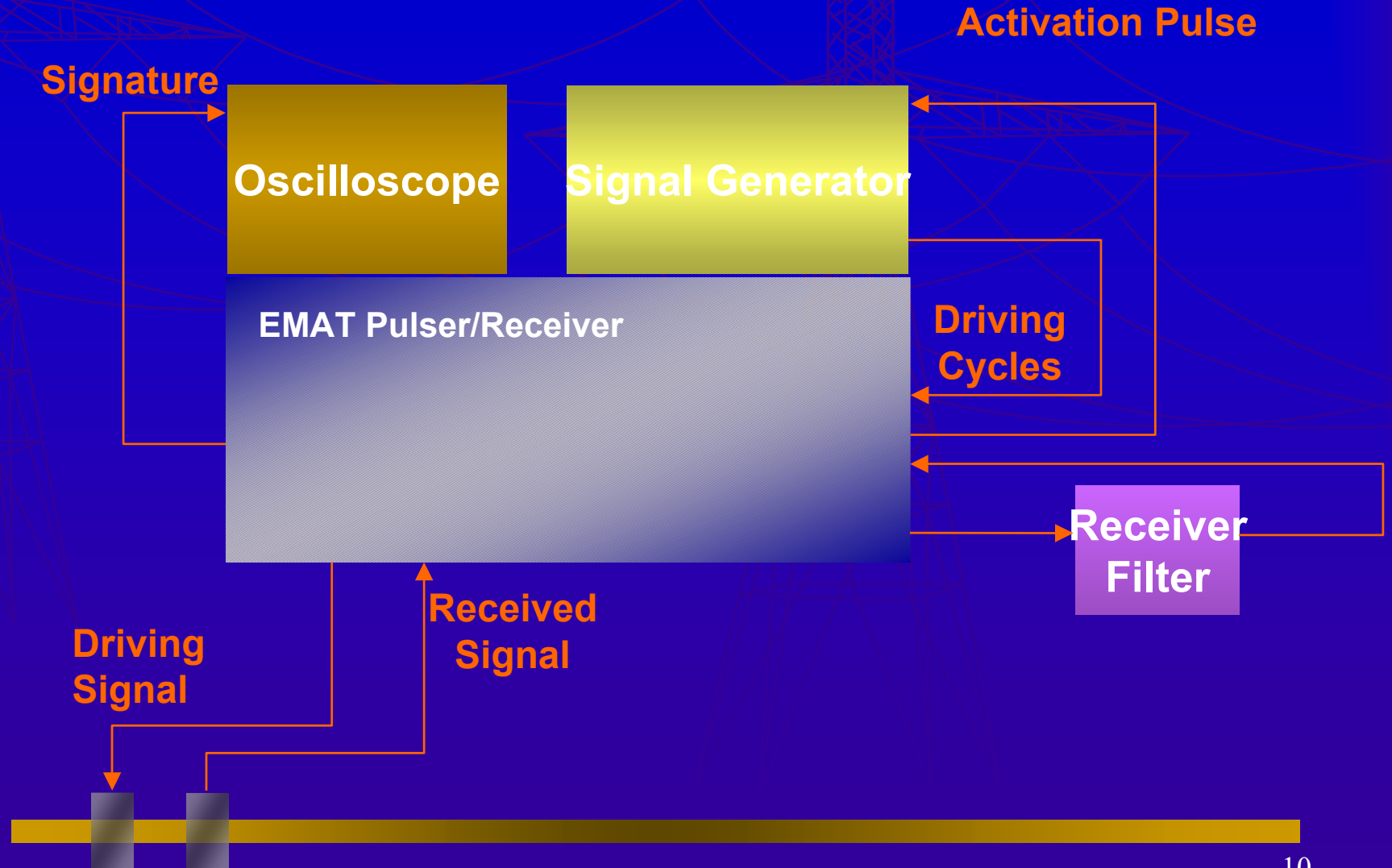
Nodes are zero crossings in a Bessel function

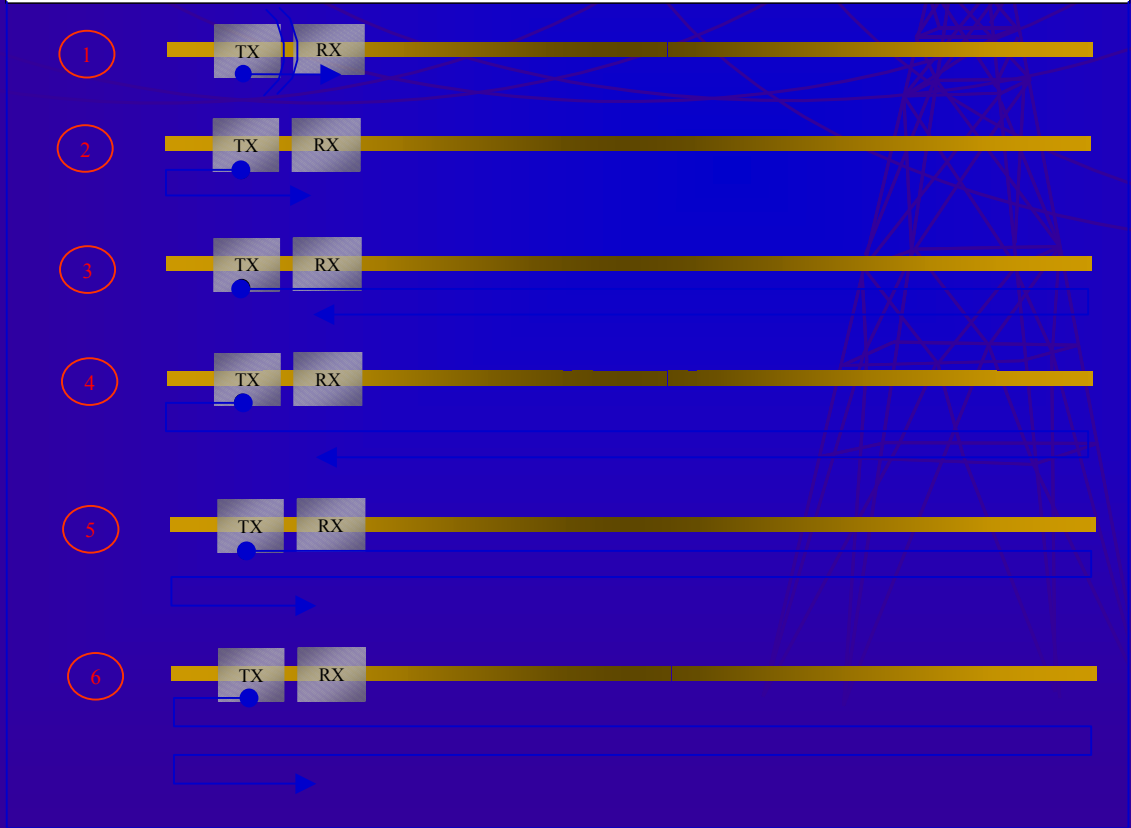
Trapped Torsional Mode

Force at single point in cross-section of cylinder



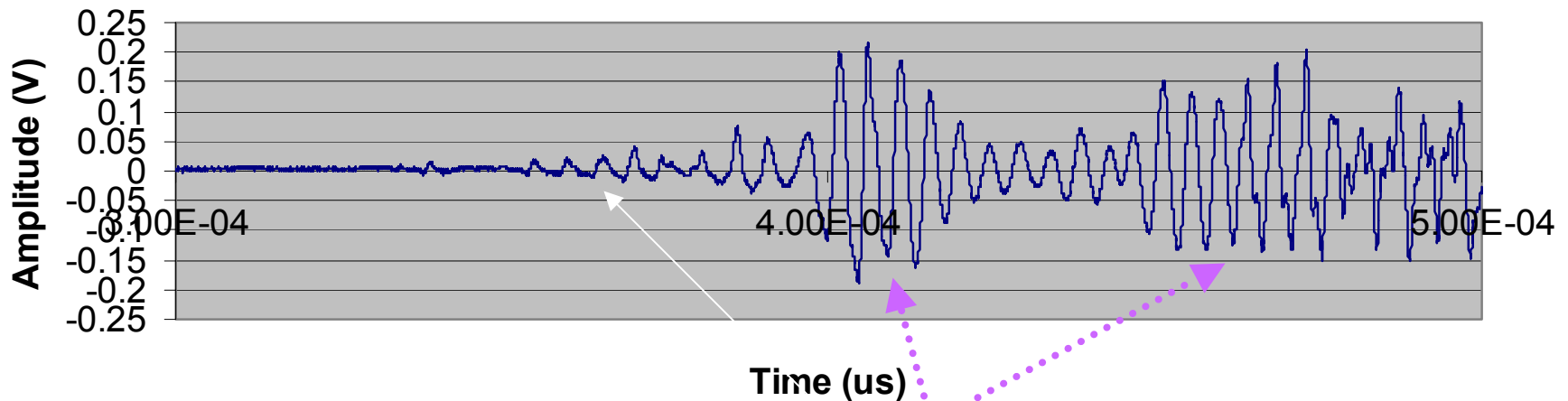
Experimental Setup





Early Experimental Results

Signal from Damaged Conductor

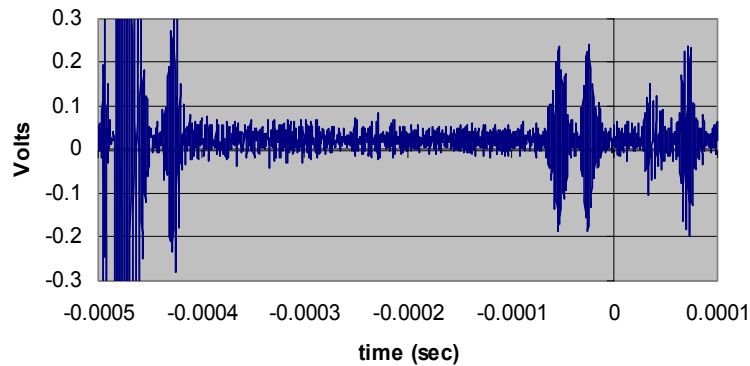


Signal moves down conductor
and reflects off of damage

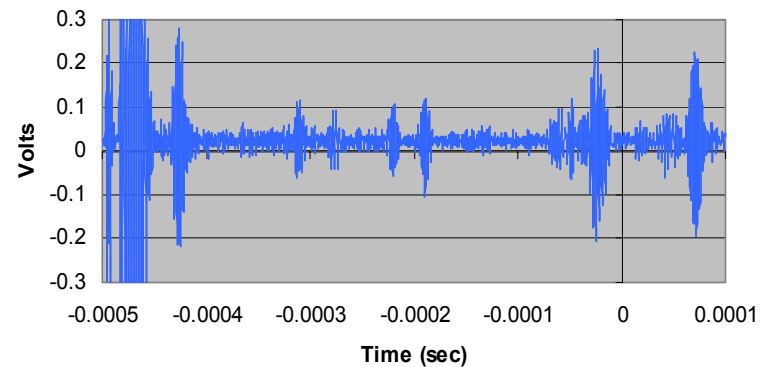
Transducers
applied Here

Perpendicular Cut

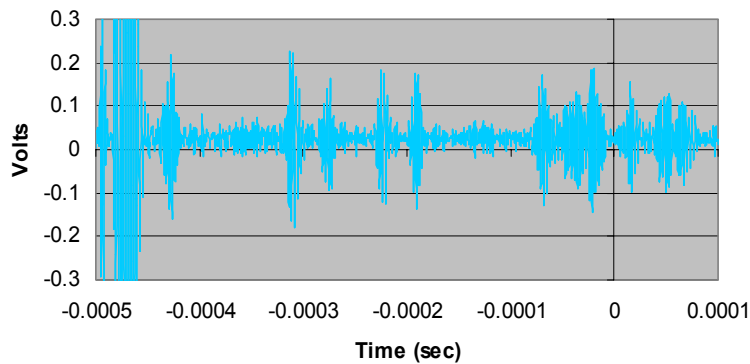
Clean Sample



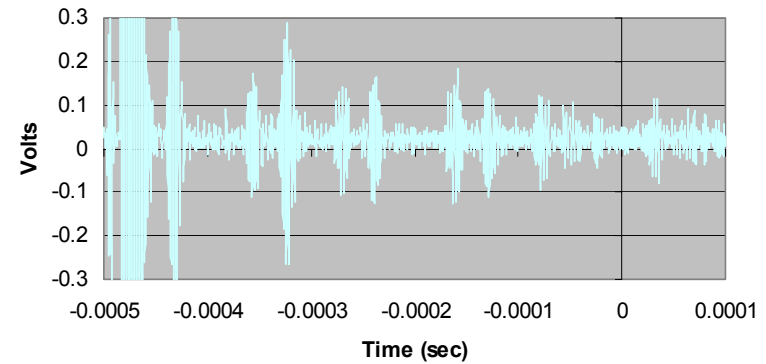
10% Cut Perpendicular to Riser Axis



25% Cut Perpendicular to Riser Axis



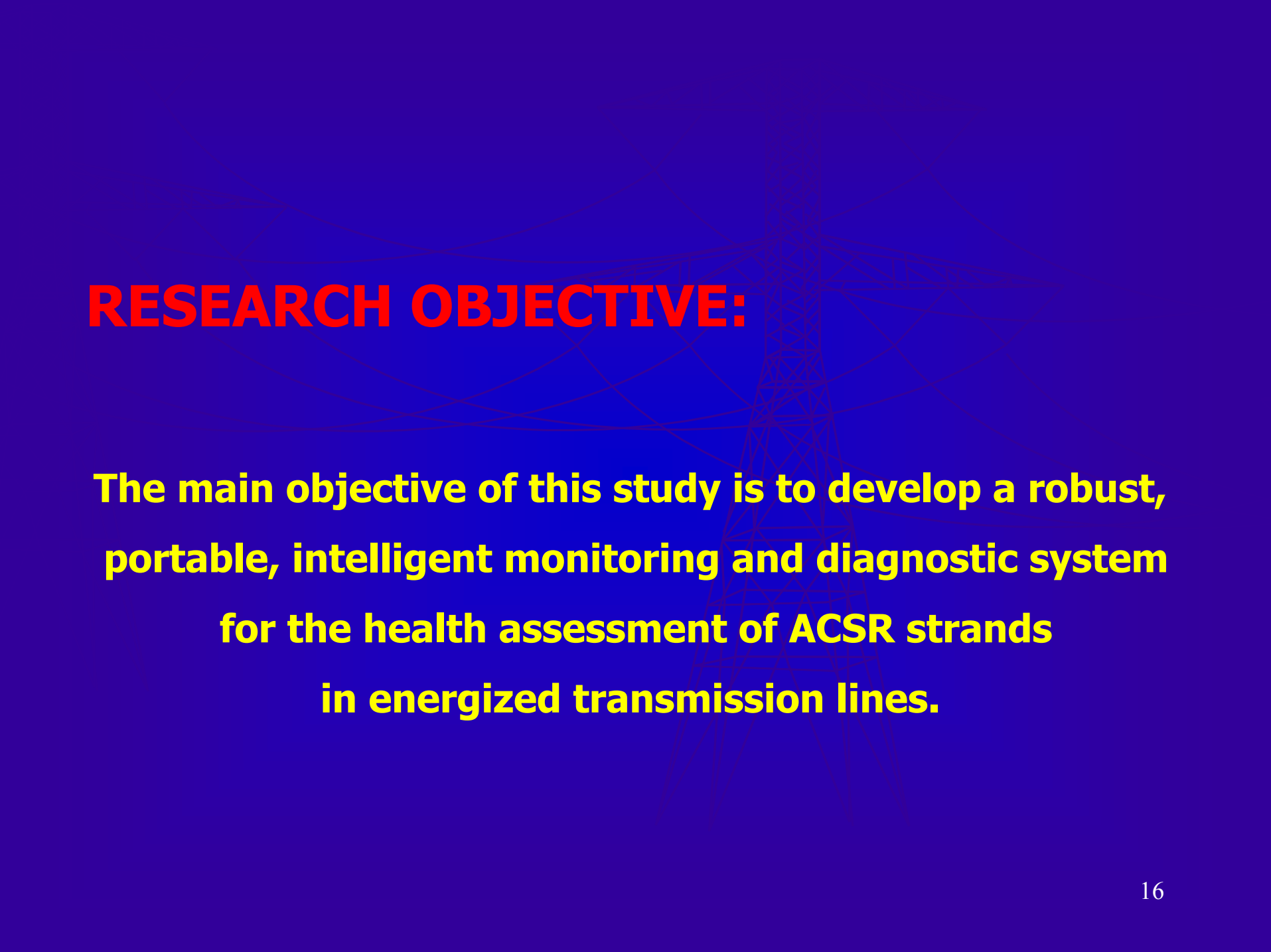
50% Cut Perpendicular to Riser Axis





Broken Strands in ACSR





RESEARCH OBJECTIVE:

The main objective of this study is to develop a robust, portable, intelligent monitoring and diagnostic system for the health assessment of ACSR strands in energized transmission lines.

A Monitoring System Should Be:

- Robust to operating and environmental conditions
- Intelligent to analyze data and provide useful information
- Stable enough as to not set false alarms
- Easy to use (user friendly)

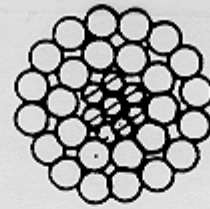
A Monitoring System Should Be:

(continued)

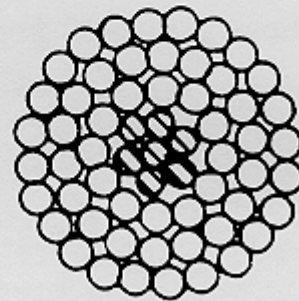
- Portable
- Easily attachable and detachable
- Capable of providing adequate bandwidth
- Inexpensive

Causes of Damage

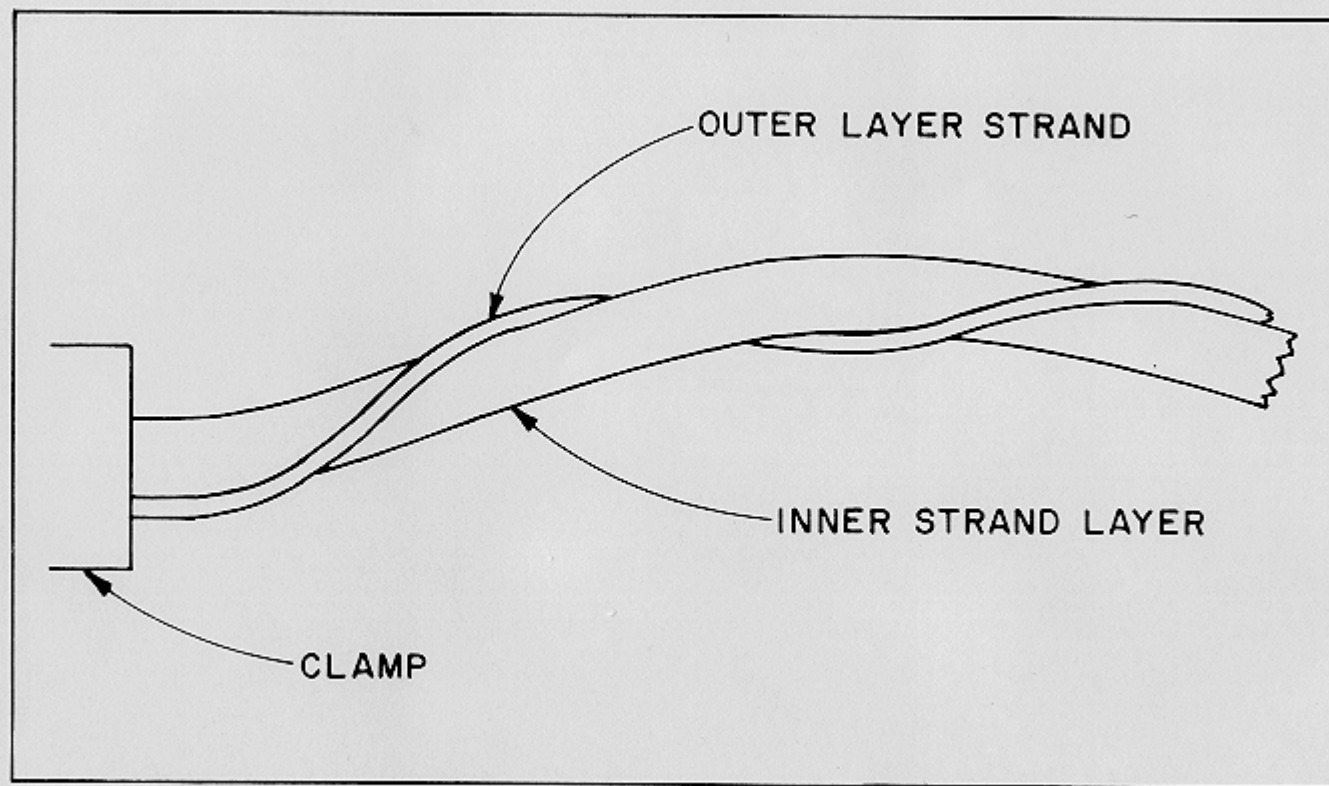
- **Aeolian Vibration**
- **Galloping**
- **Turbulent Winds**
- **Ice Loading**
- **Other**

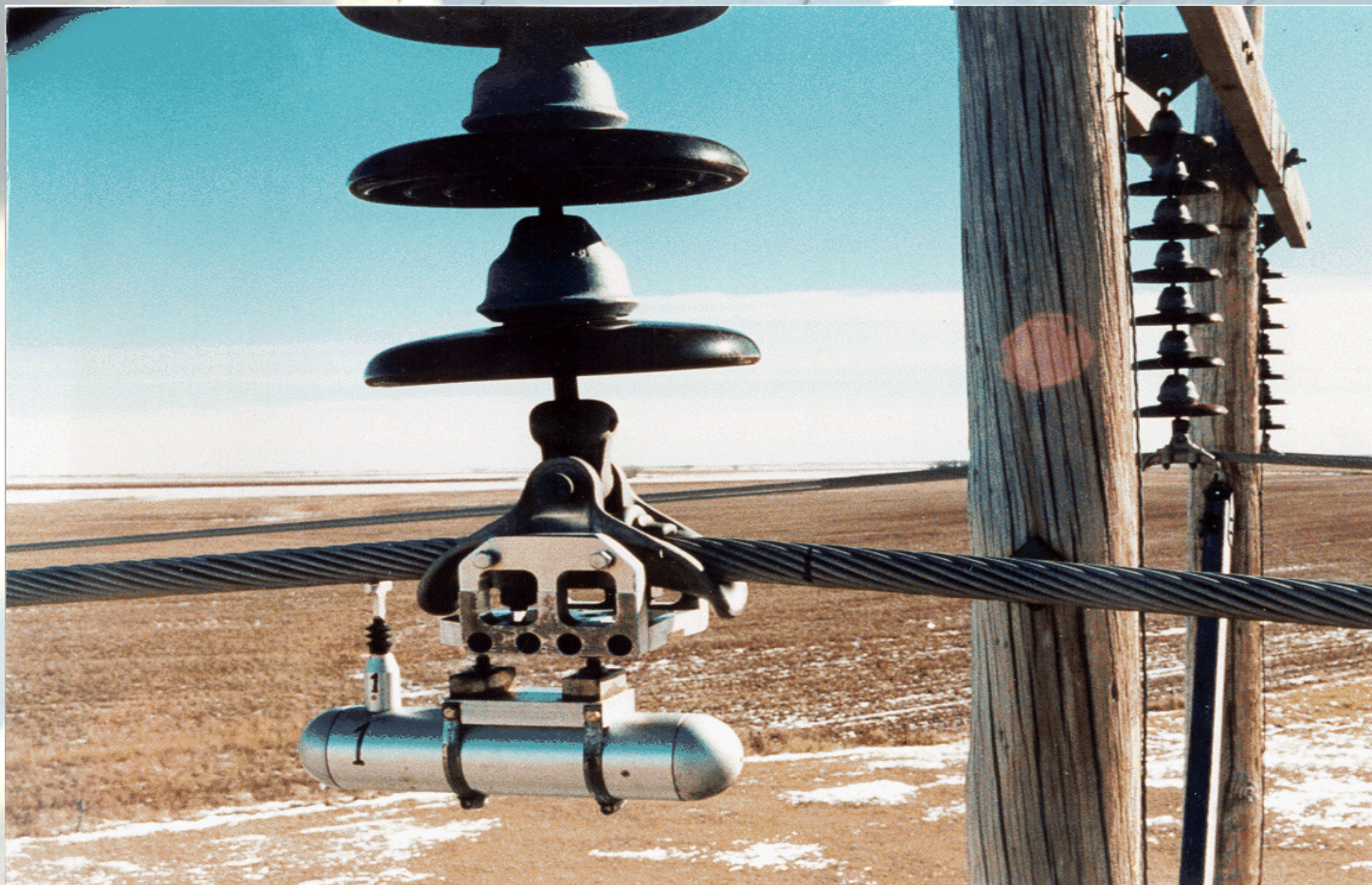


26 A1/7 S.



54 A1/7 S.





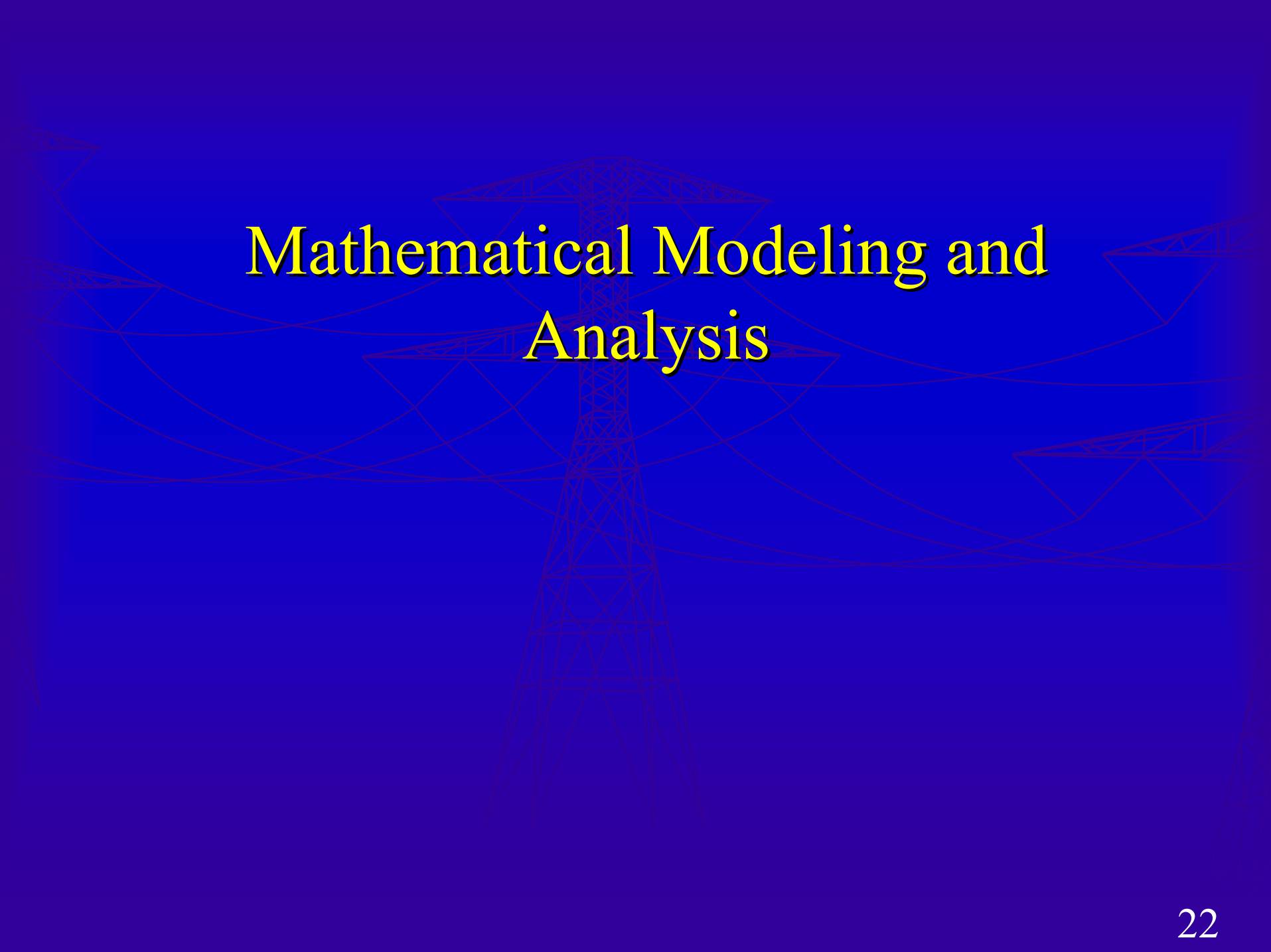


Present available tools and techniques suffer from

- Accuracy**
- Reliability**
- Complexity**
- Cost**
- Required Training**

Technical Approach

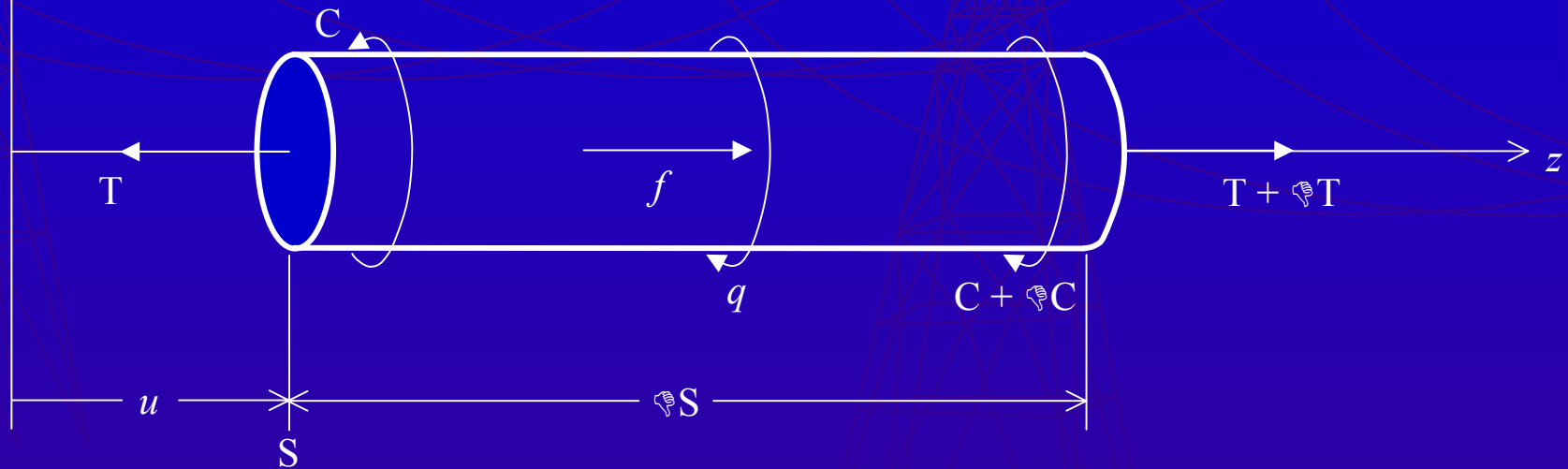
- Mathematical Analysis
- System Design
- Laboratory Experimental Design and Construction
- Field Tests



Mathematical Modeling and Analysis

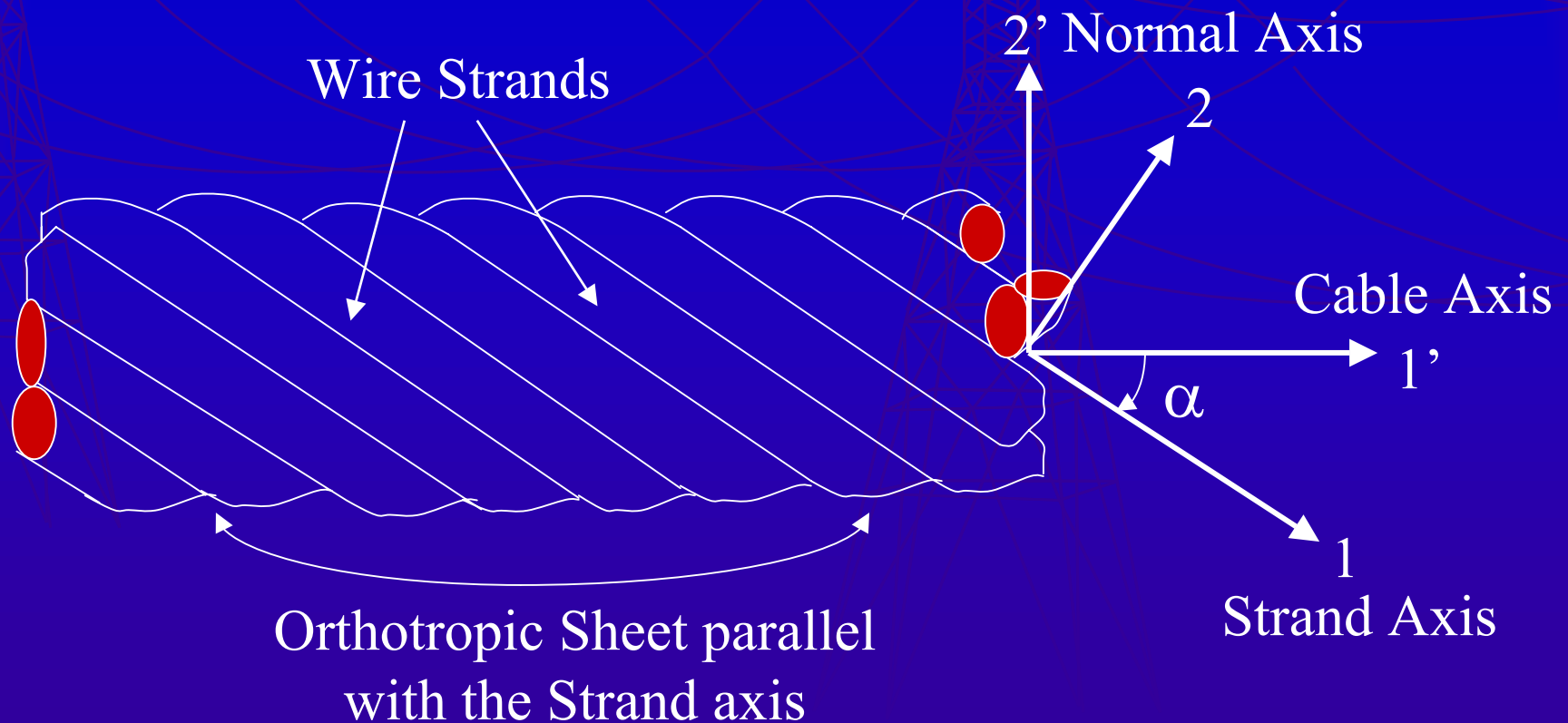
Analytical Modeling – *Equations of Motion*

- Consider a straight section of wire rope loaded simultaneously in both tension and torsion:

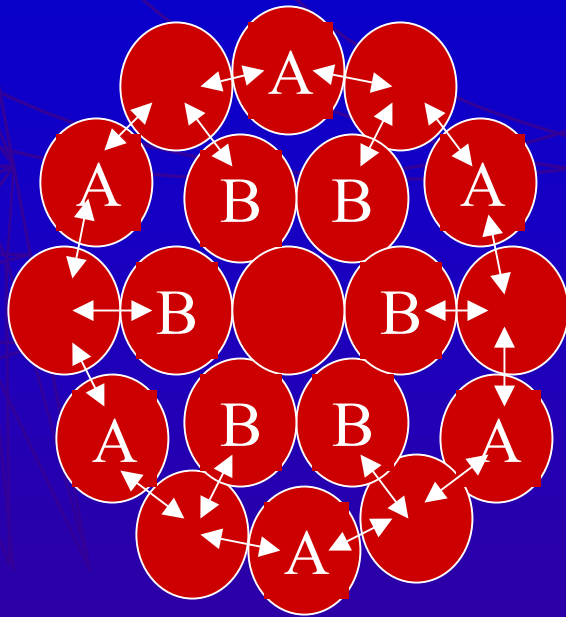


- where f is the external force and q is the external moment (both per unit of stressed rope lengths) 🖐 26

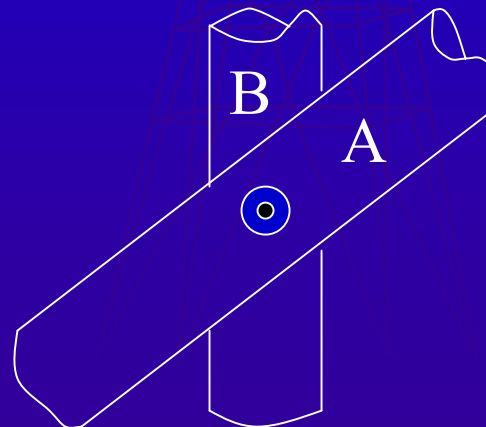
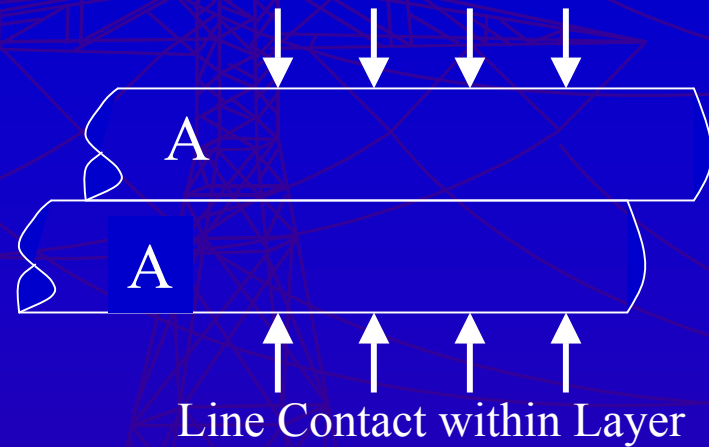
Orthotropic Sheet (Layers of Wires) Model



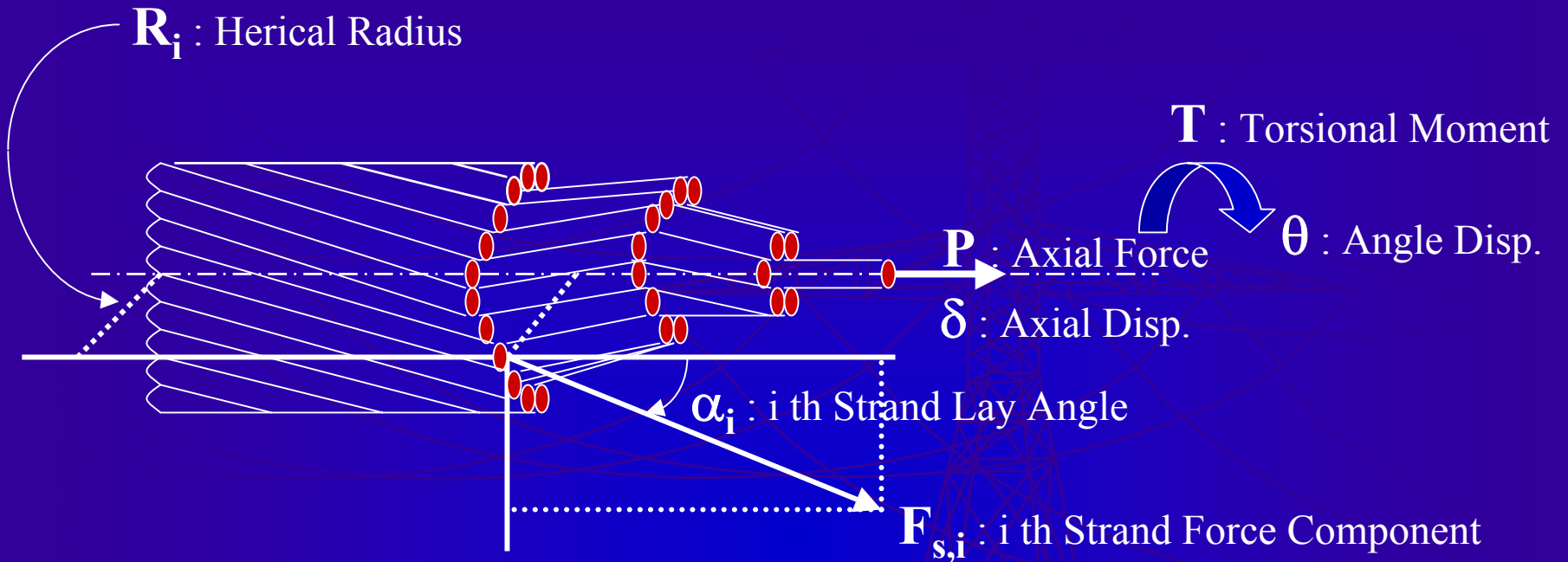
Interwire/Interlayer Contact Forces



Cross Section Diagram
of Wire Rope



Trellis Contact between Layer³⁸



$$F_s = \sum_{i=1}^n F_{s,i} = \sum_{i=1}^n a_i E_i \varepsilon_{s,i}$$

F_s : Total Force induced by Strands

a_i : Net Area of i th Strand

E_i : Young' Modulus of i th Strand

$\varepsilon_{s,i}$: Strain of i th Strand

$$\varepsilon_{s,i} = \cos^2 \alpha_i \left(\frac{\delta}{\lambda} \right) + R_i \sin \alpha_i \cos \alpha_i \left(\frac{\theta}{\lambda} \right)$$

Axial Force, A_1 and A_2

$$P = \sum_{i=1}^n F_{s,i} \cos \alpha_i = A_1 \left(\frac{\delta}{\lambda} \right) + A_2 \left(\frac{\theta}{\lambda} \right)$$

$$A_1 = \sum_{i=1}^n a_i E_i \cos^3 \alpha_i$$

$$A_2 = \sum_{i=1}^n a_i E_i R_i \cos^2 \alpha_i \sin \alpha_i$$

Torsional Moment, A_3 and A_4

$$T = \sum_{i=1}^n \left(R_i F_{s,i} \sin \alpha_i + J_i G_i \left(\frac{\theta}{\lambda} \right) \right) = A_3 \left(\frac{\delta}{\lambda} \right) + A_4 \left(\frac{\theta}{\lambda} \right)$$

J_i : Polar Moment of Inertia

G_i : Shear Modulus

$$A_3 = \sum_{i=1}^n a_i E_i R_i \cos^2 \alpha_i \sin \alpha_i$$

$$A_4 = \sum_{i=1}^n \left(a_i E_i R_i^2 \cos \alpha_i \sin^2 \alpha_i + J_i G_i \right)$$

Formulas for Constitutive Constant

$$A_1 = \left(\frac{4}{\pi} \sum_{i=1}^n a_i k_{11,i} \right) + a_{core} E_{core}$$

$$A_2 = \frac{4}{\pi} \sum_{i=1}^n a_i R_i k_{61,i} l_i$$

$$A_3 = \frac{4}{\pi} \sum_{i=1}^n a_i R_i k_{16,i} l_i$$

$$A_4 = \frac{4}{\pi} \sum_{i=1}^n a_i R_i^2 k_{66,i}$$

a_i : Each Wire Net Area

R_i : Helical Radius

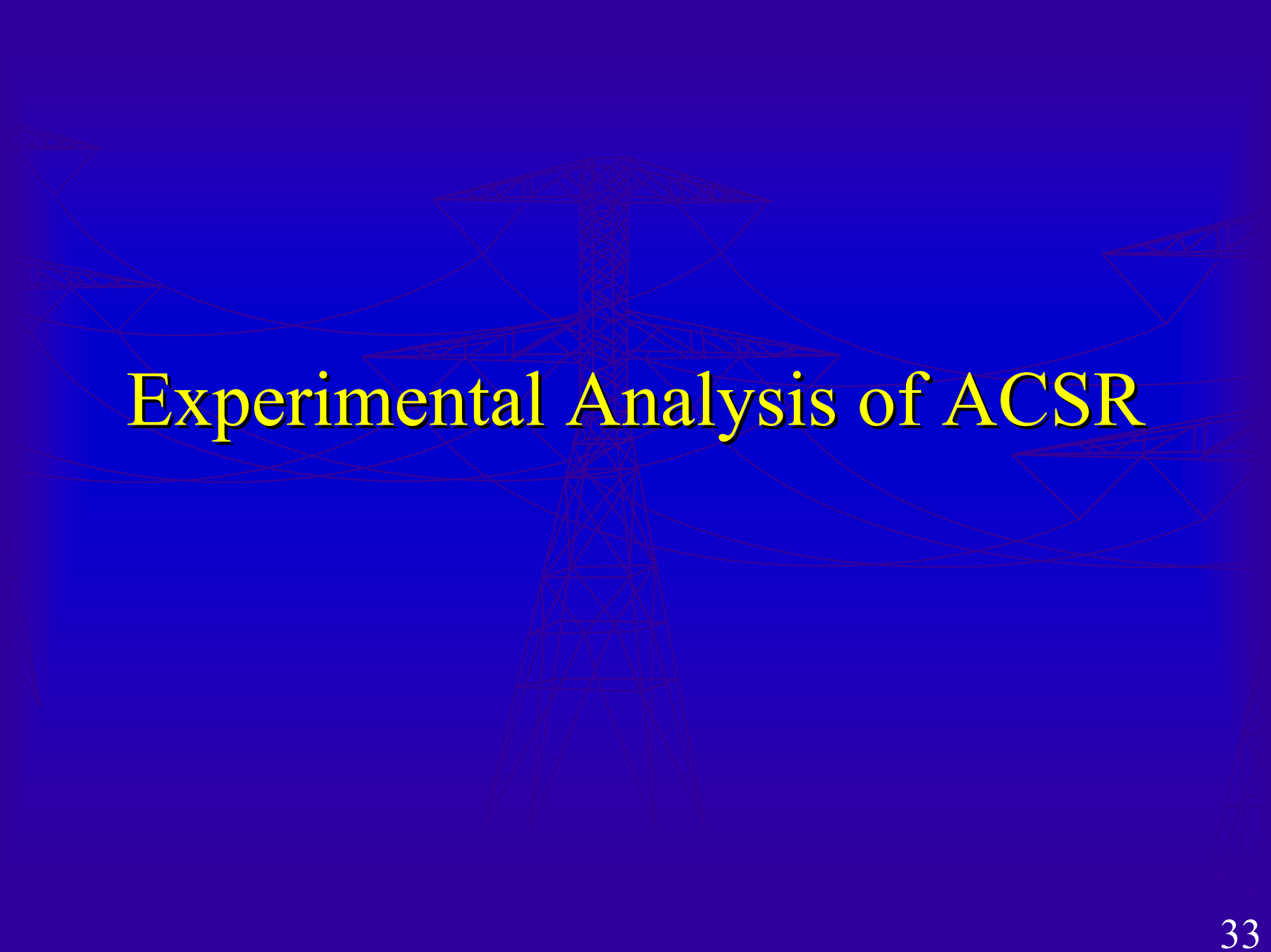
$k_{11,i}$: Stiffness in Axial direction

$k_{61,i}$: Coupled Stiffness in Axial
Shear direction

$k_{16,i}$: Coupled Stiffness

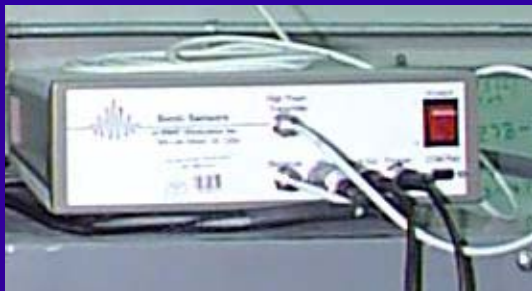
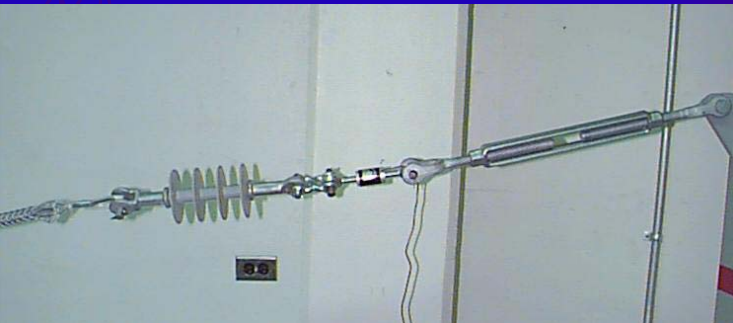
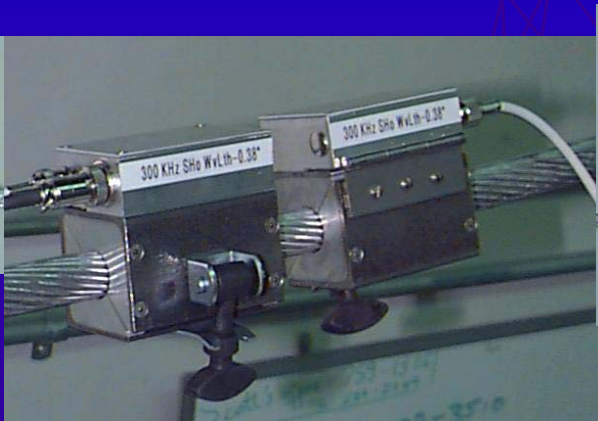
$k_{66,i}$: Stiffness in Shear direction

l_i : Wire lay direction (-1 or 1)

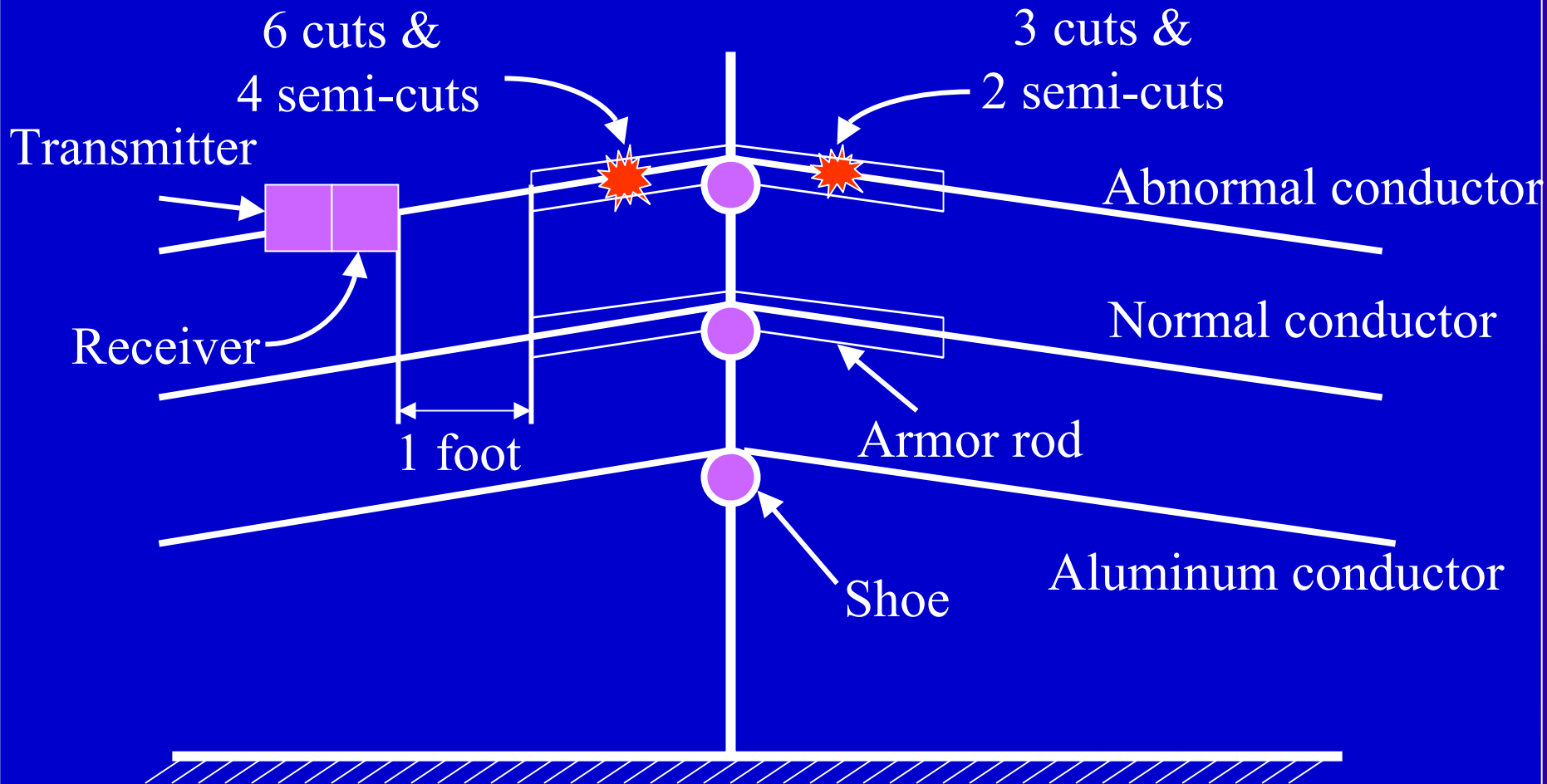


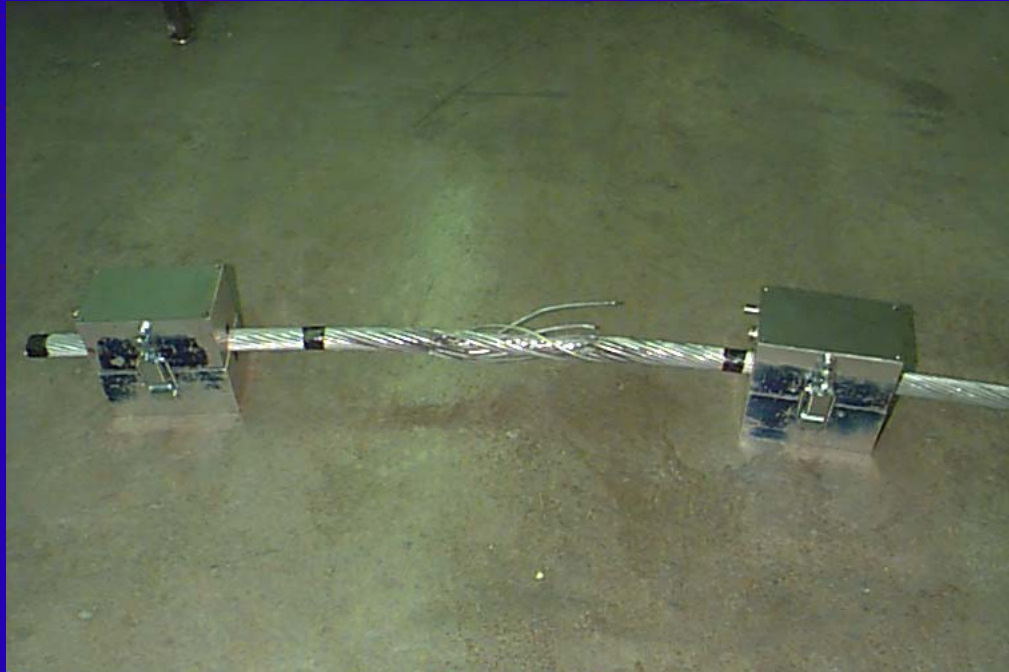
Experimental Analysis of ACSR

Experimental System

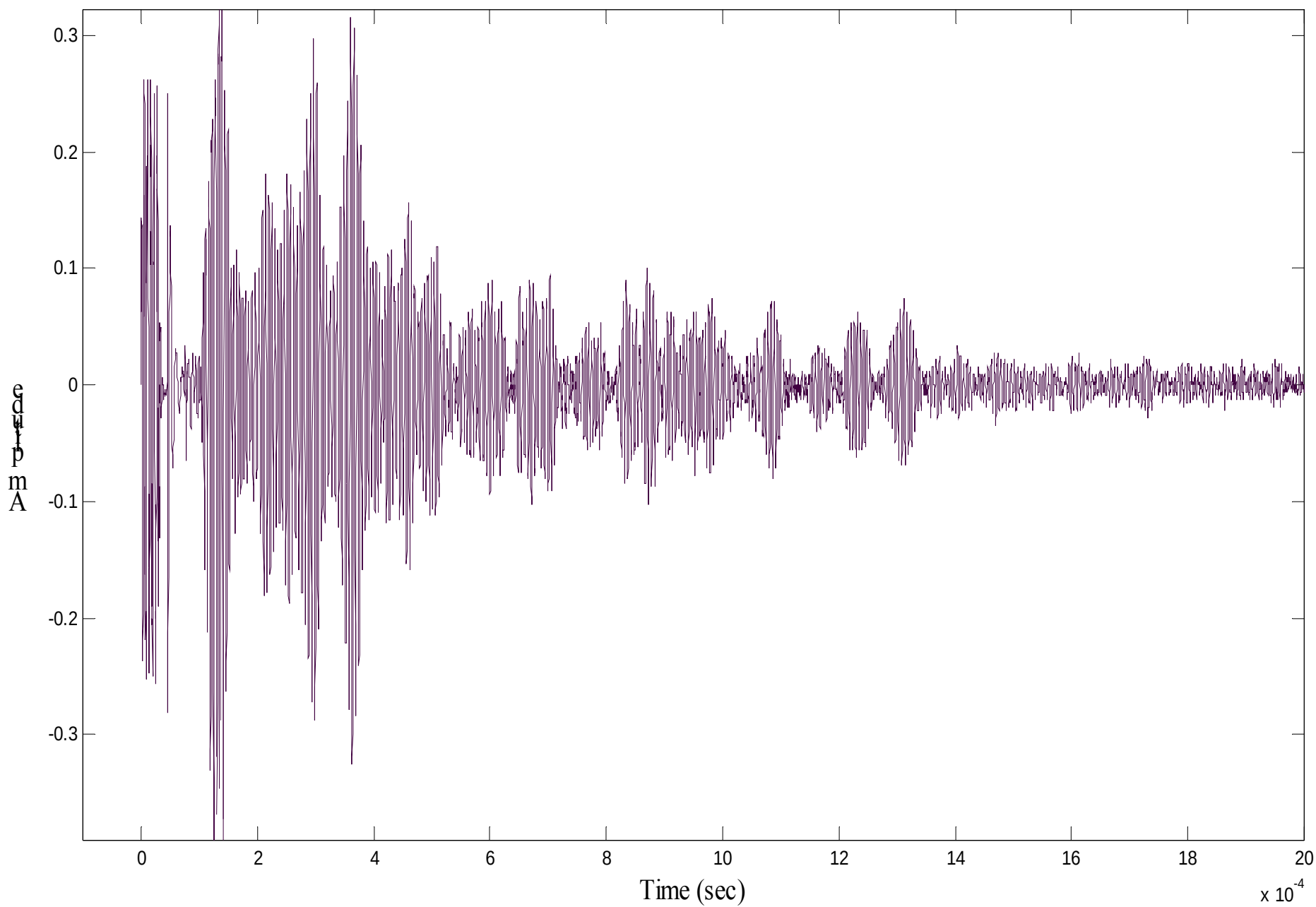


Experimental Setup in the Lab

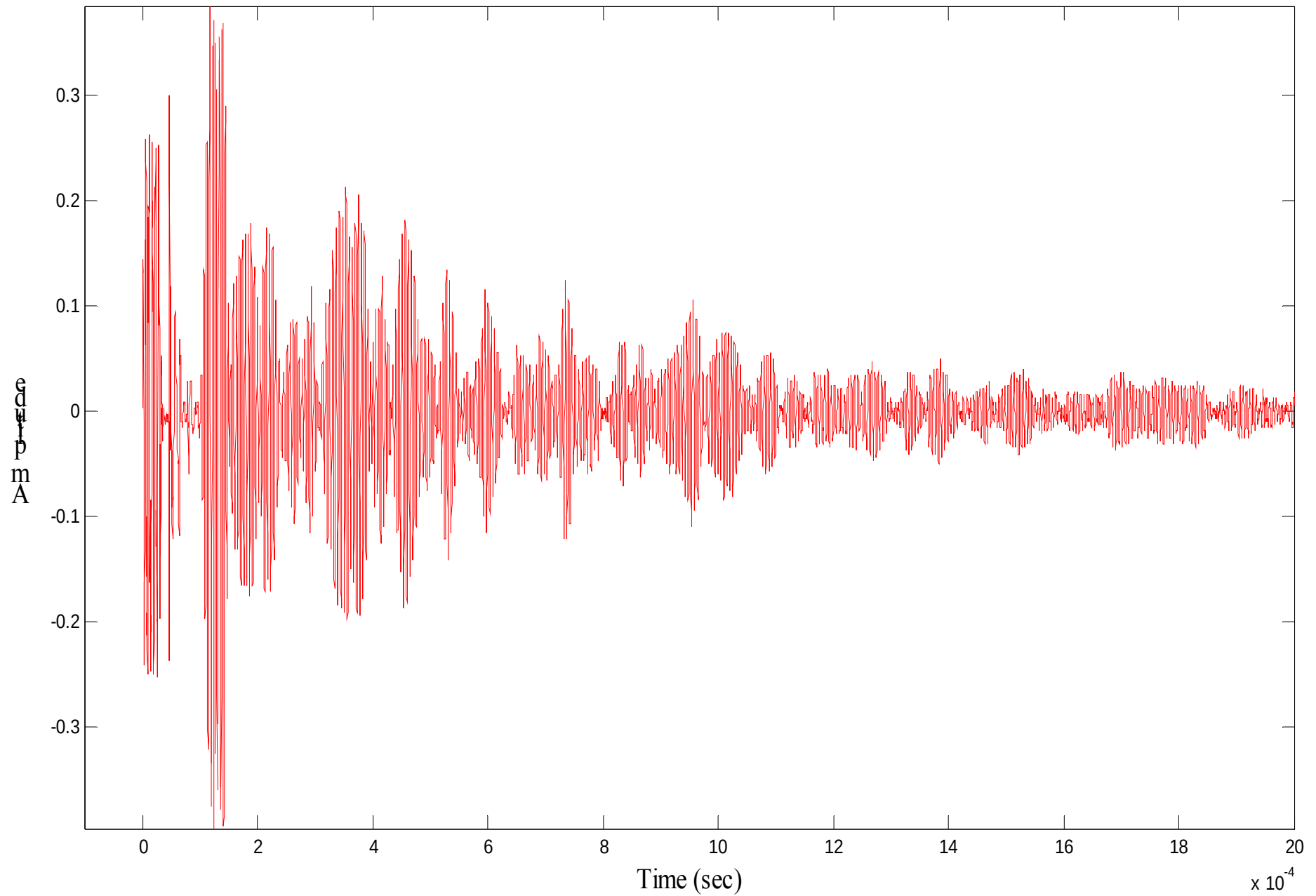




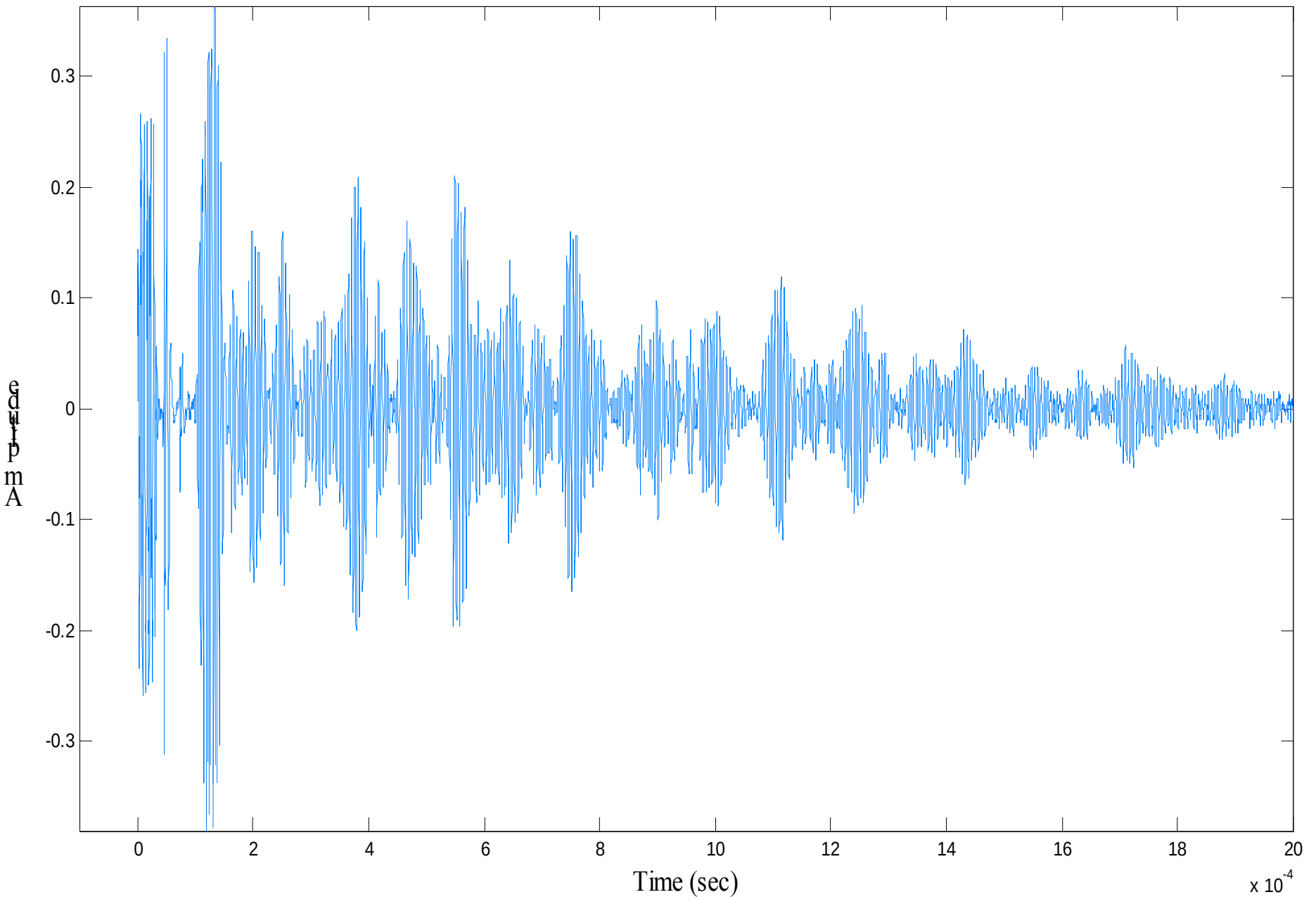
Signal of Bare Conductor



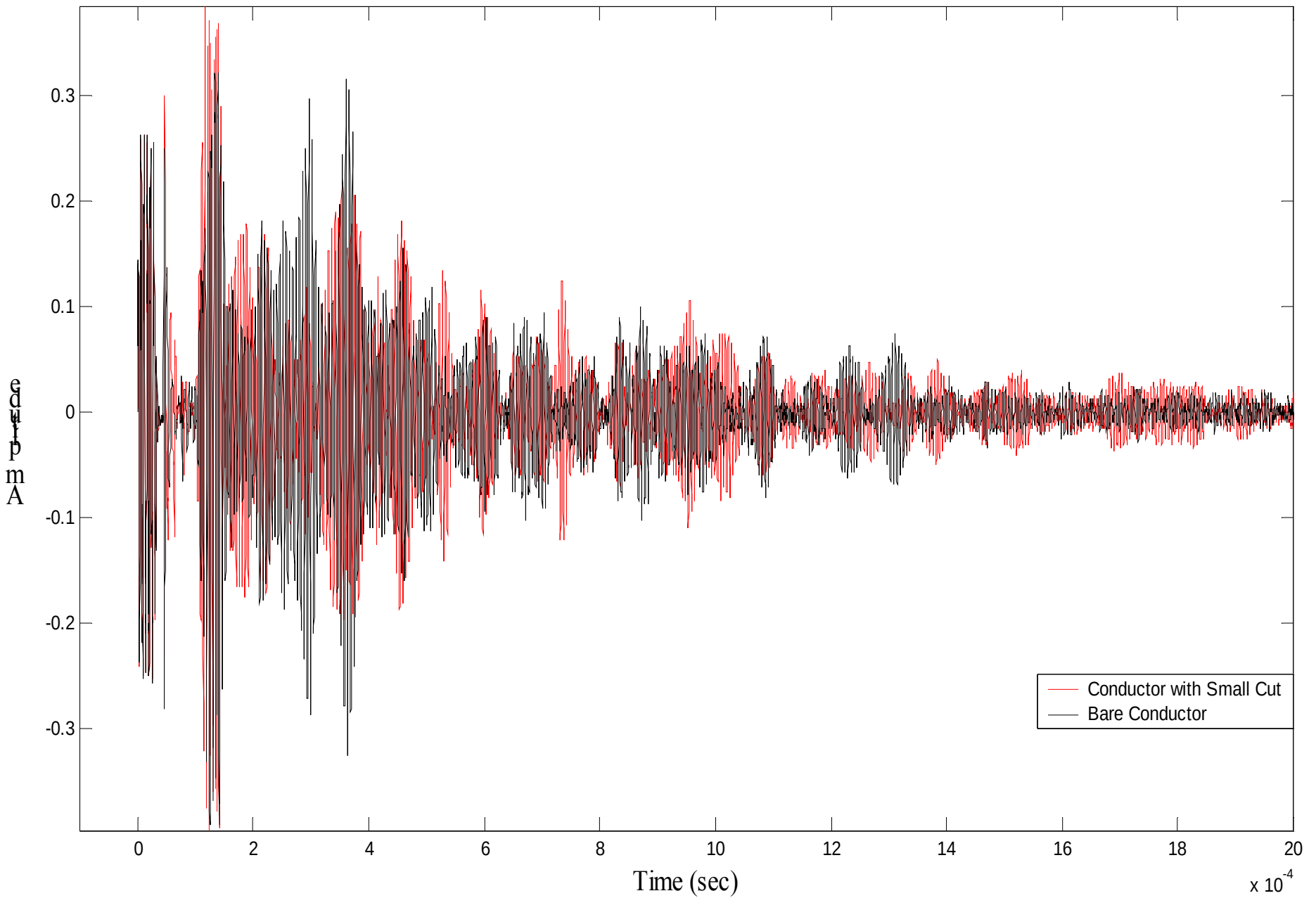
Signal of Bare Conductor with Small Cut



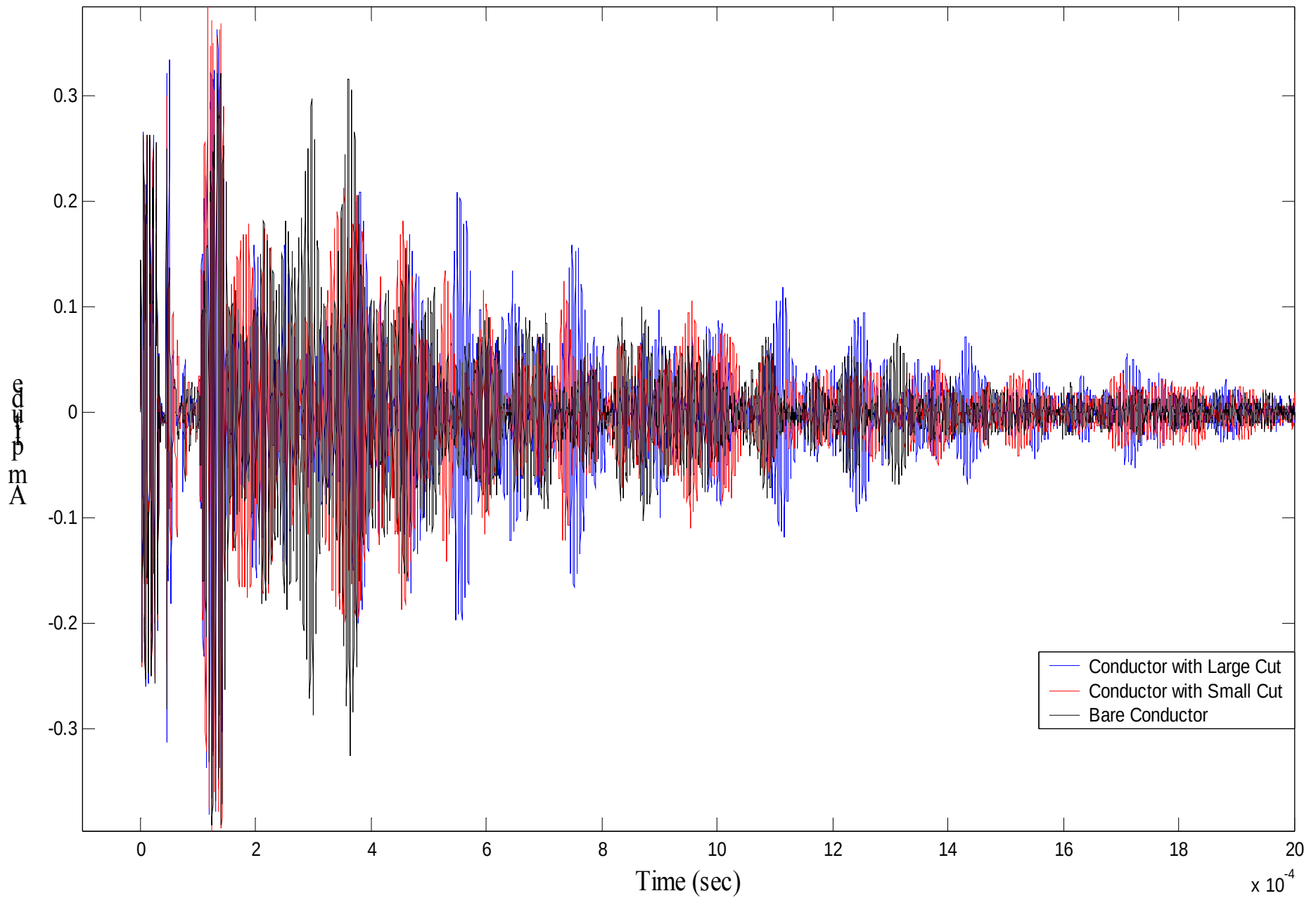
Signal of Bare Conductor with Large Cut



Bare Conductor Signal Comparison



Comparison with Larger Cut



Field Tests

- Tri- State Transmission Lines in Nebraska
- EPRI High Voltage/High Current and Environmental Chamber in Lenox, MA
- EPRI High Current, High Temperature facilities in Haslet, TX

Field Testing of ACSR Transmission Line





Conclusions

- **A portable, non-invasive, and intelligent sensor system for integrity assessment of transmission lines and other conductors has been developed.**
- **This system can be used on energized lines.**
- **This monitoring system has passed high voltage, high current, and temperature performance tests at EPRI facilities.**
- **Prototypes are being made for beta testing at utility facilities.**

Thank You



Questions?

