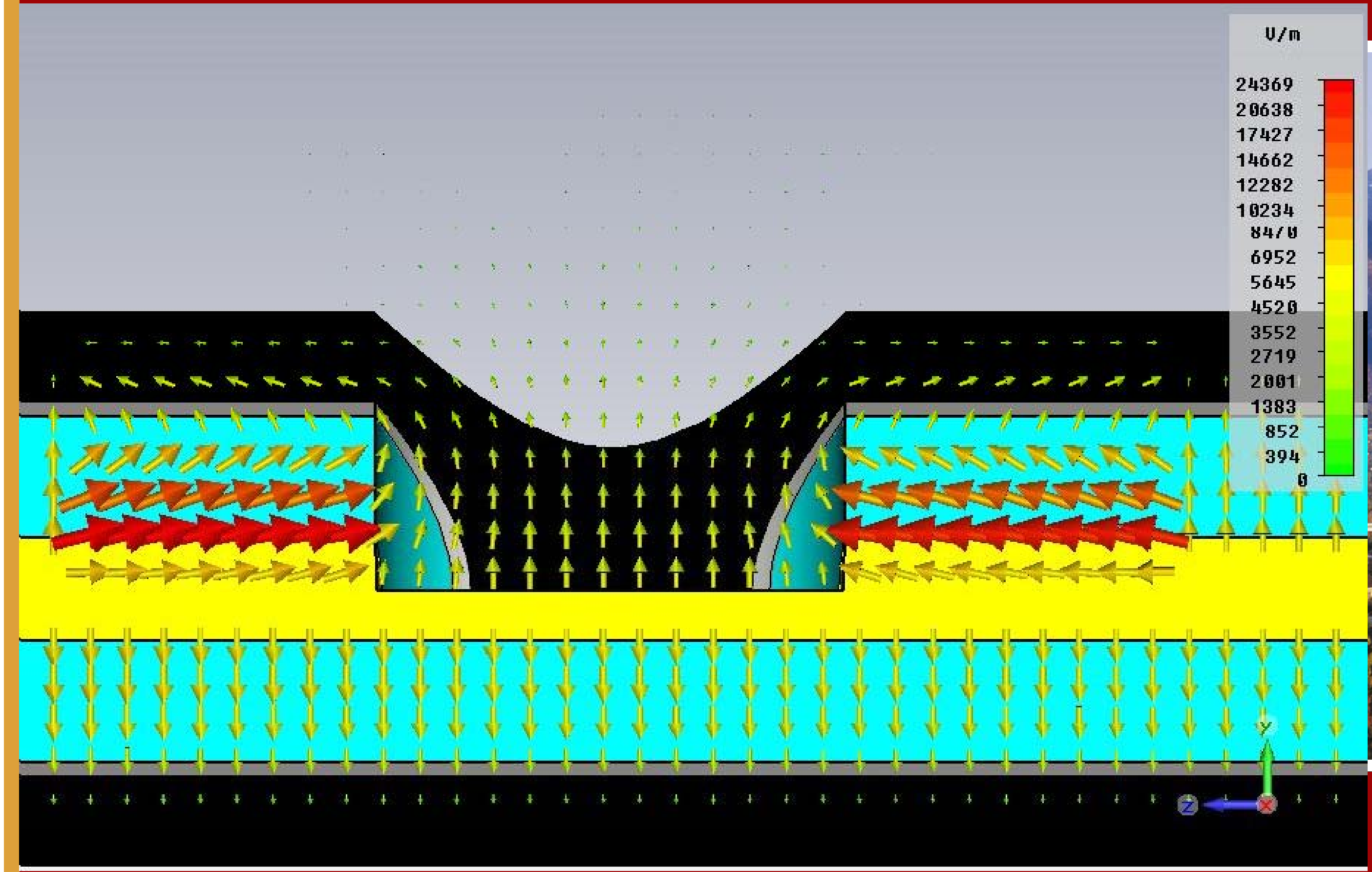
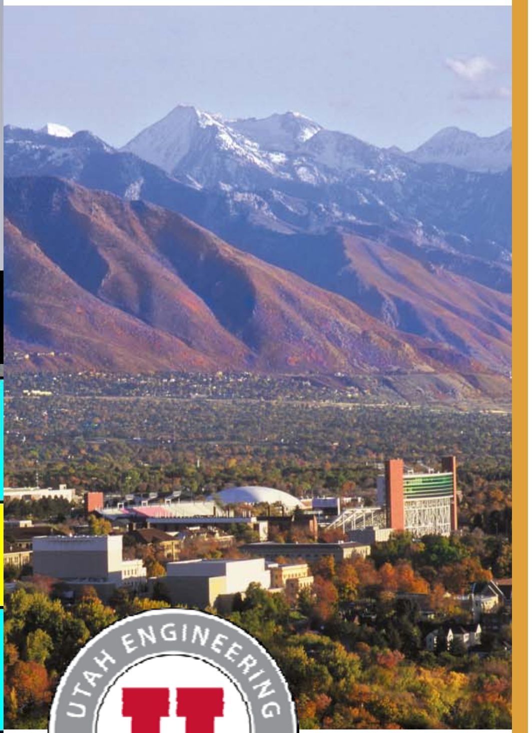
Locating Small Apertures In Cable Shielding





Lucas Thomson, Dr. Brian Jones, Dr. Cynthia Furse

L. Thomson, B. Jones, J. Stephenson, C. Furse, 'Non-Contact Connections for Reflectometry and Location of Faults in Cable Shields,' 2012 Aircraft Airworthiness and Sustainability Conference, April 2-5, 2012, Baltimore, MD

Locating Small Apertures in Cable Shielding

Lucas Thomson(1), Brian Jones(1), and Cynthia Furse(1),(2)*
(1) University of Utah, Salt Lake City, UT, 84117
(2) Livewire Innovation

This paper addresses the propagation of a signal through a small aperture in cable shielding. This may enable the location of holes (faults) in shielded cables using reflectometry. Reflectometry is an effective method for locating hard faults, such as an open or short, in transmission lines. However if the fault is small, such as a partial break in cable shielding, current methods are not capable of detecting and locating the fault. The impedance change due to the small breaks in shielding are so small that environmental variation masks them. As an alternative, this paper evaluates a novel method of using the transmitted field through the hole and propagating down the length of the cable to locate the fault in the shield.

The premise of this work is that when a break in cable shielding occurs, the signal that was exclusively internal to the cable now exists on the outside of the cable and can be used to locate the fault. This paper includes simulations of the fields that escape the hole. These results are compared to those of an analytical model for small faults: (R.E Collin, Foundations for Microwave Engineering, IEEE Press Series on Electromagnetic Wave Theory, 2nd edition, John Wiley and Sons, 2000). Next, both simulated and measured results are given for the fields propagating on the outside of the cable. The velocity of propagation and polarization are evaluated. Once the signal is propagating along the exterior of the cable, there are various methods for detecting it. In this paper, a ferrite loaded toroid sensor as shown in Figure 1 is used to receive the external magnetic fields. The design of the sensor will be discussed from its analytical model to an analysis of measured and simulated data.

Aging and Damaged Infrastructure

Reflectometry

Incident Pulse sent down wire   Reflected Pulse comes back

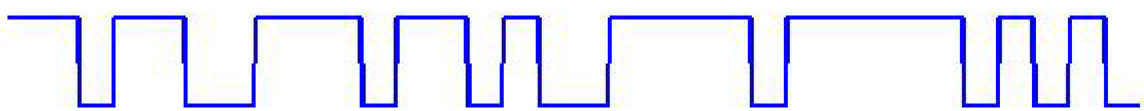
Time delay between Incident and Reflected Pulses tells distance to fault.

Common Reflectometry Methods

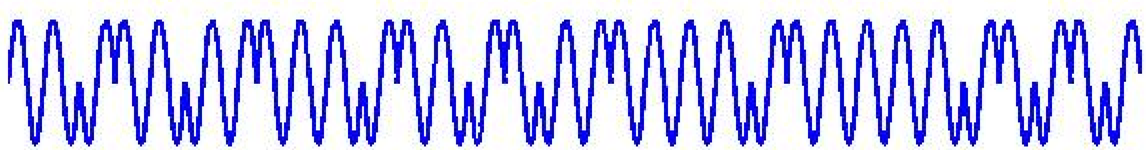
- *TDR: Time*

- *FDR: Frequency*

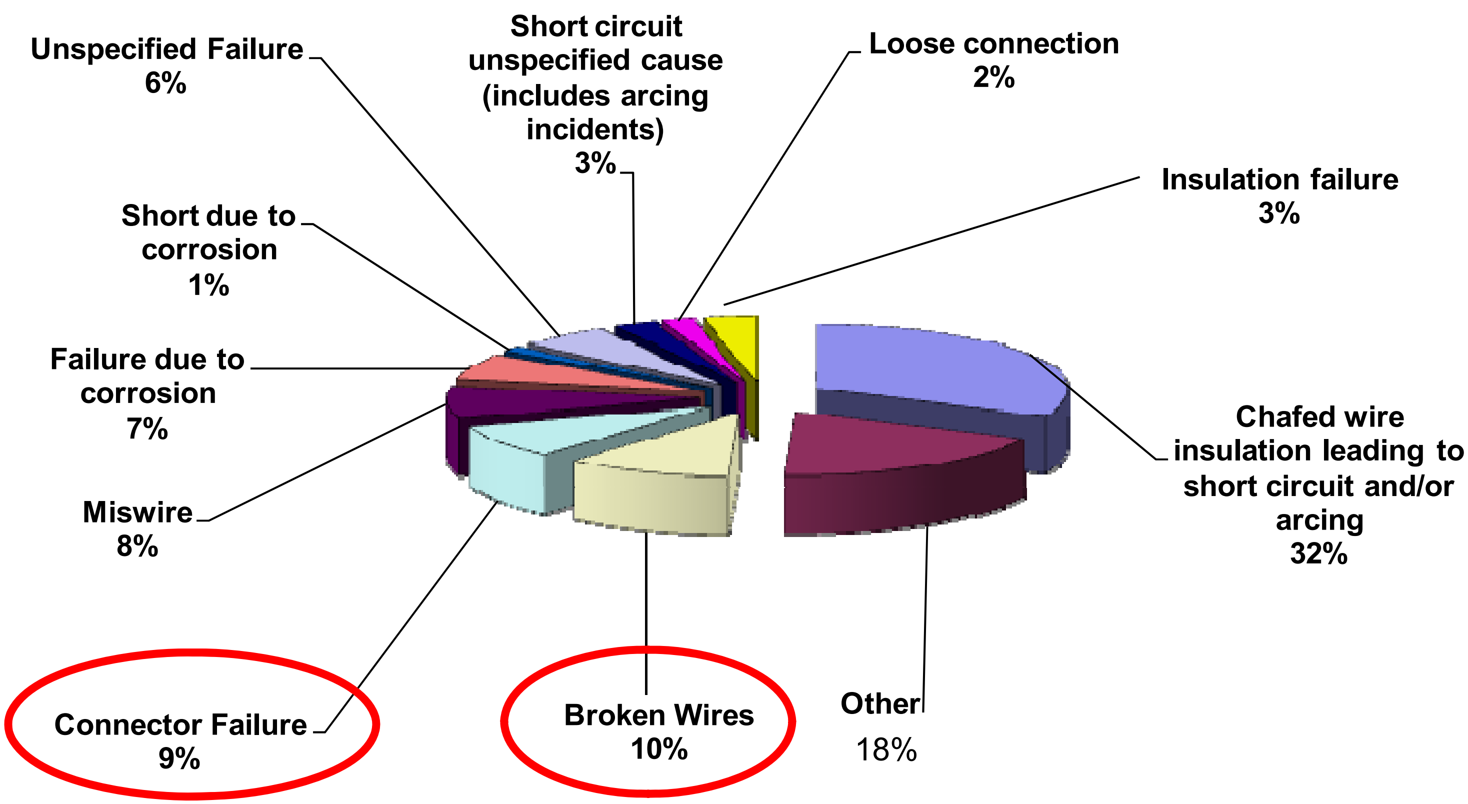
- *STDR: Sequence*



- *SSTDR: Spread Spectrum*

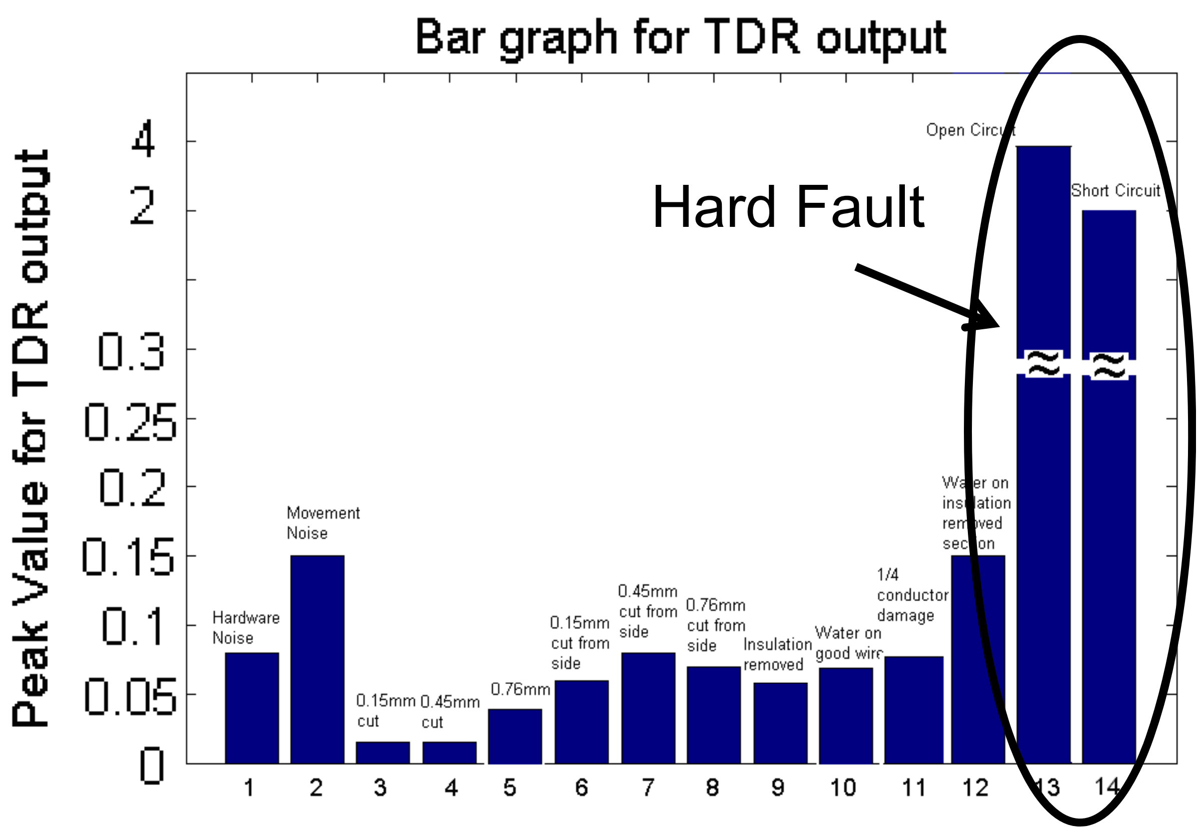


Finding 'Hard' Faults



Data: D. Lee and P. Arnason, "U.S. Navy Wiring Systems Lessons Learned", *Presentation at the Joint Conference on Aging Aircraft, 2000.*

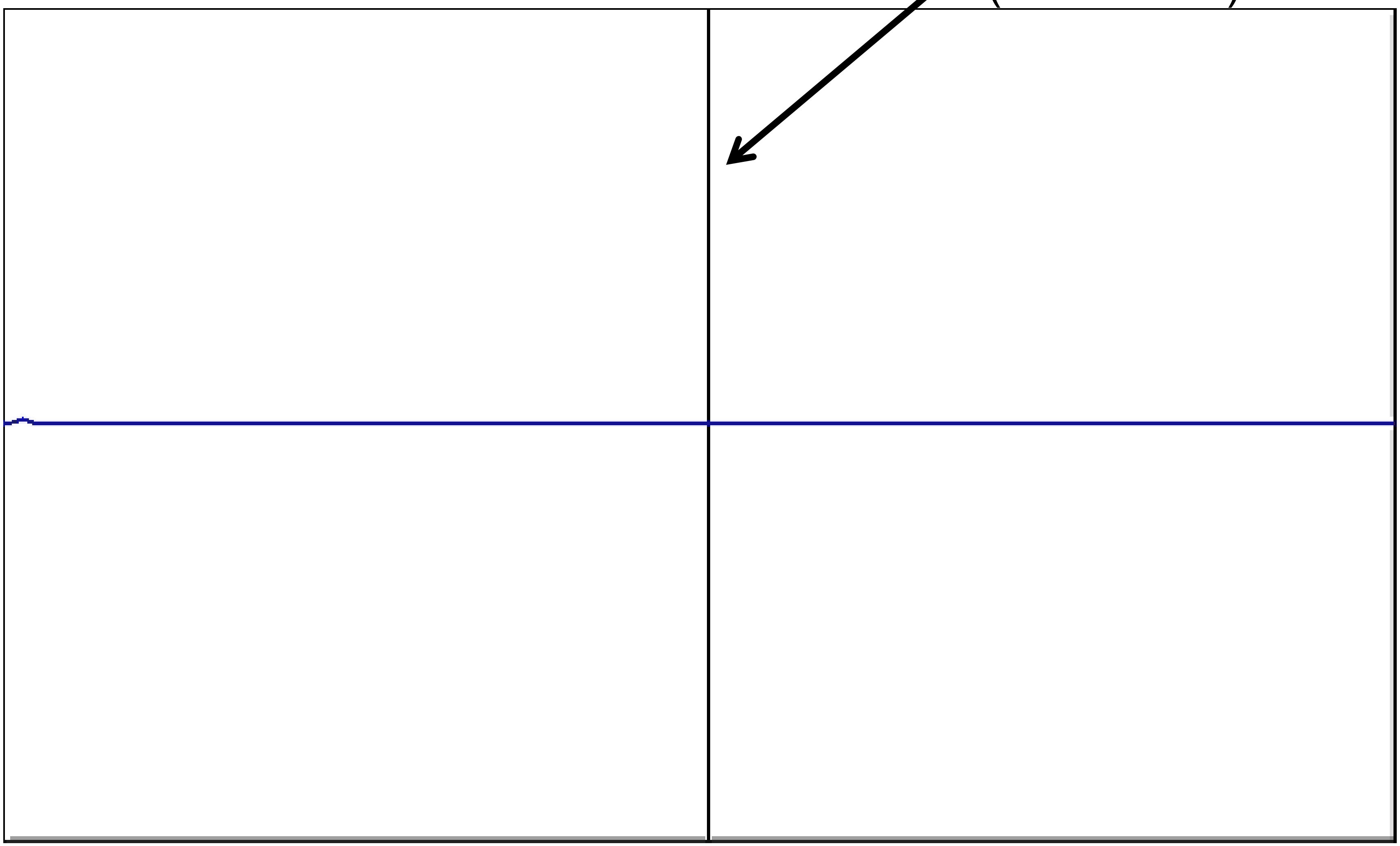
TDR Fault Response



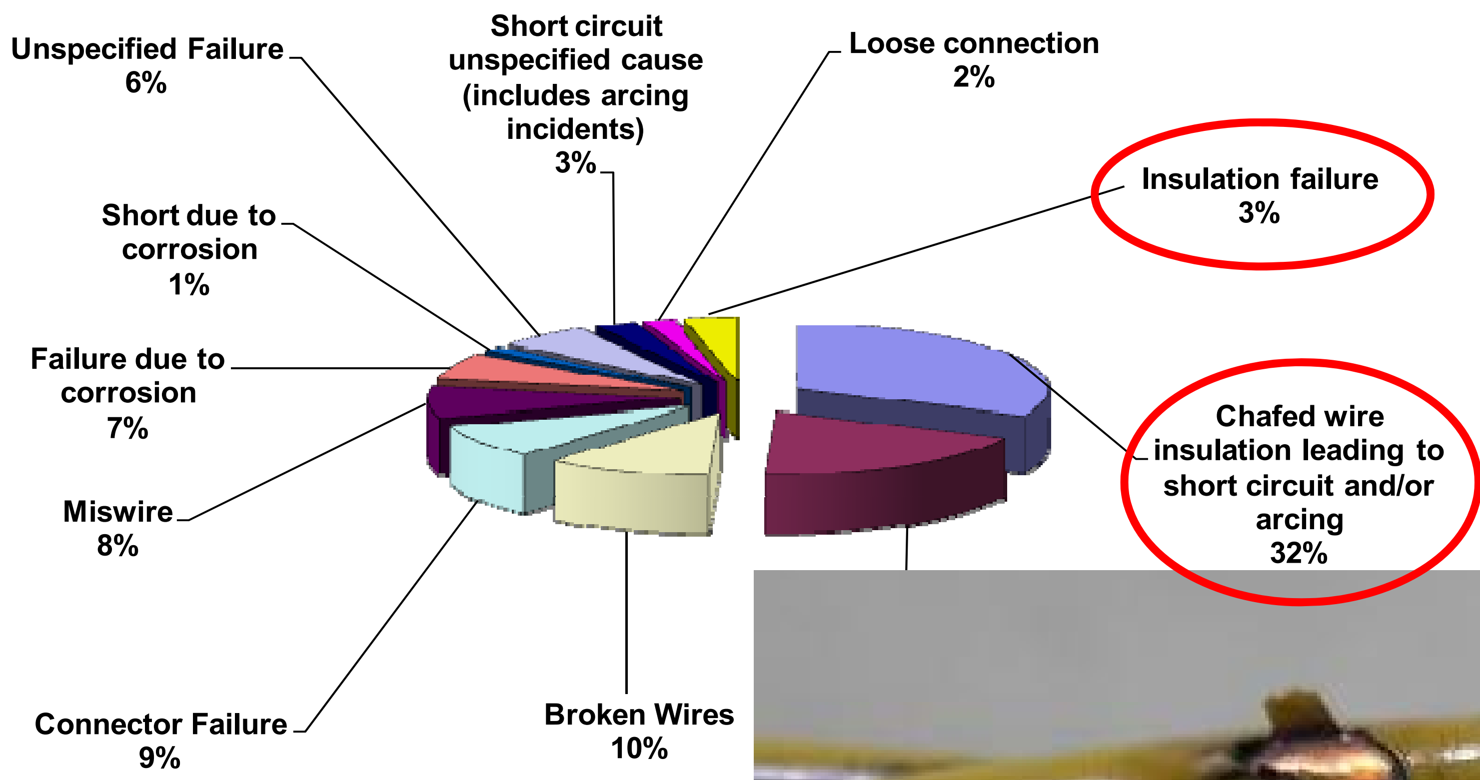
L. A. Griffiths, R. Parakh, C. Furse, B. Baker, "The Invisible Fray: A Critical Analysis of the Use of Reflectometry for Fray Location," *IEEE Sensors J.*, vol. 6, no. 3, pp. 697- 706, Jun. 2006.

Hard Fault

Open Circuit ➔Γ= +1
(Hard Fault)



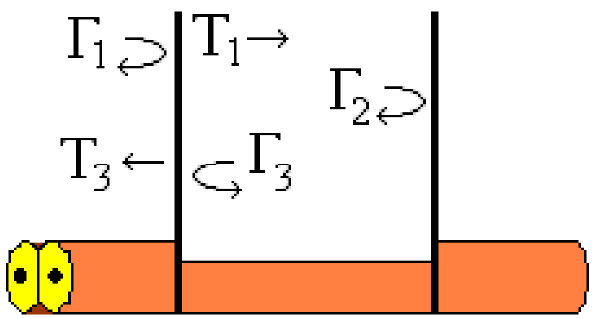
Finding ‘Soft’ Faults



Data: D. Lee and P. Arnason, “U.S. Navy Wiring Syst
Joint Conference on Aging Aircraft, 2000.

Chafe/Fray

- *A common method of fault location is reflectometry, however this method is not able to detect the very small reflections from shield damage.*

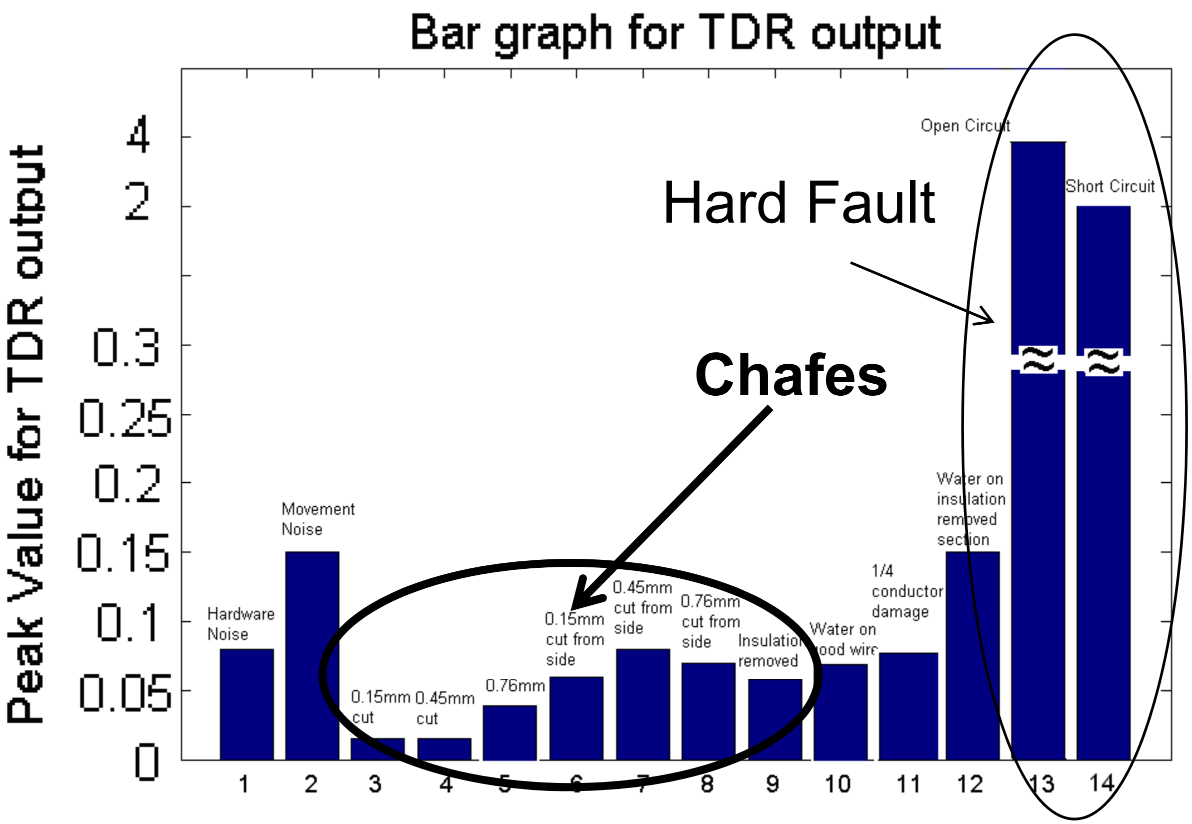


Fray

- *For small faults the initial reflected signal will be cancelled out by the secondary reflected signal*

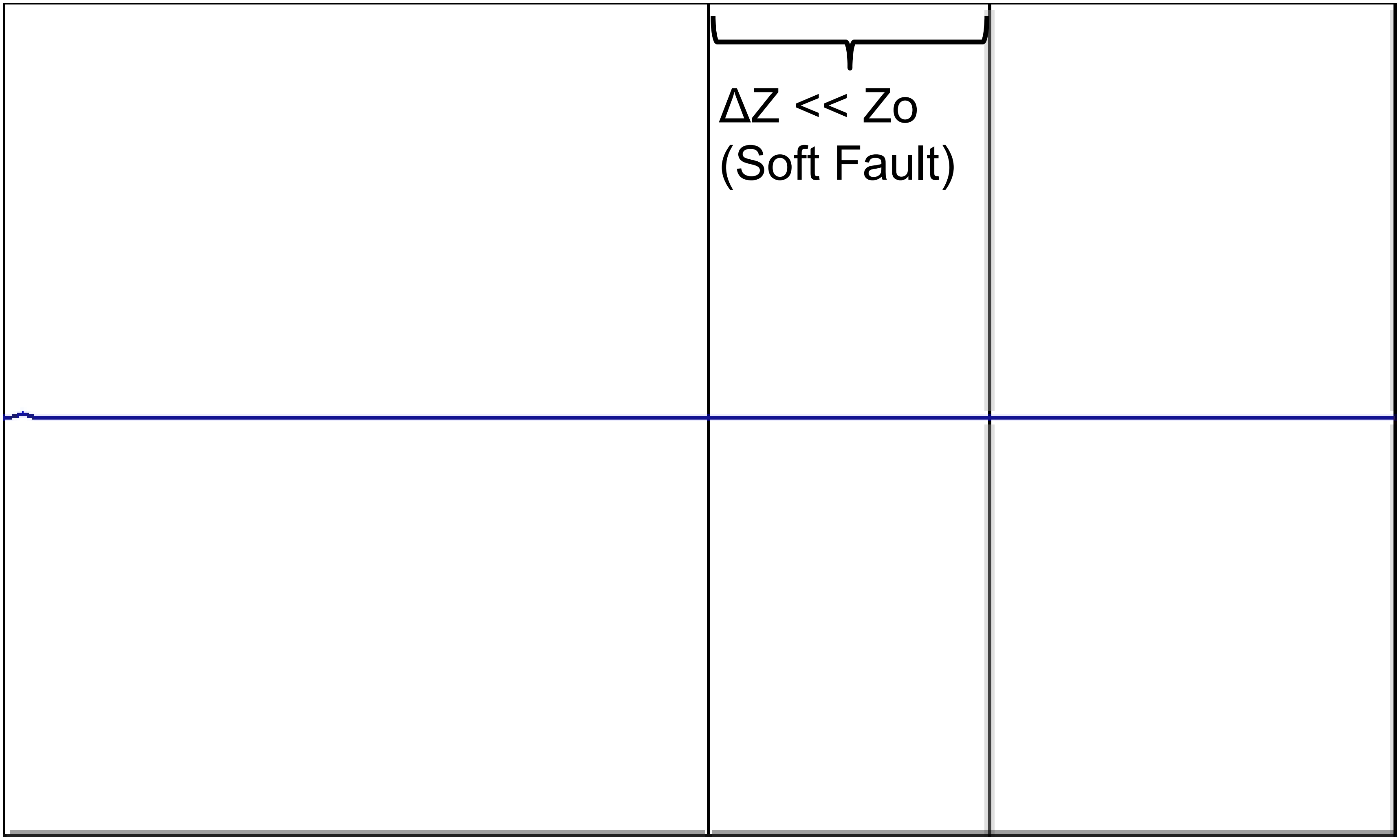
L. A. Griffiths, R. Parakh, C. Furse, B. Baker, "The Invisible Fray: A Critical Analysis of the Use of Reflectometry for Fray Location," *IEEE Sensors J.*, vol. 6, no. 3, pp. 697- 706, Jun. 2006.

TDR Fault Response

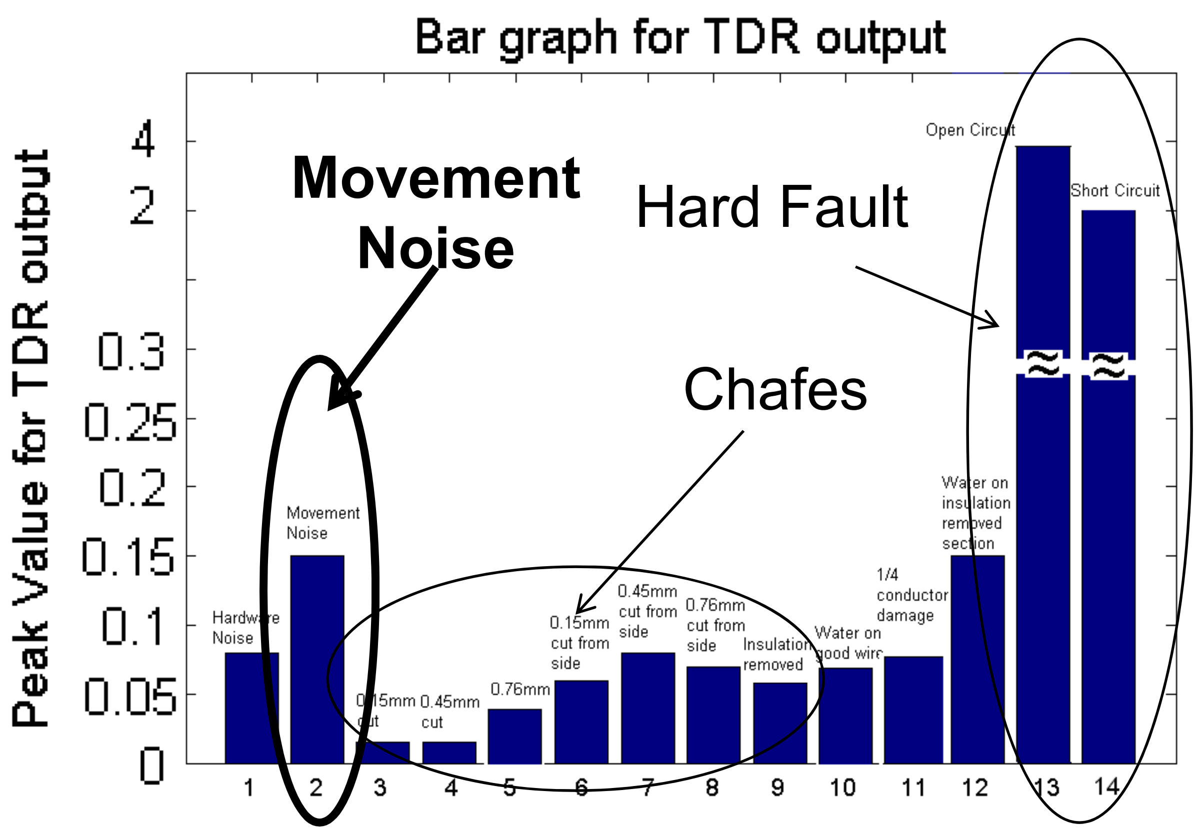


L. A. Griffiths, R. Parakh, C. Furse, B. Baker, "The Invisible Fray: A Critical Analysis of the Use of Reflectometry for Fray Location," *IEEE Sensors J.*, vol. 6, no. 3, pp. 697- 706, Jun. 2006.

Soft Fault

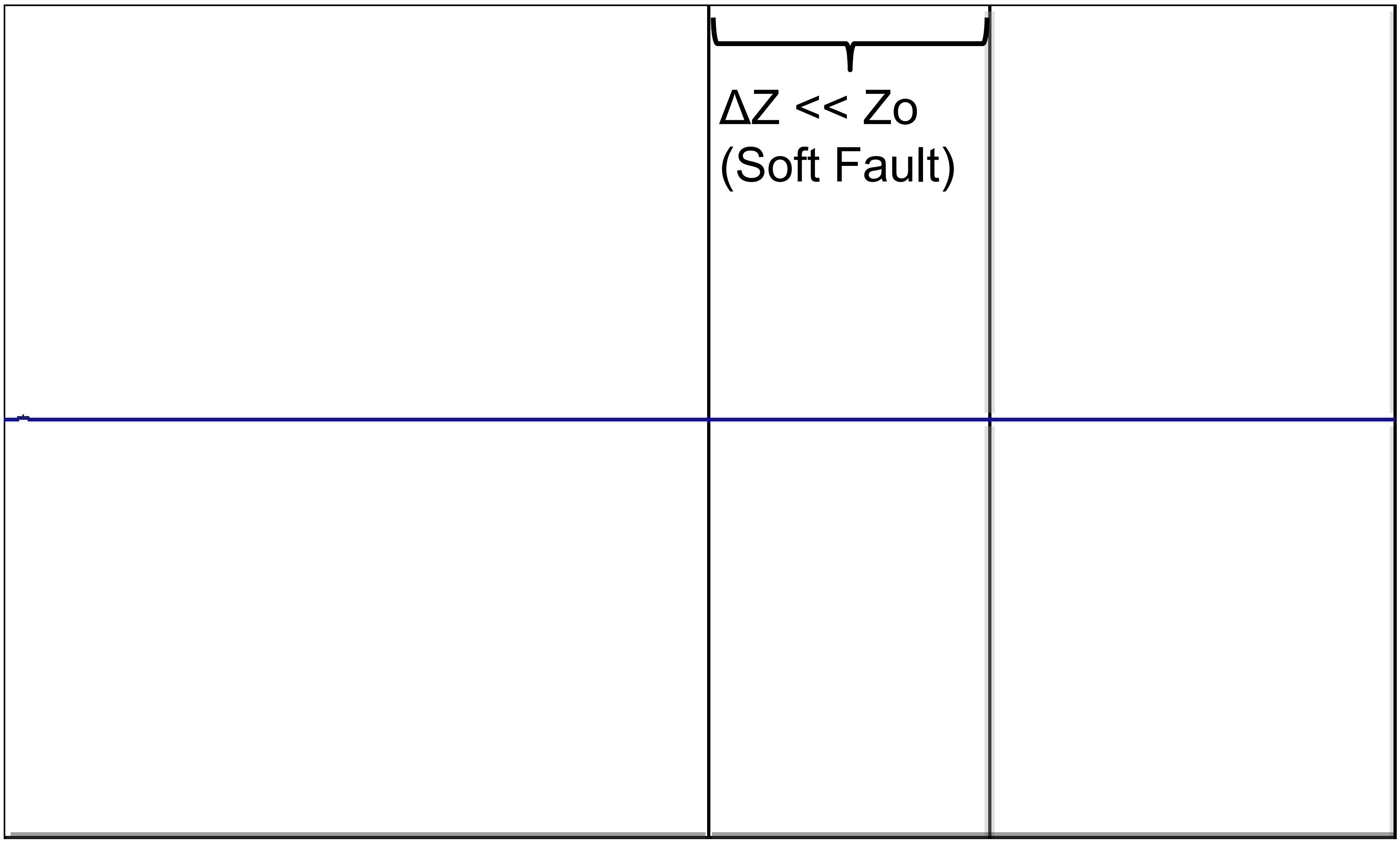


TDR Fault Response



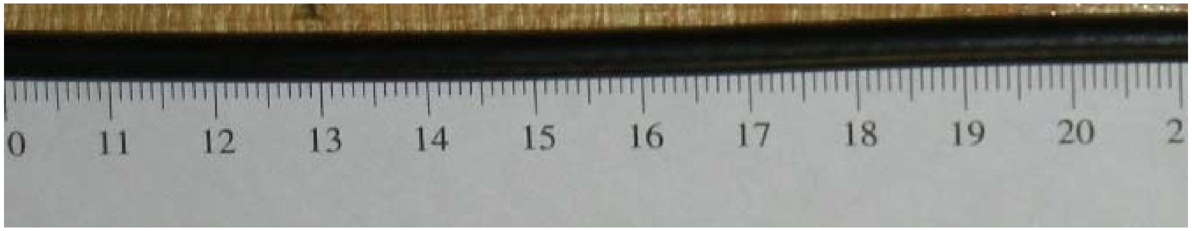
L. A. Griffiths, R. Parakh, C. Furse, B. Baker, "The Invisible Fray: A Critical Analysis of the Use of Reflectometry for Fray Location," *IEEE Sensors J.*, vol. 6, no. 3, pp. 697- 706, Jun. 2006.

Soft Fault w/ Noise

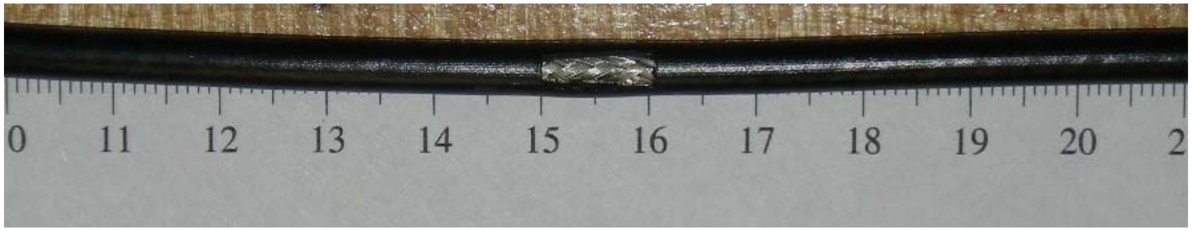


Faulty Shield on Coaxial Cable

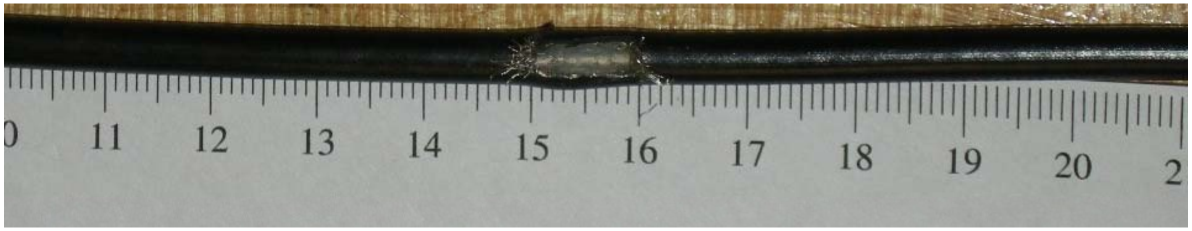
Undamaged Cable



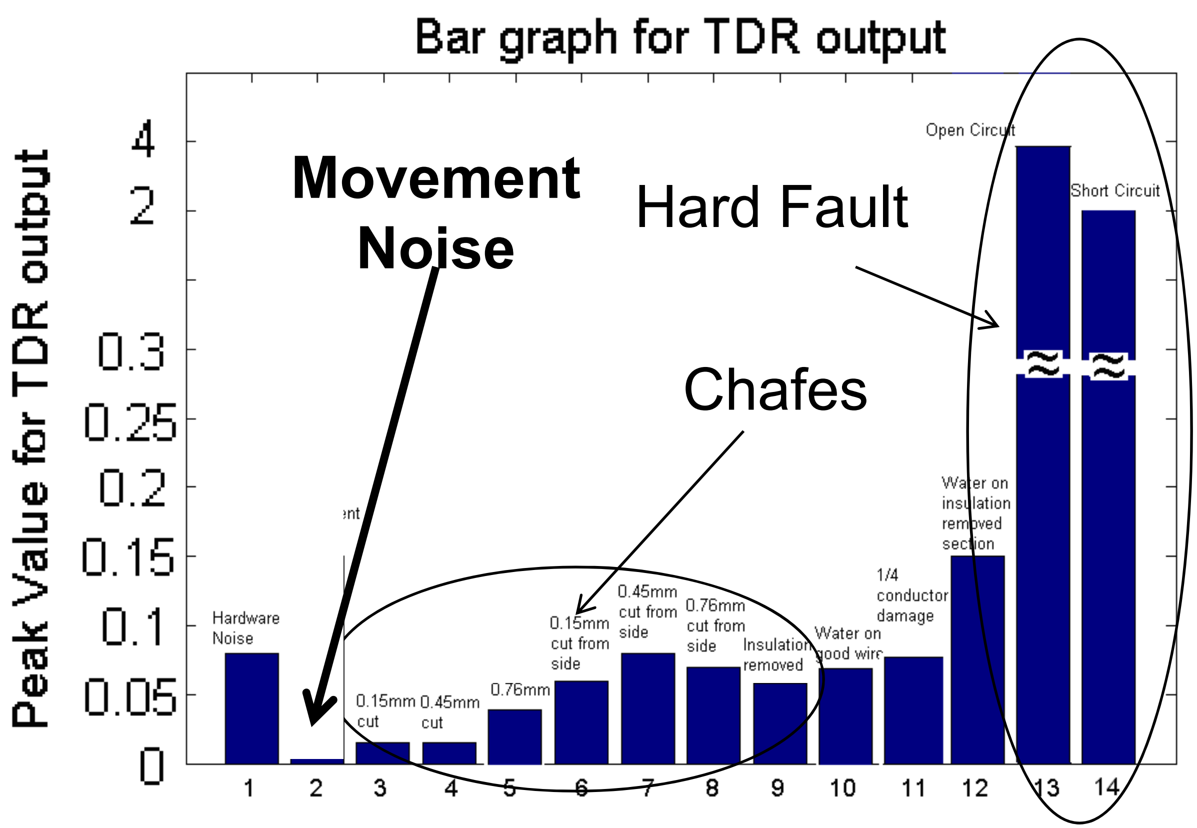
Exposed Shield



Faulty Shield

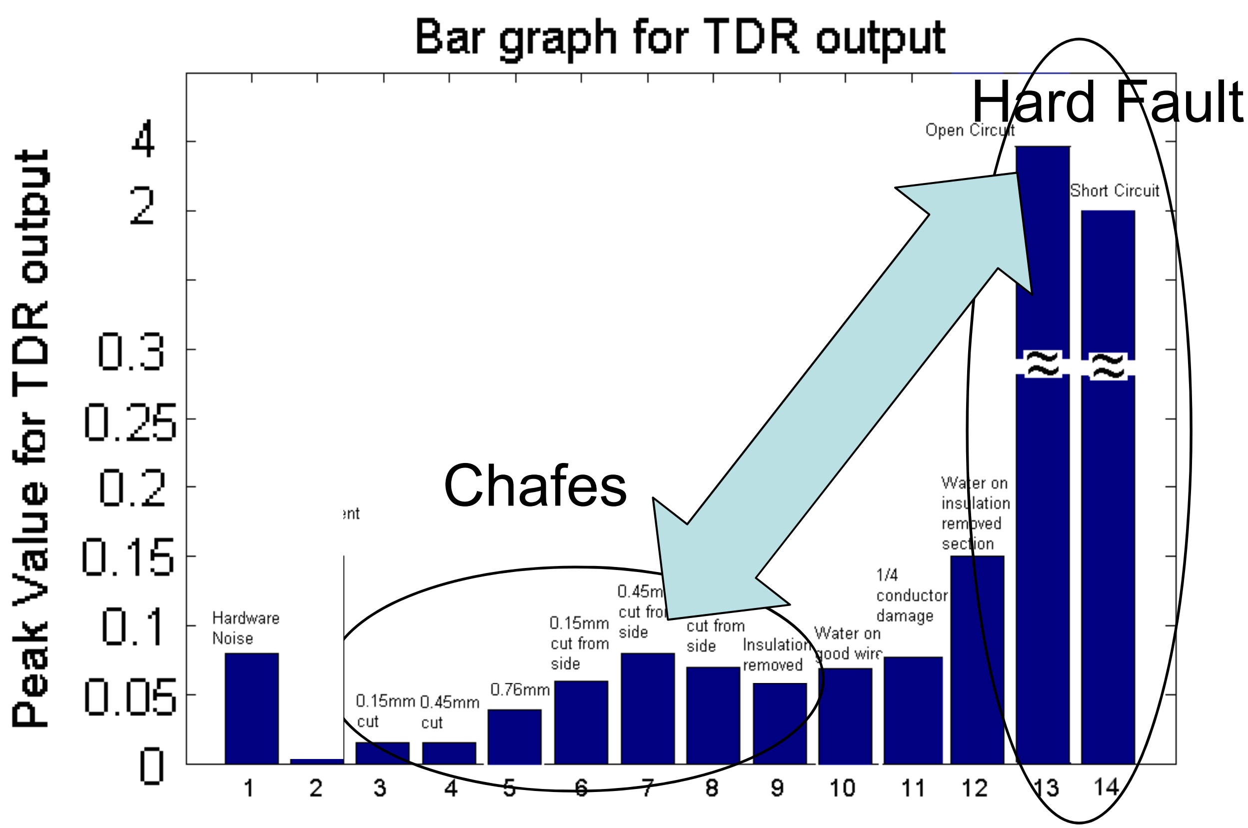


Coax – no impedance change from environmental changes



L. A. Griffiths, R. Parakh, C. Furse, B. Baker, "The Invisible Fray: A Critical Analysis of the Use of Reflectometry for Fray Location," *IEEE Sensors J.*, vol. 6, no. 3, pp. 697- 706, Jun. 2006.

TDR – Requires Large Dynamic Range

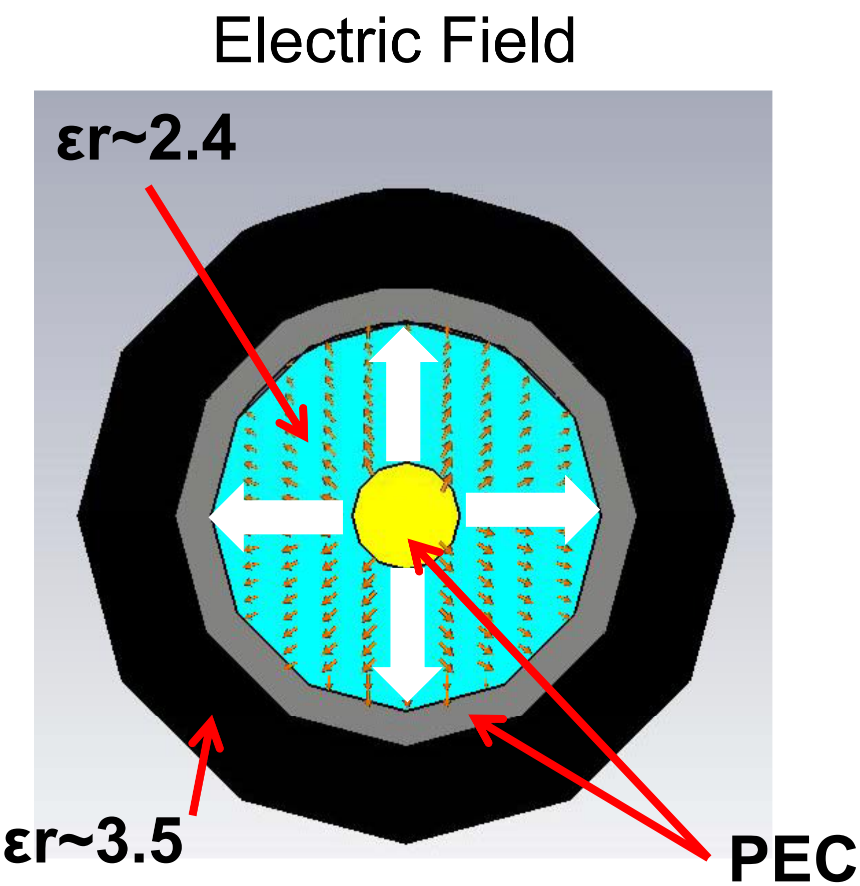


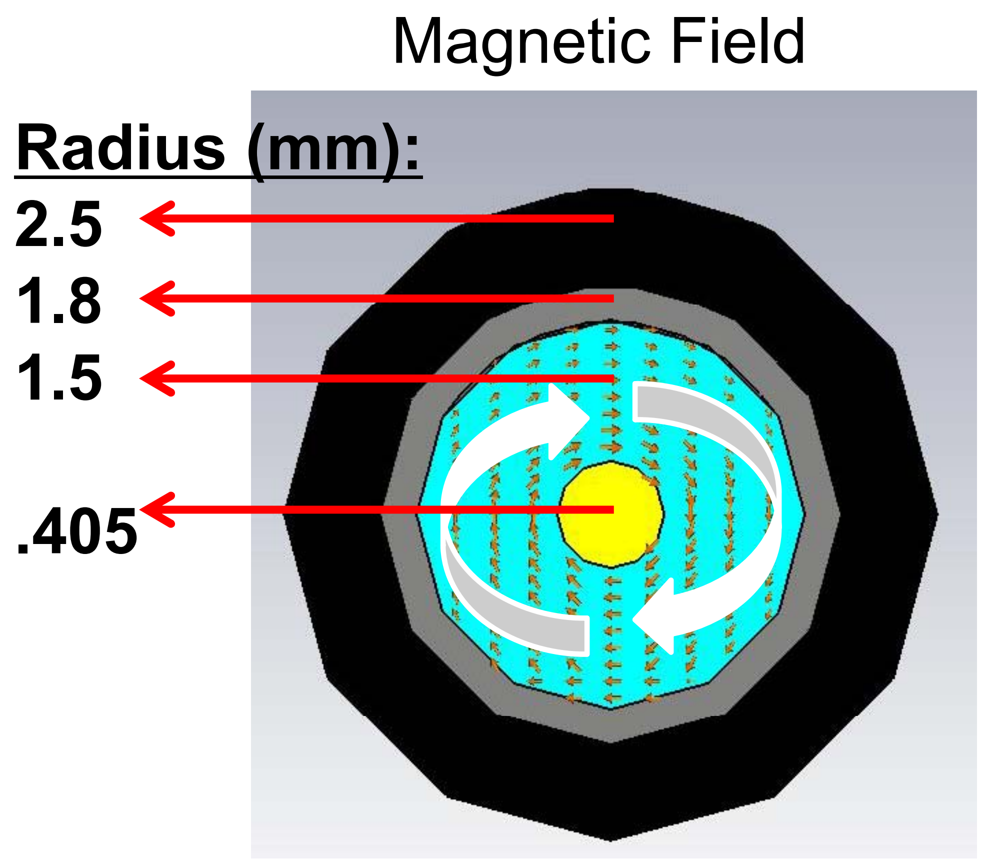
L. A. Griffiths, R. Parakh, C. Furse, B. Baker, "The Invisible Fray: A Critical Analysis of the Use of Reflectometry for Fray Location," *IEEE Sensors J.*, vol. 6, no. 3, pp. 697- 706, Jun. 2006.

A different method:

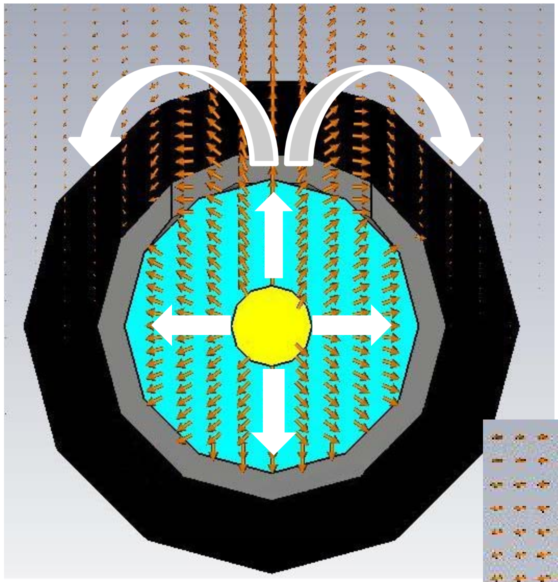
Fields Contained – Quasi TEM

ZERO fields leak from to outside



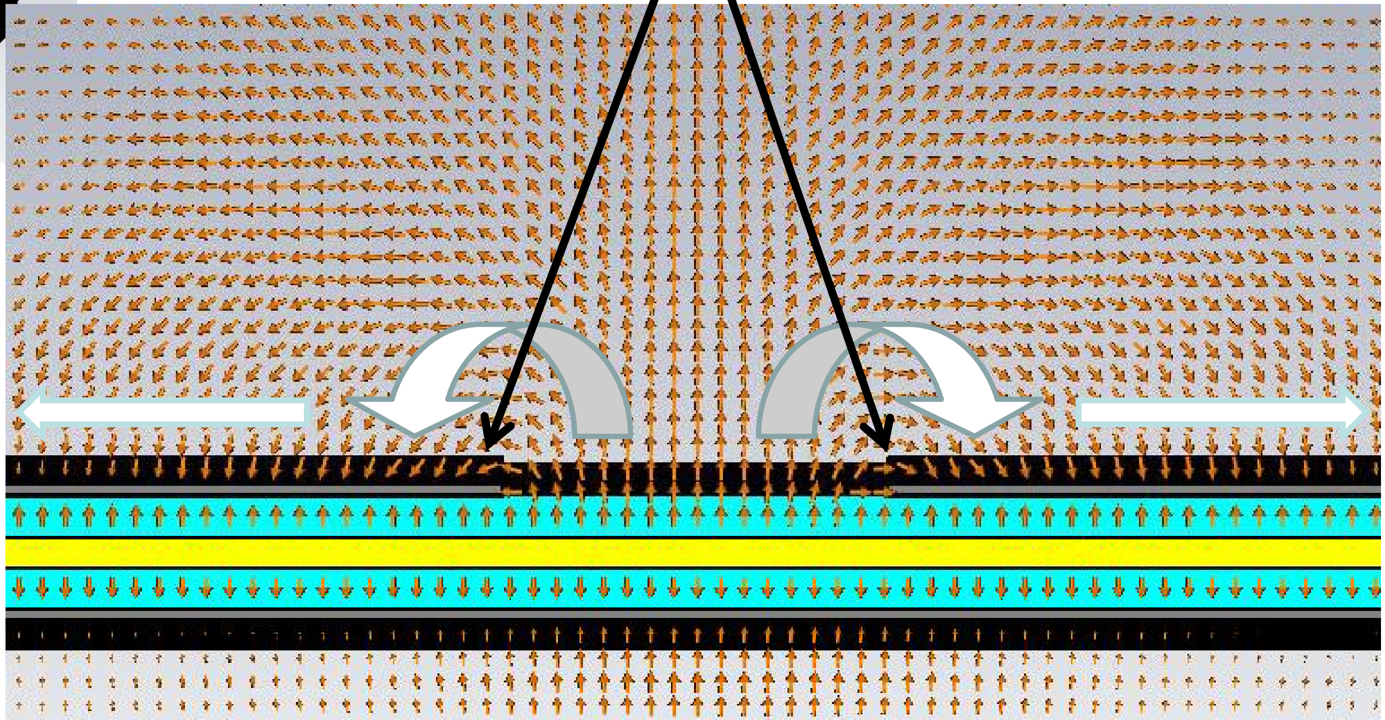


E-Fields From Fault

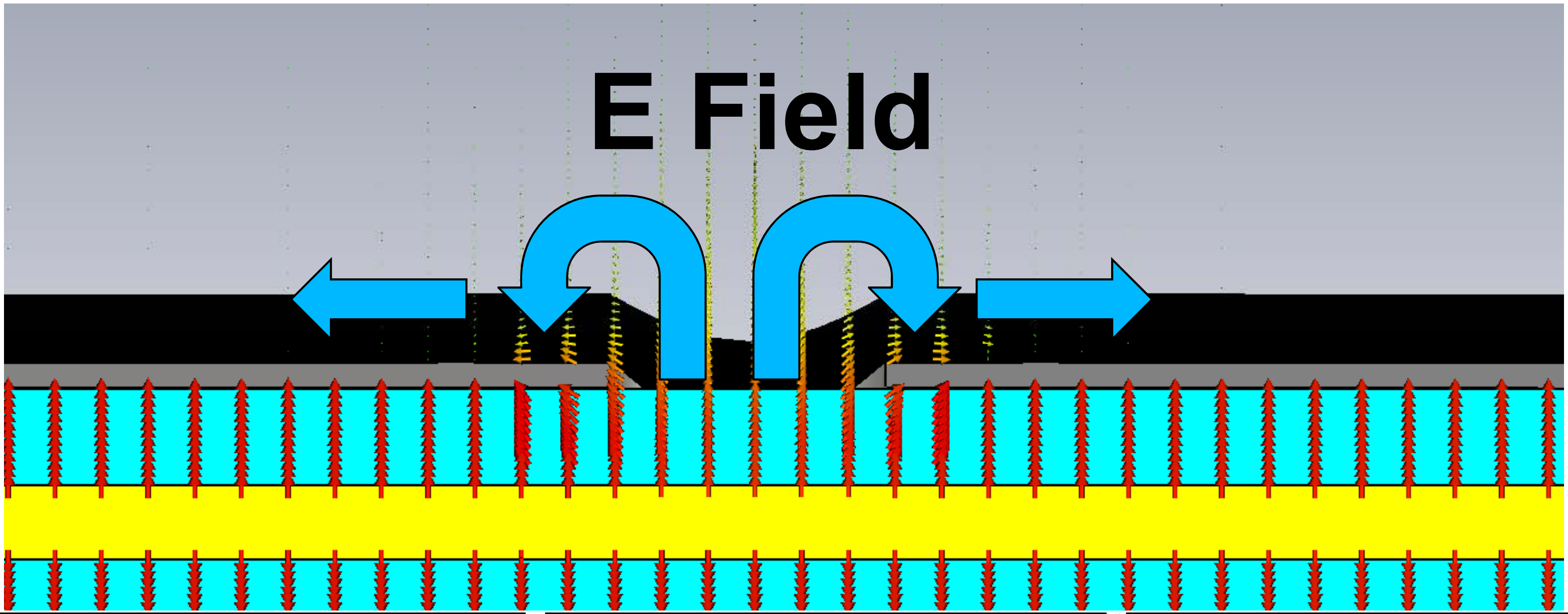


Fringing Fields (non-zero!) .. Smaller dynamic Range

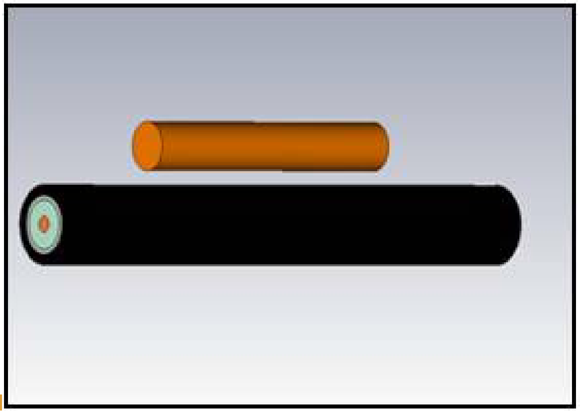
TM Modes Only (Surface Wave)

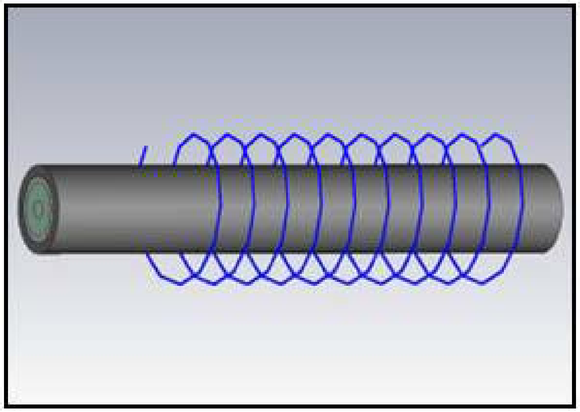


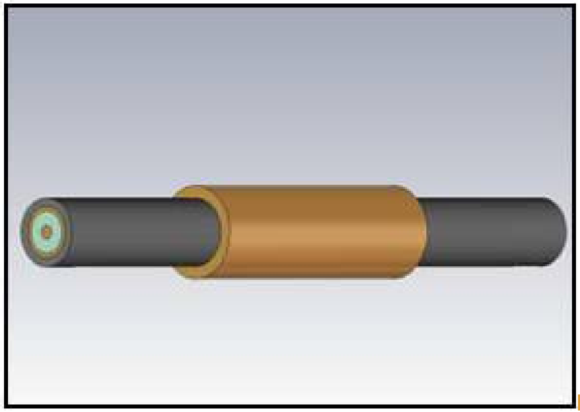
Receiver Choices - Capacitive



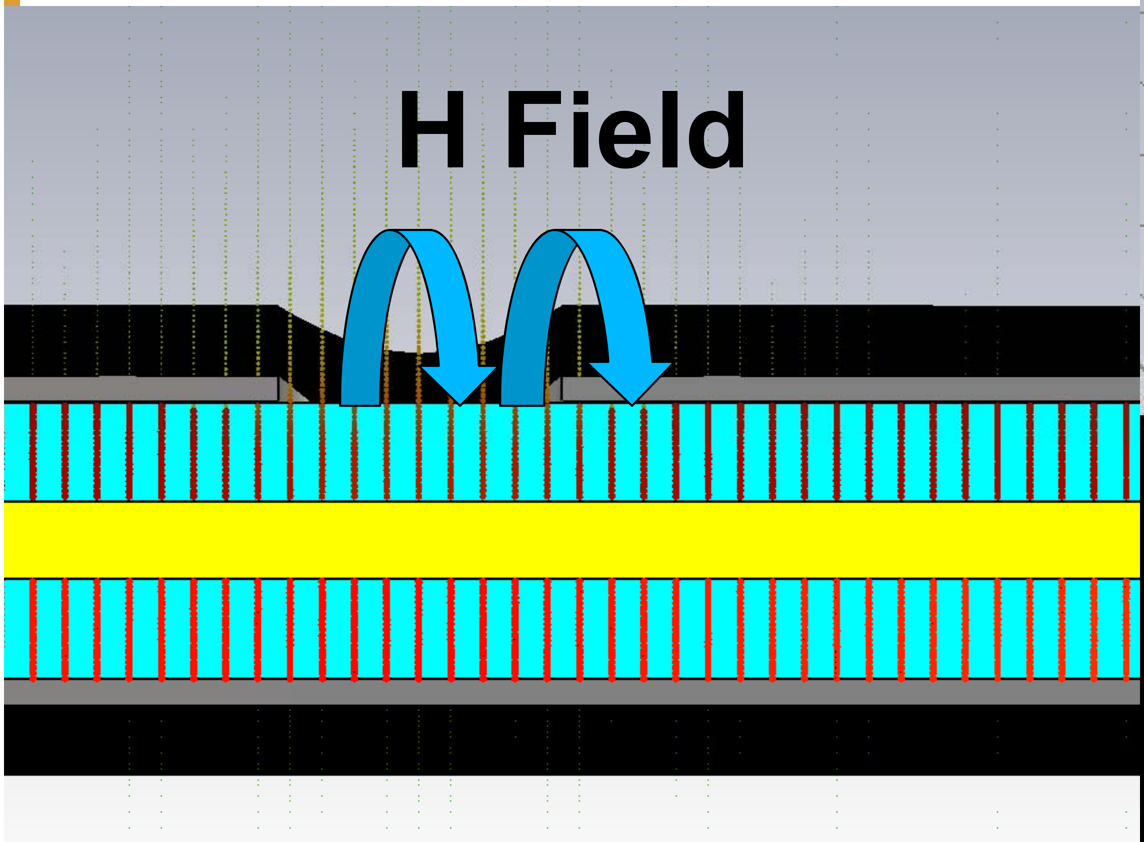
Parallel Cylinder	Spiral	Concentric Cylinder

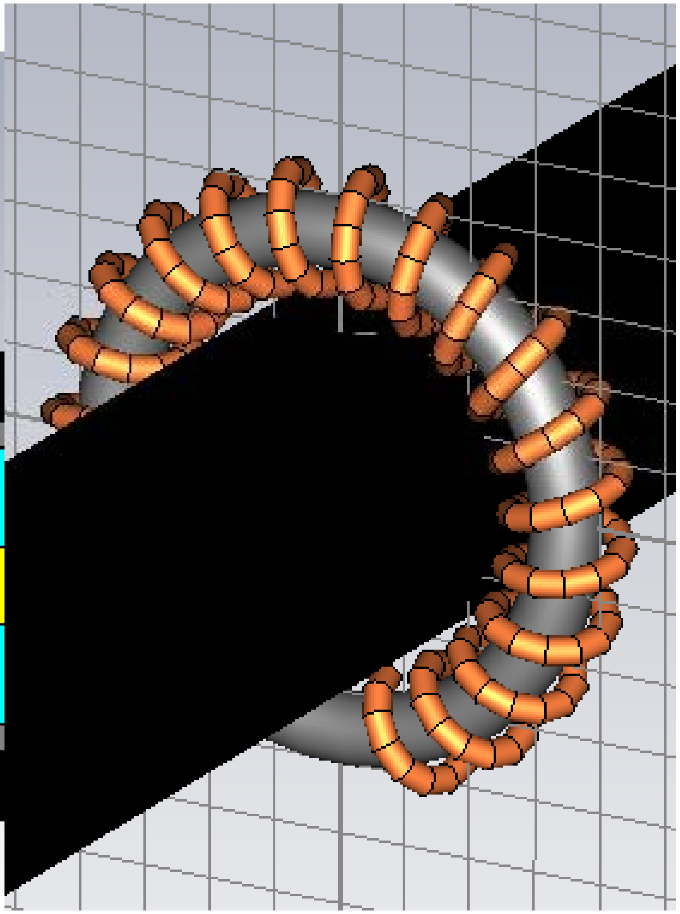




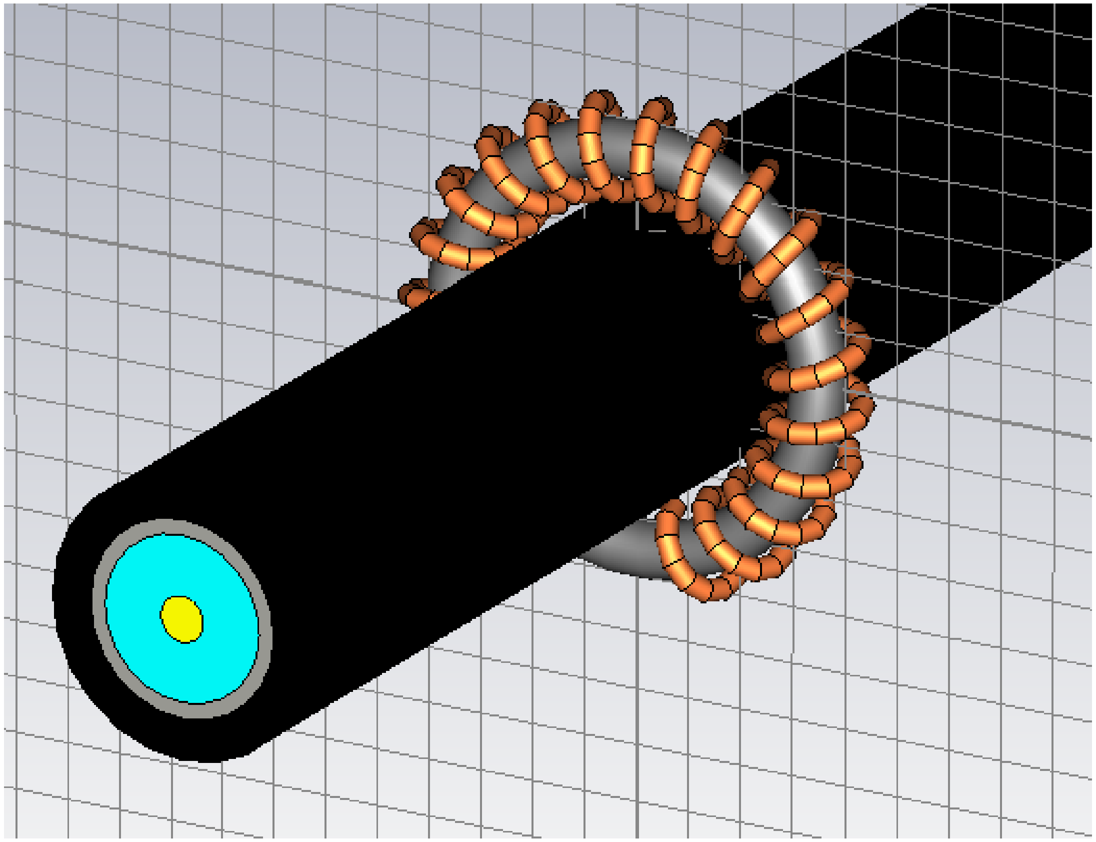


Receiver Choices - Inductive



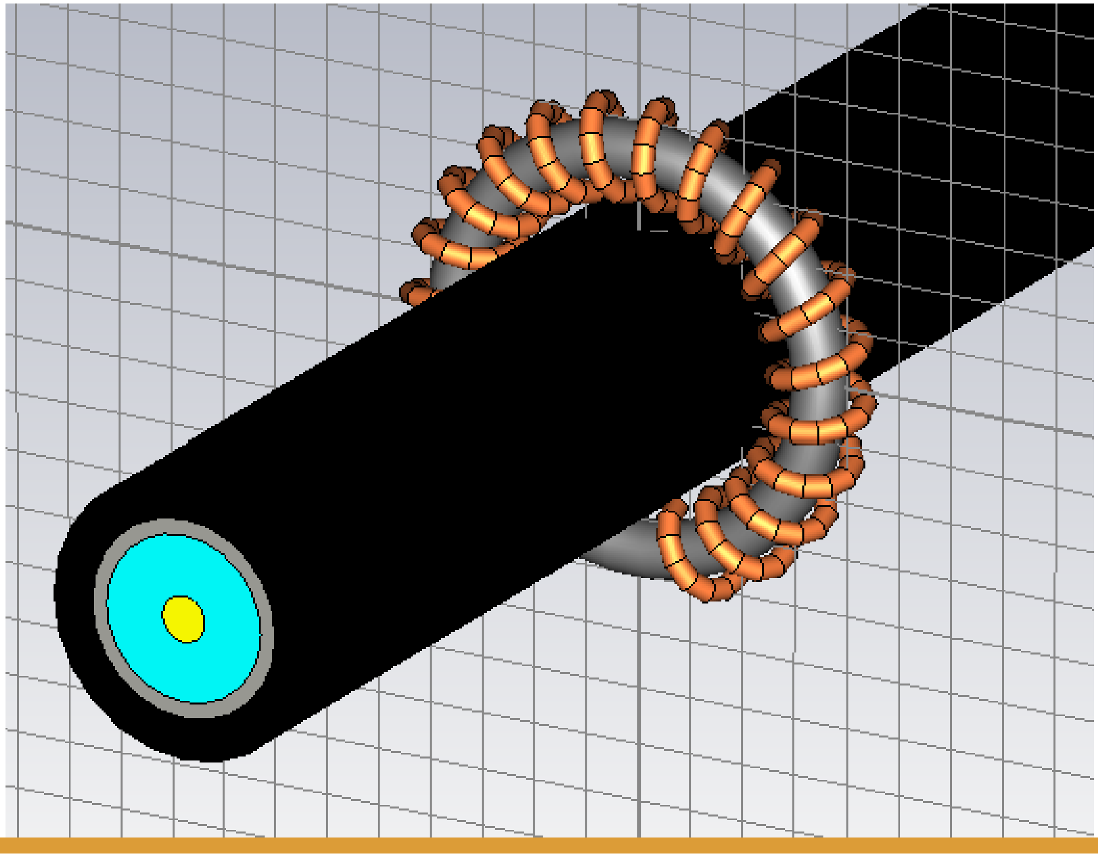


Toroid Sensor for Detection of External Fields

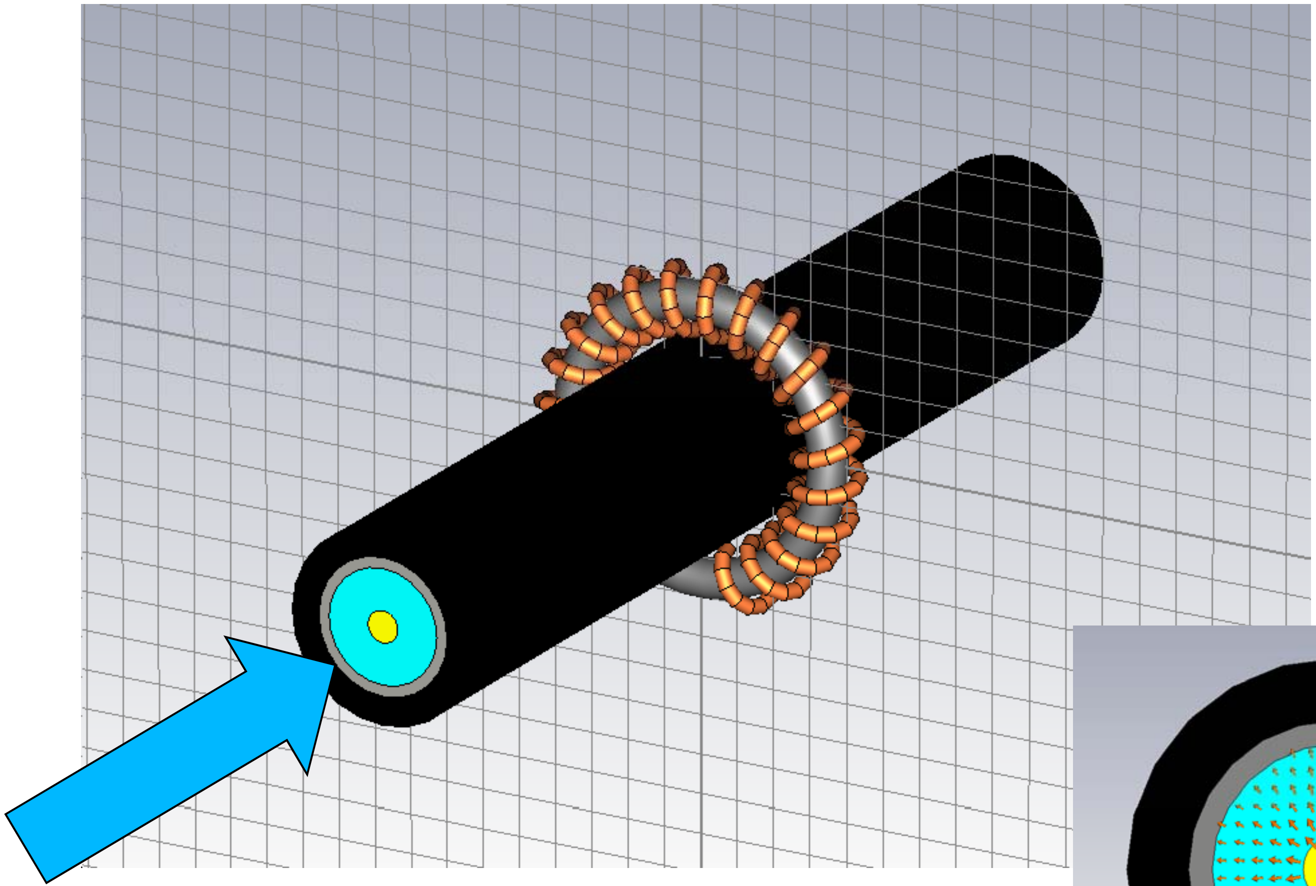


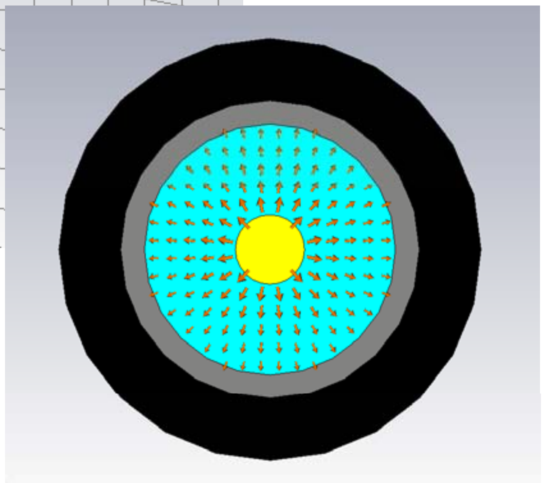
Why Does It Work?

- Coax is shielded.
- NO SSTDR signal from inside should be outside.
- ANY SSTDR signal is from the hole.
- We can receive the signal, detect the hole, locate the hole.

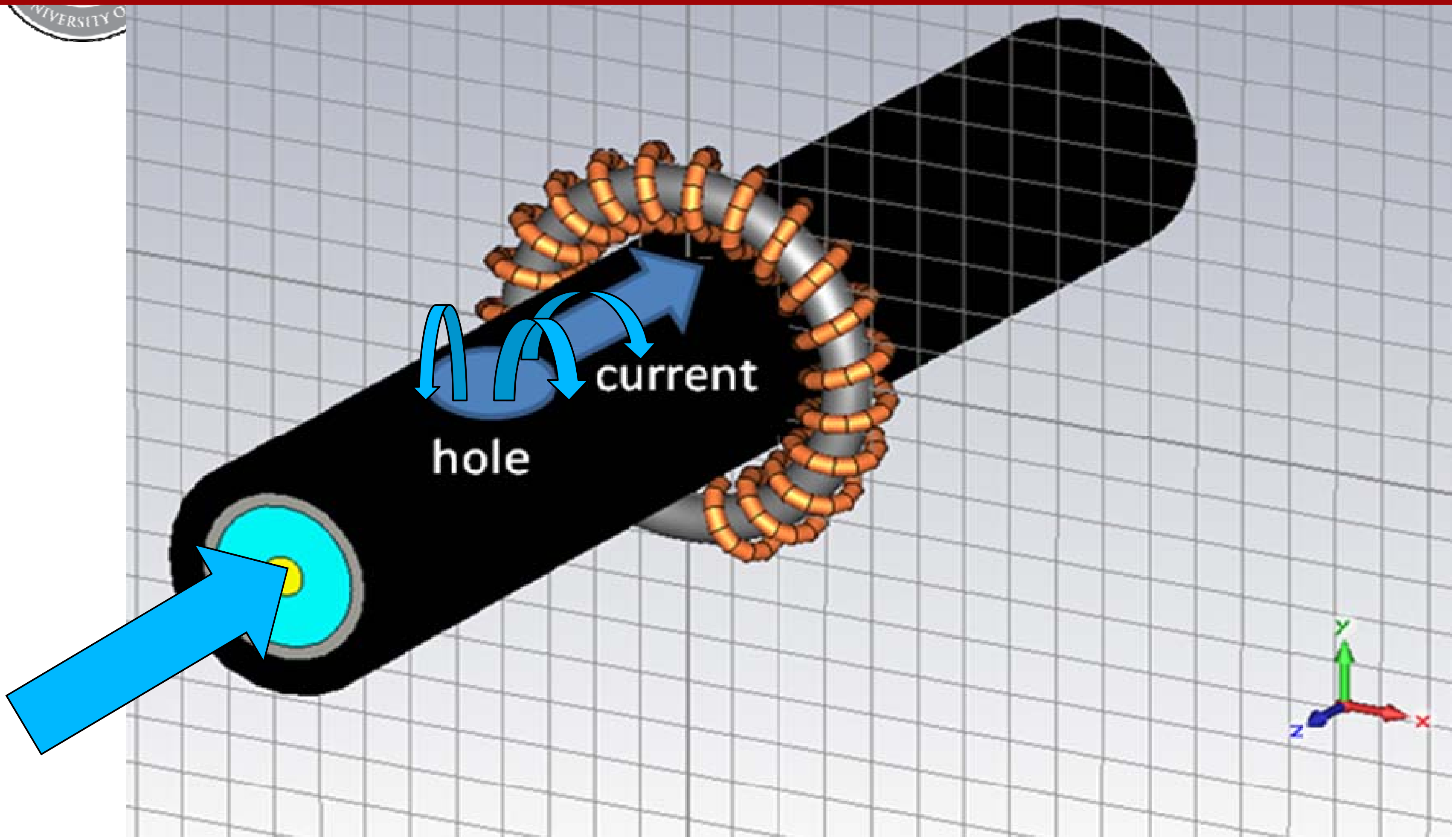


Incident Excitation → E&H Fields Inside Cable



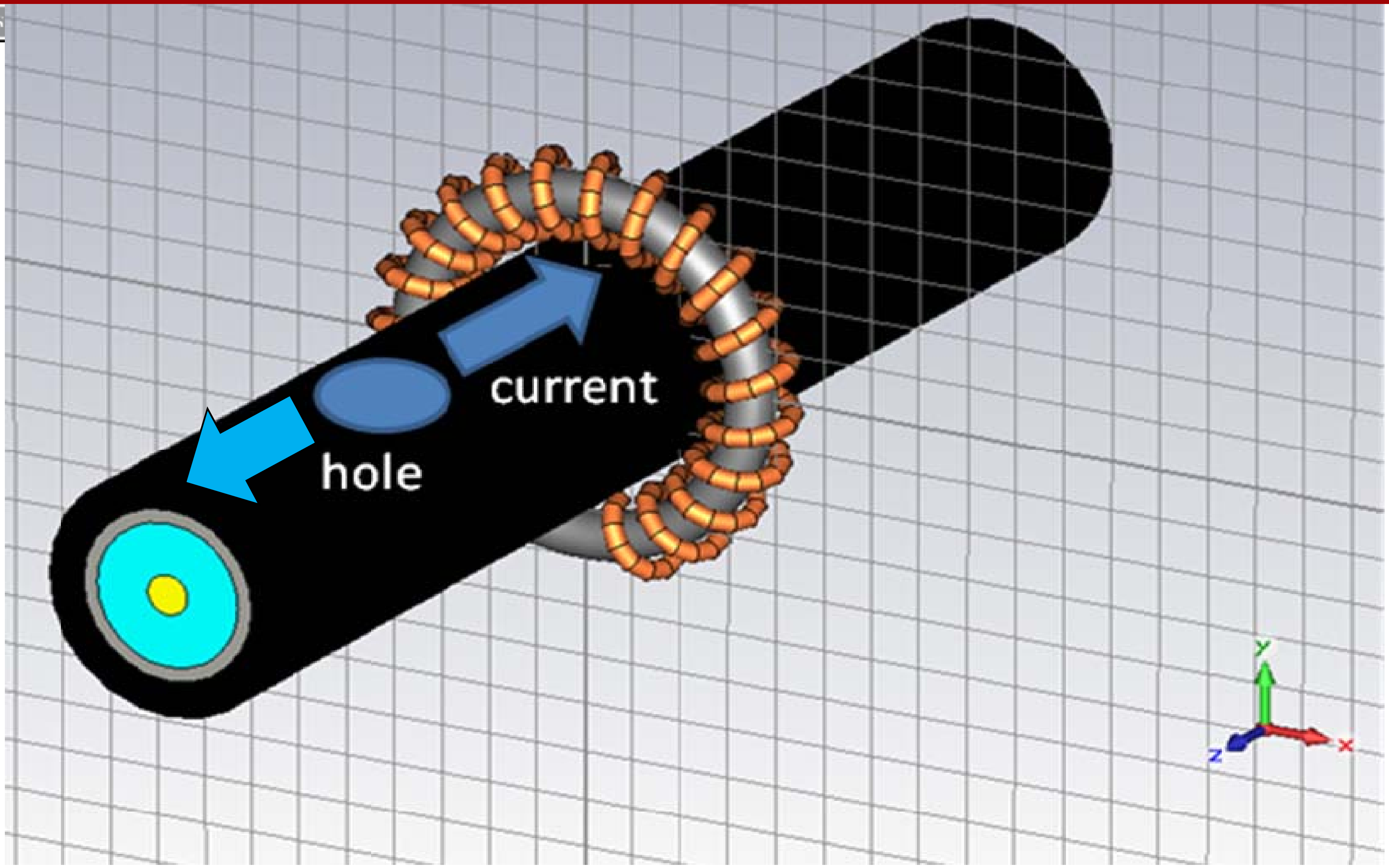


Internal E&H Fields Leak Out of Hole (HP Filter



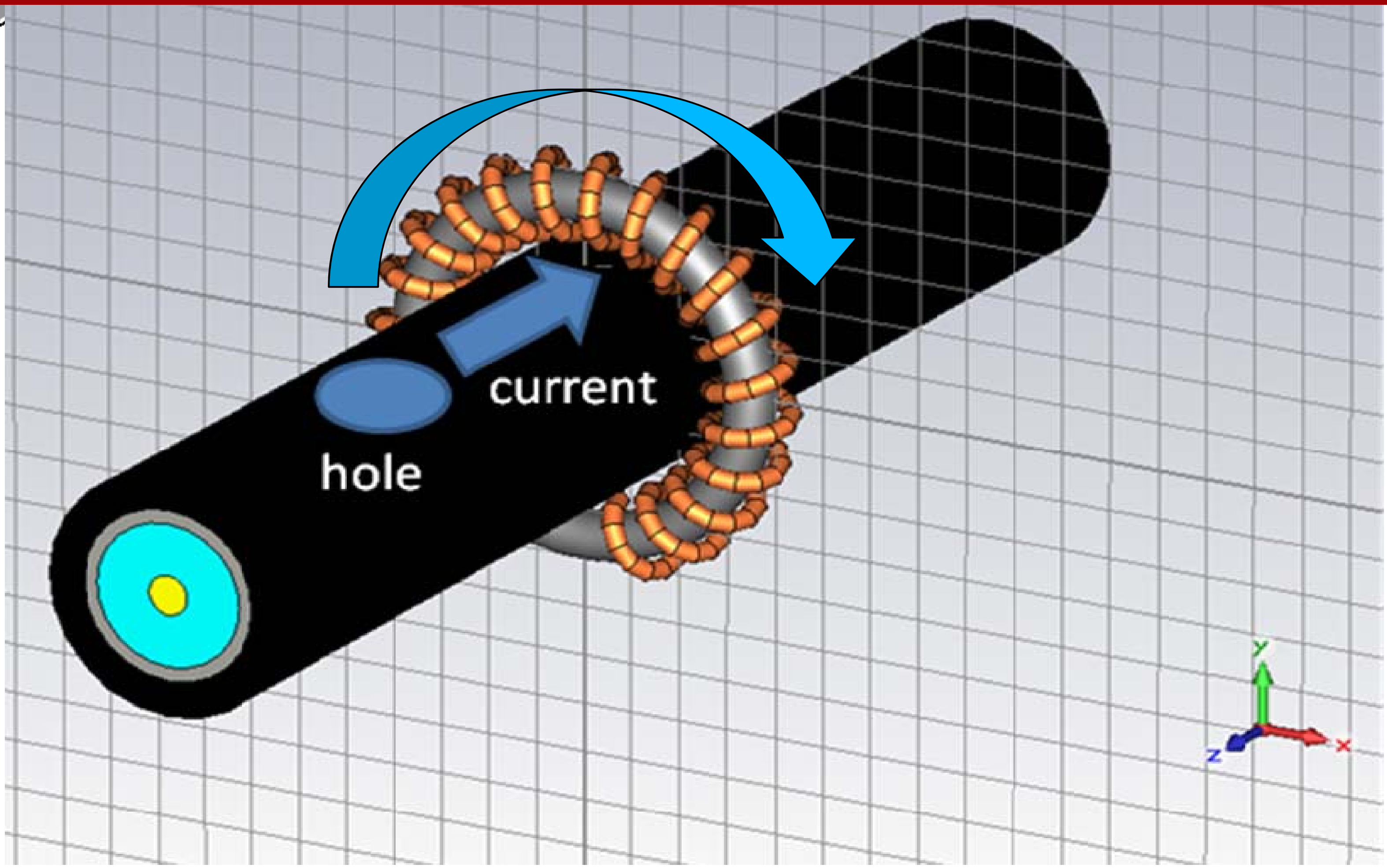
- *Hole = HP Filter (Current is derivative of Incident Signal)*

Leaky (H) Fields Produce Surface Current



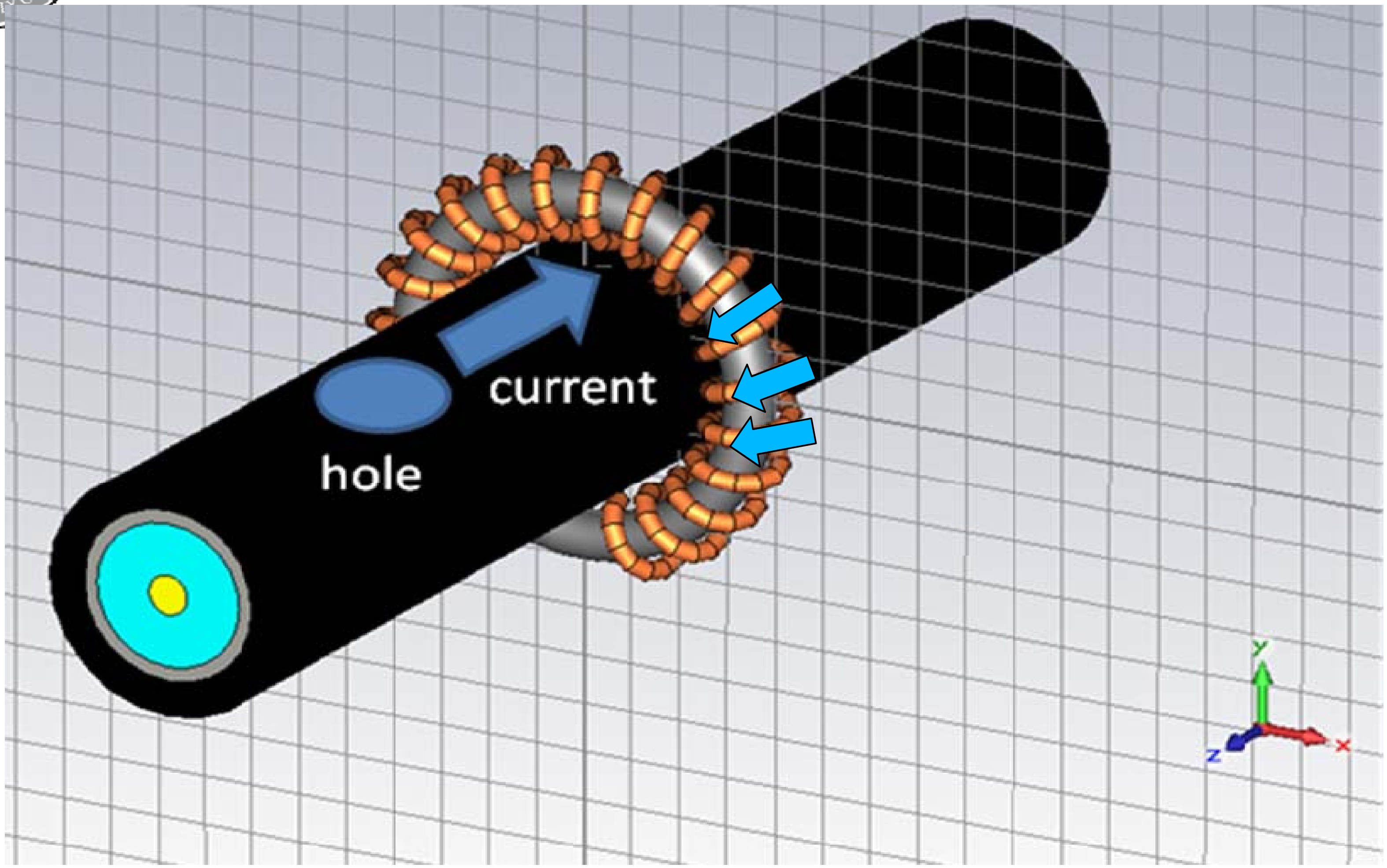
- *Line is LP Filter (Current is attenuated)*

Surface Current Produces Magnetic Field In Ferrite

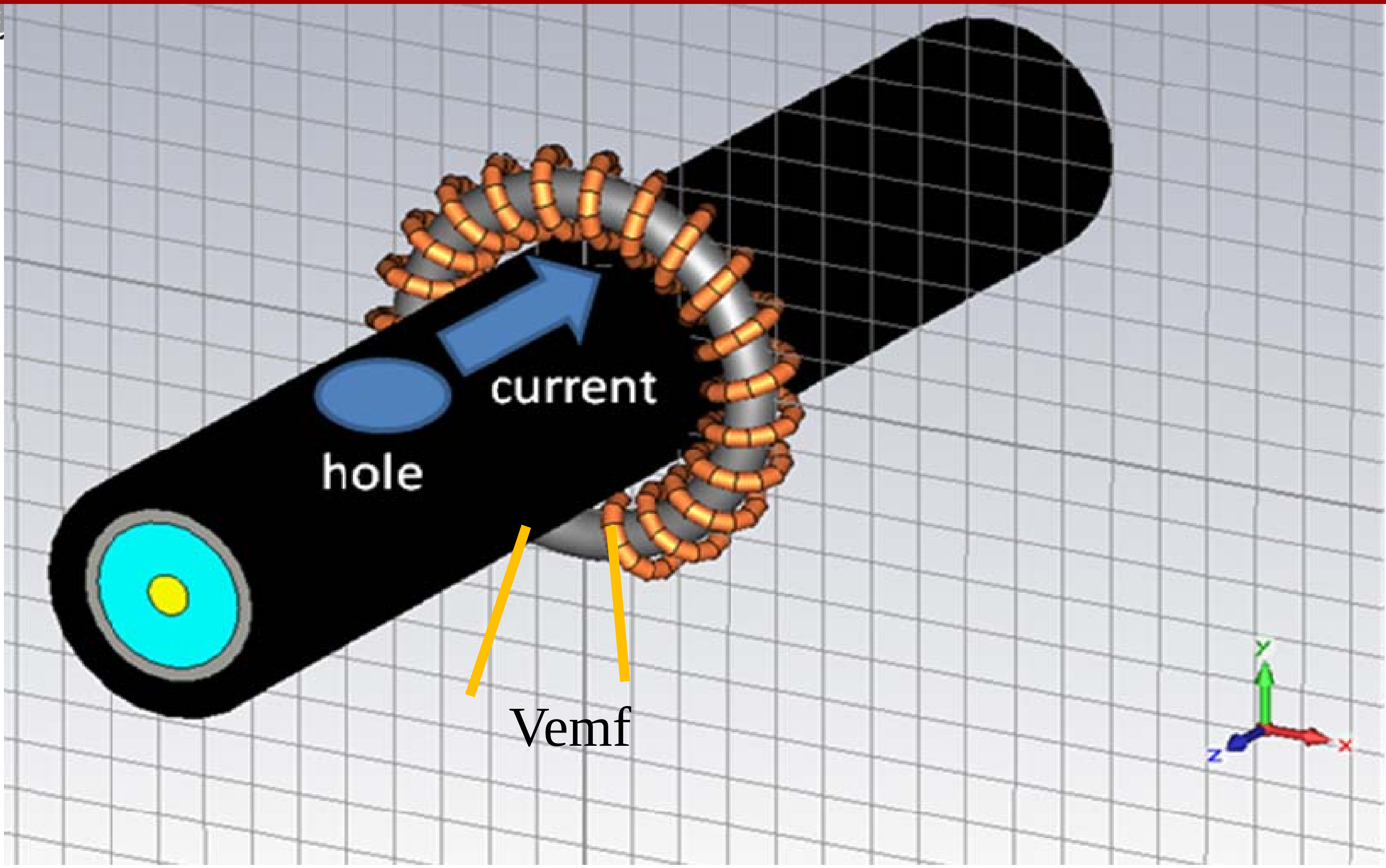


- *Ferrite = LP Filter (depends on material)*
- *Ferromagnetic core acts like a flux concentrator*

Magnetic Field In Ferrite Produces Current in Coil

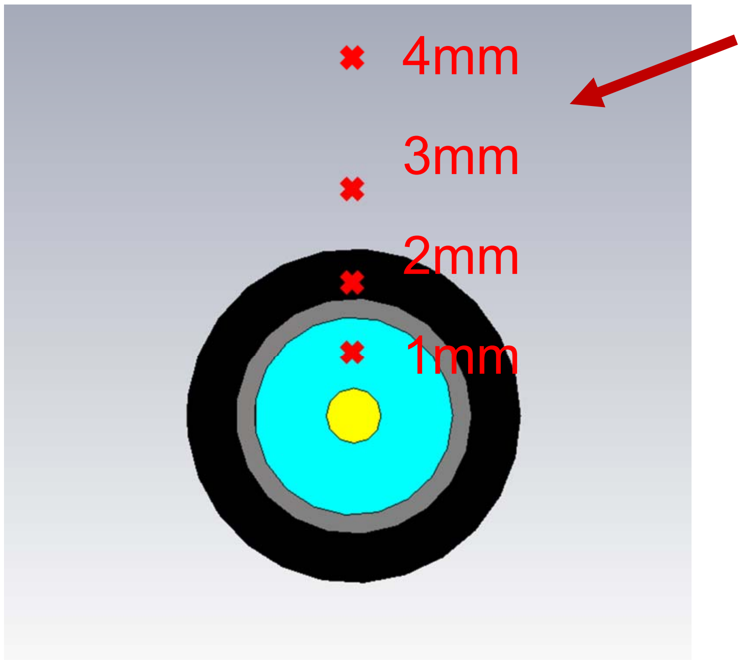


Current in Coil produces Vemf

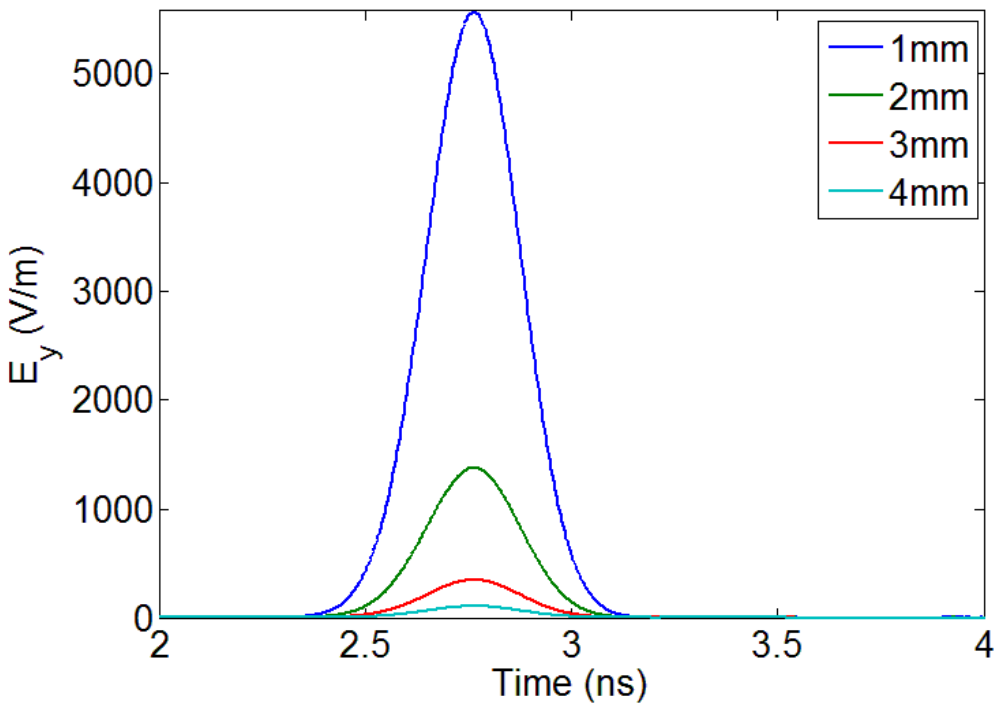


- *Toroid = HP Filter (Vemf ~ dB/dt)*
- *Nturns = Higher Vemf*

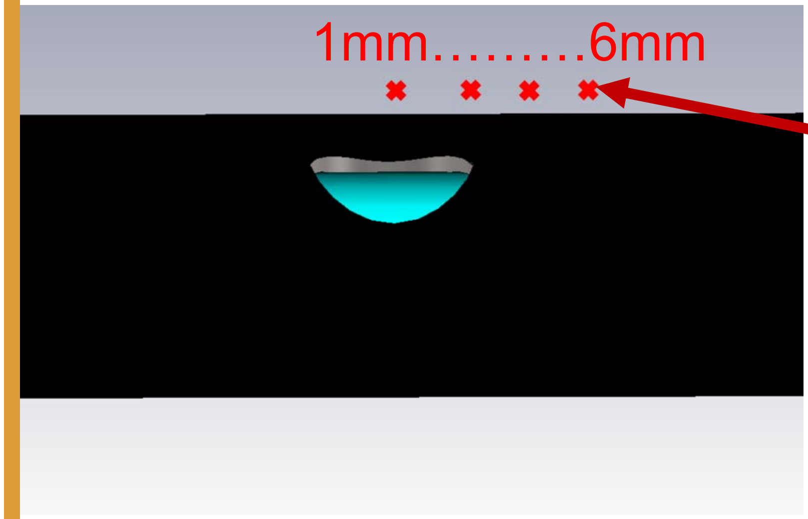
E-Field



E Field is a copy of the original signal, decreasing away from the center conductor

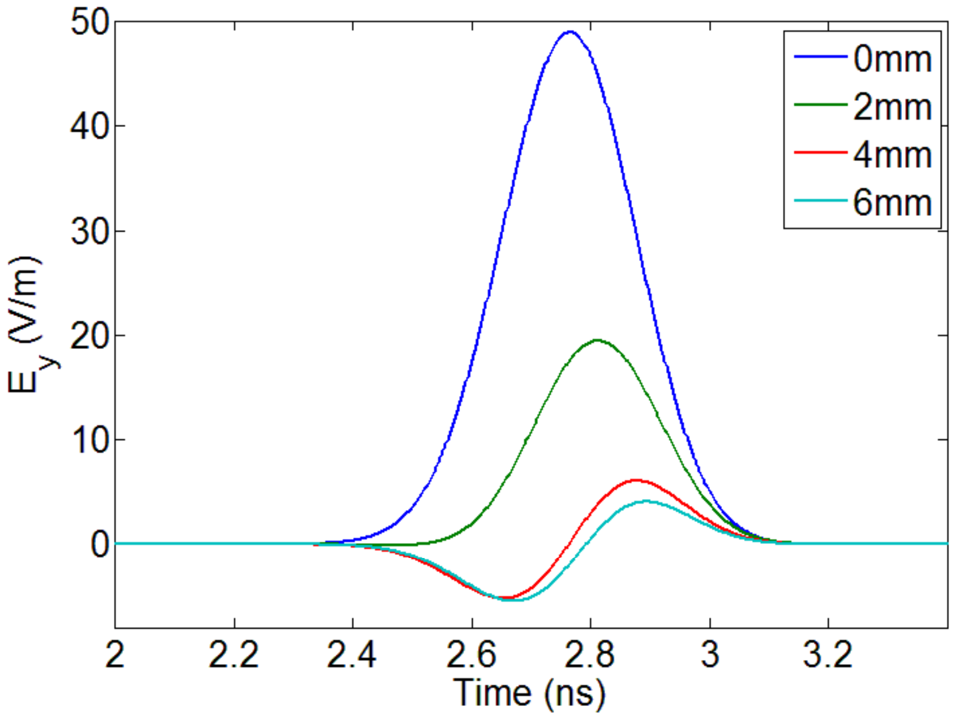


E-Field



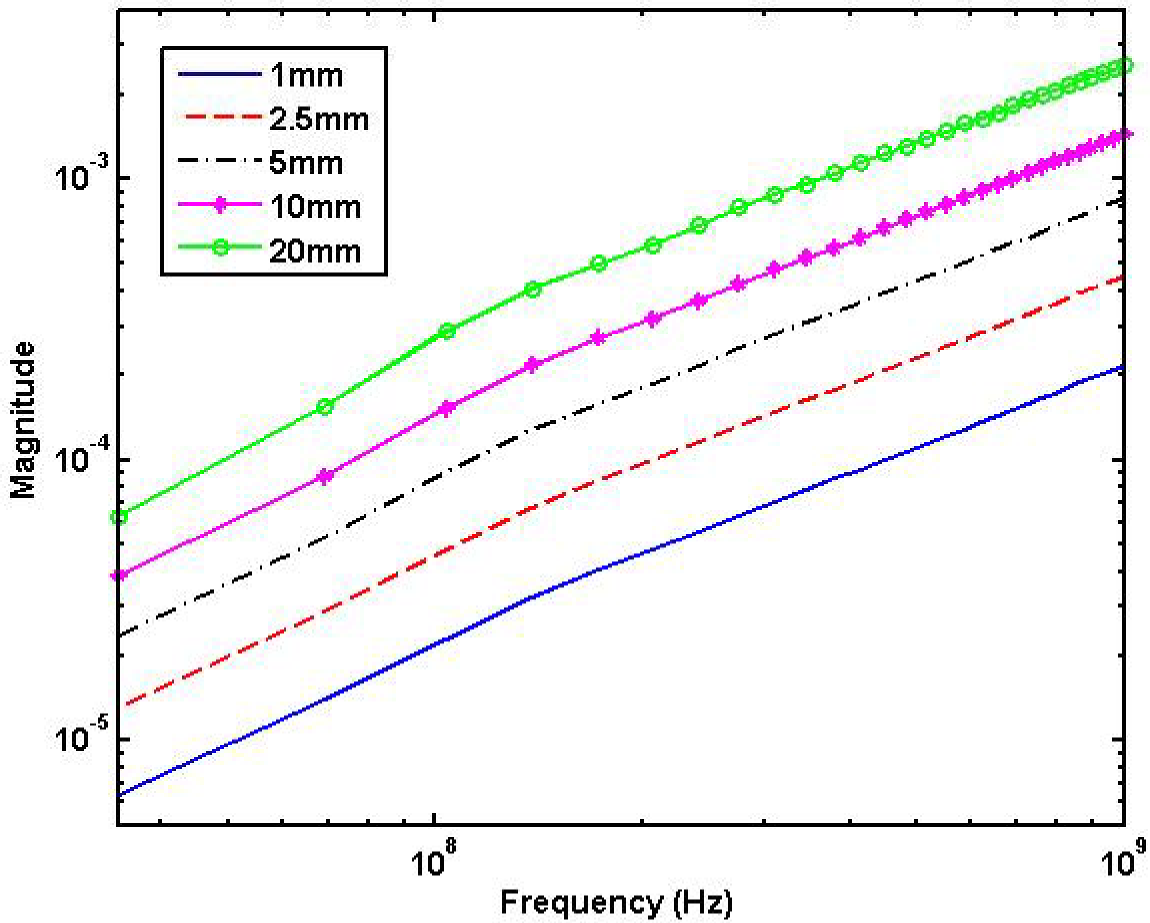
Evanescent Near Fields (copy of original signal)

Propagating Far Fields (derivative of original signal / high pass filtered)



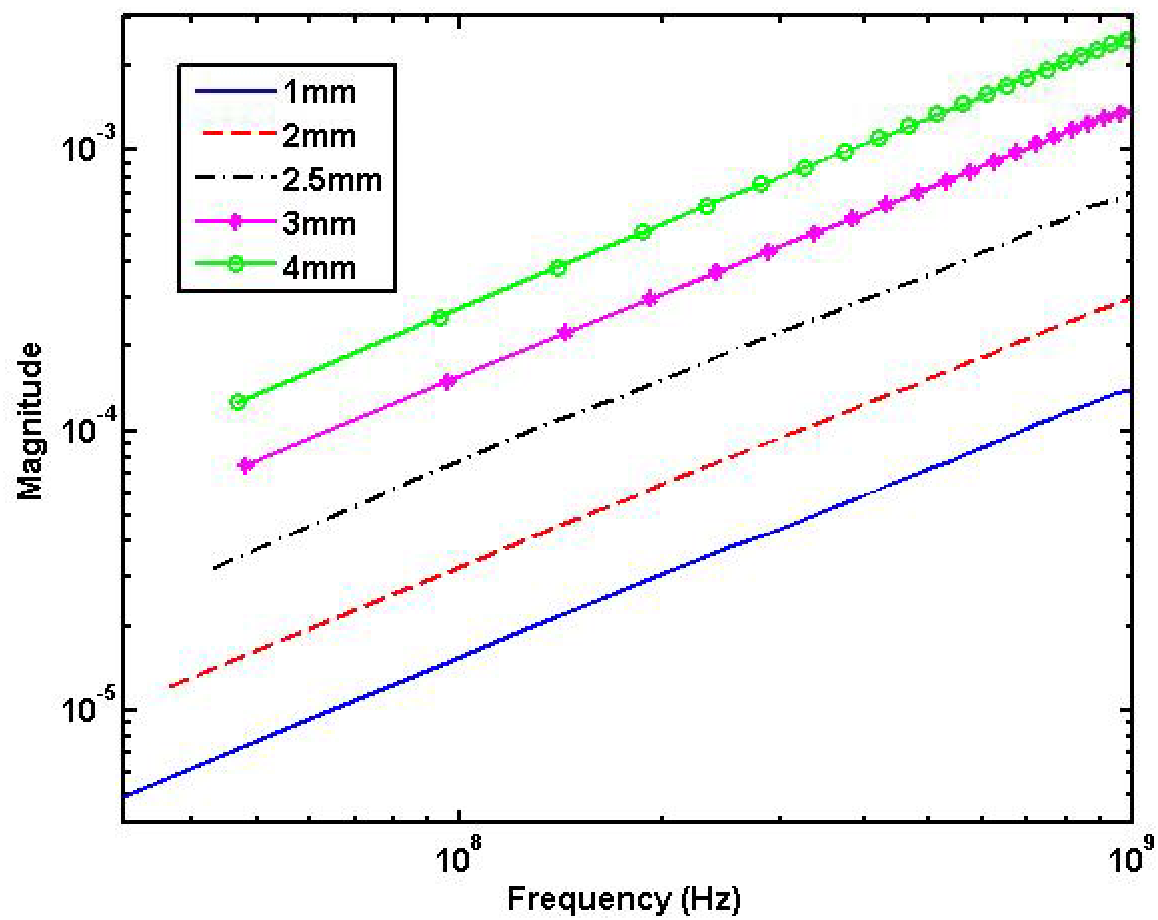
Fault Effects

3mm Wide Fault



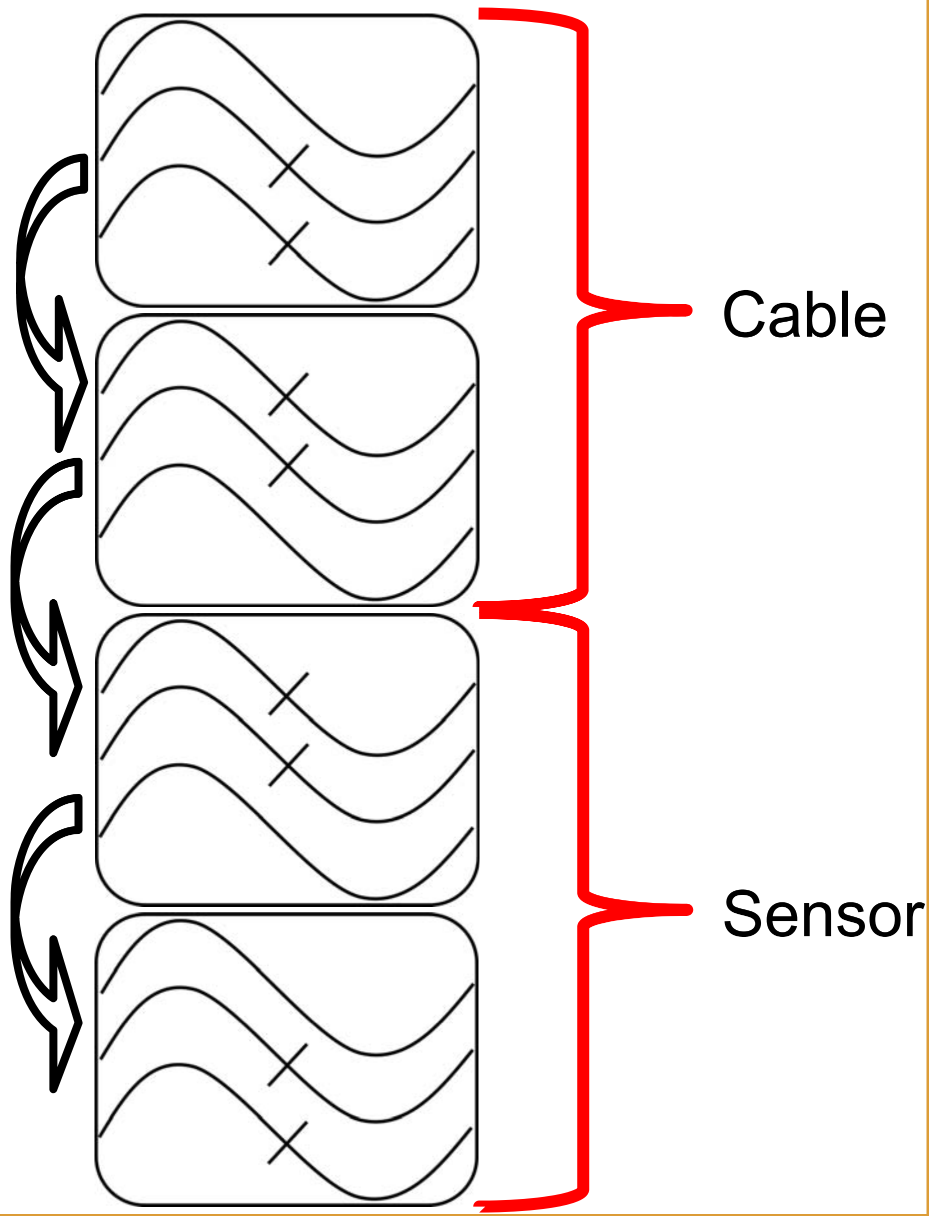
Fault Effects

10mm Long

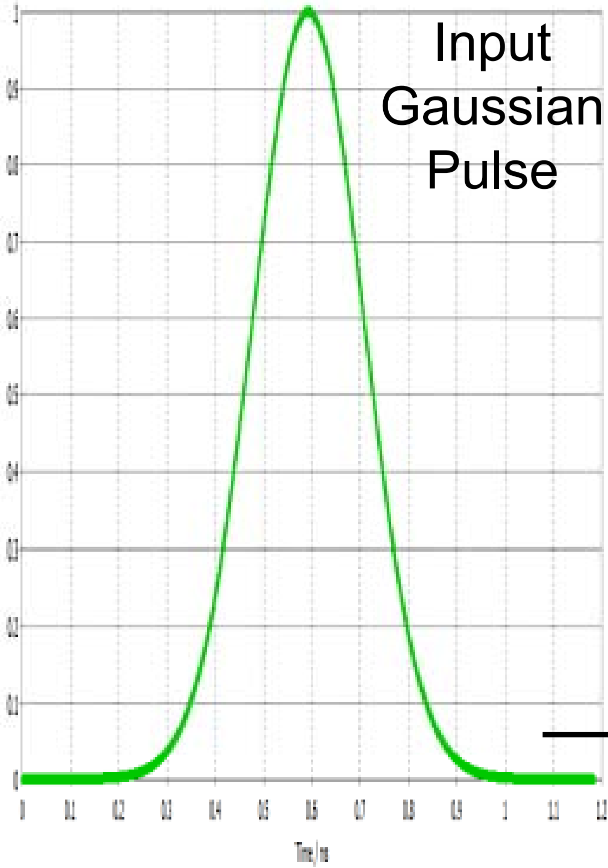


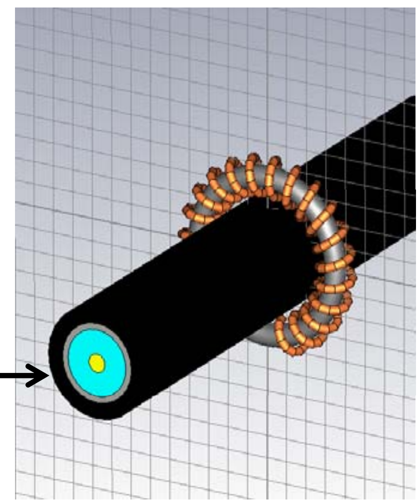
Vemf : Received Sensor Signal

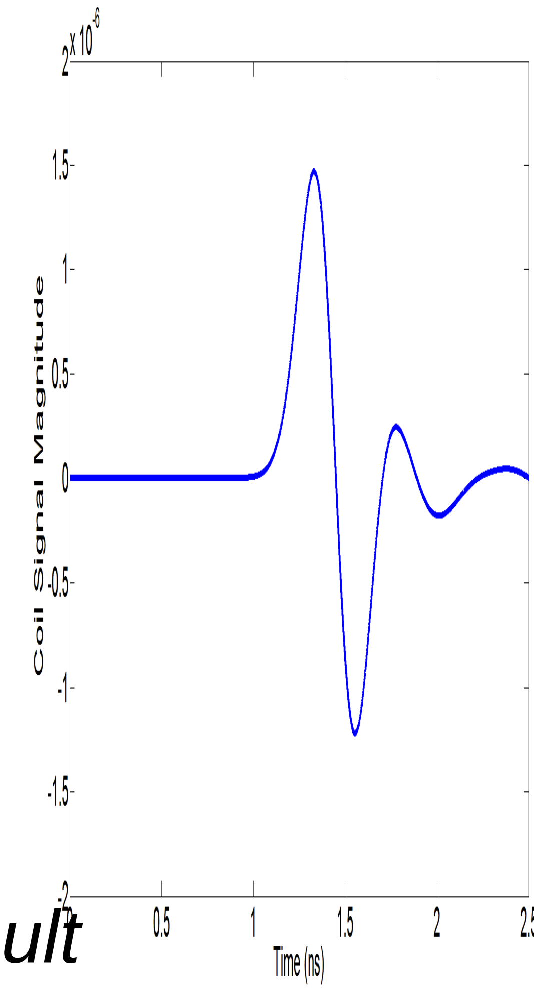
- *Hole = HP Filter (Current is HP Version of Incident Signal)*
- *Line is LP Filter (Current is attenuated)*
- *Ferrite = LP Filter (depends on material)*
- *Toroid = HP Filter (Vemf ~ dB/dt)*



Pulse Shape



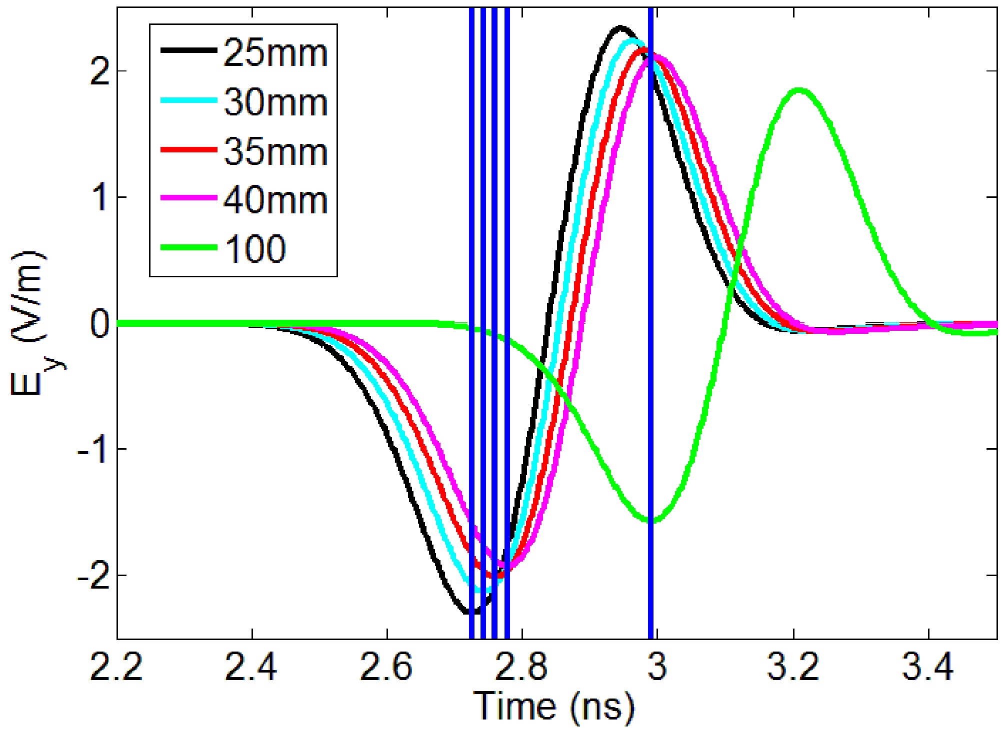




- *Circular shield fault of radius 1mm*

Velocity of Propagation - Numerical

25mm...............100mm



<u>CST Simulation</u>

VOP ~ 0.94c

(c =speed of light)

<u>Numerical Parameter Extraction</u>

VOP ~ 0.935c

Zo ~ 396 Ω

Velocity of Propagation - measured

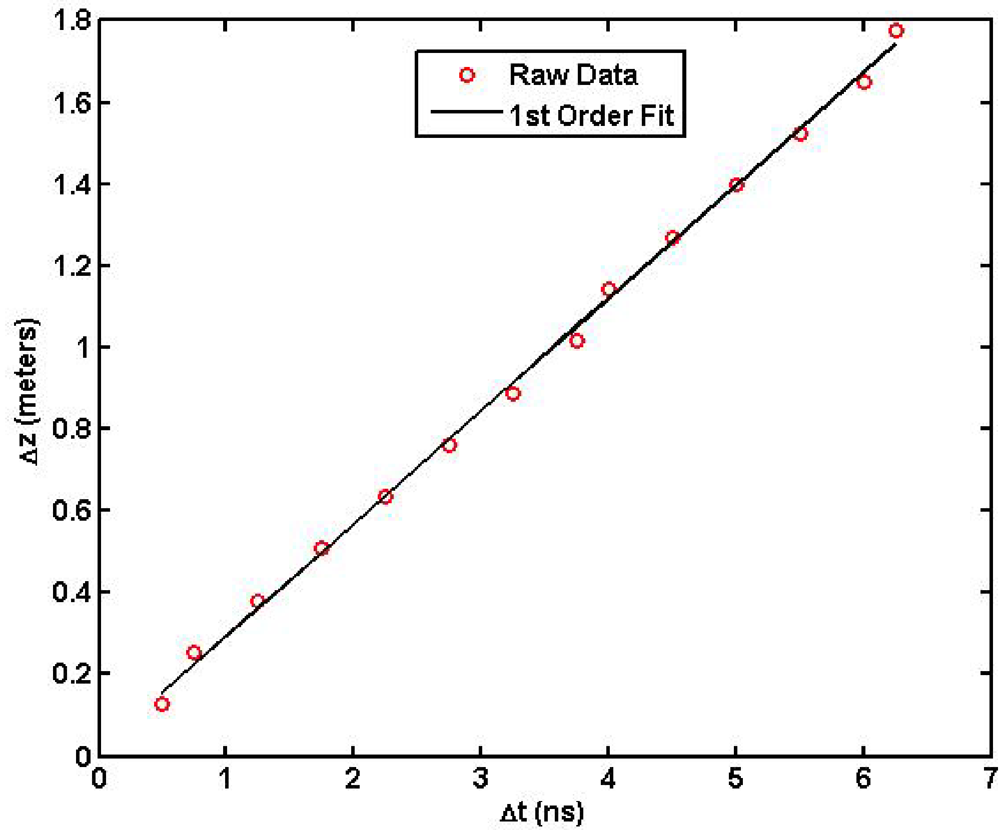
Simulation:

VOP ~ 0.94c
(c =speed of light)

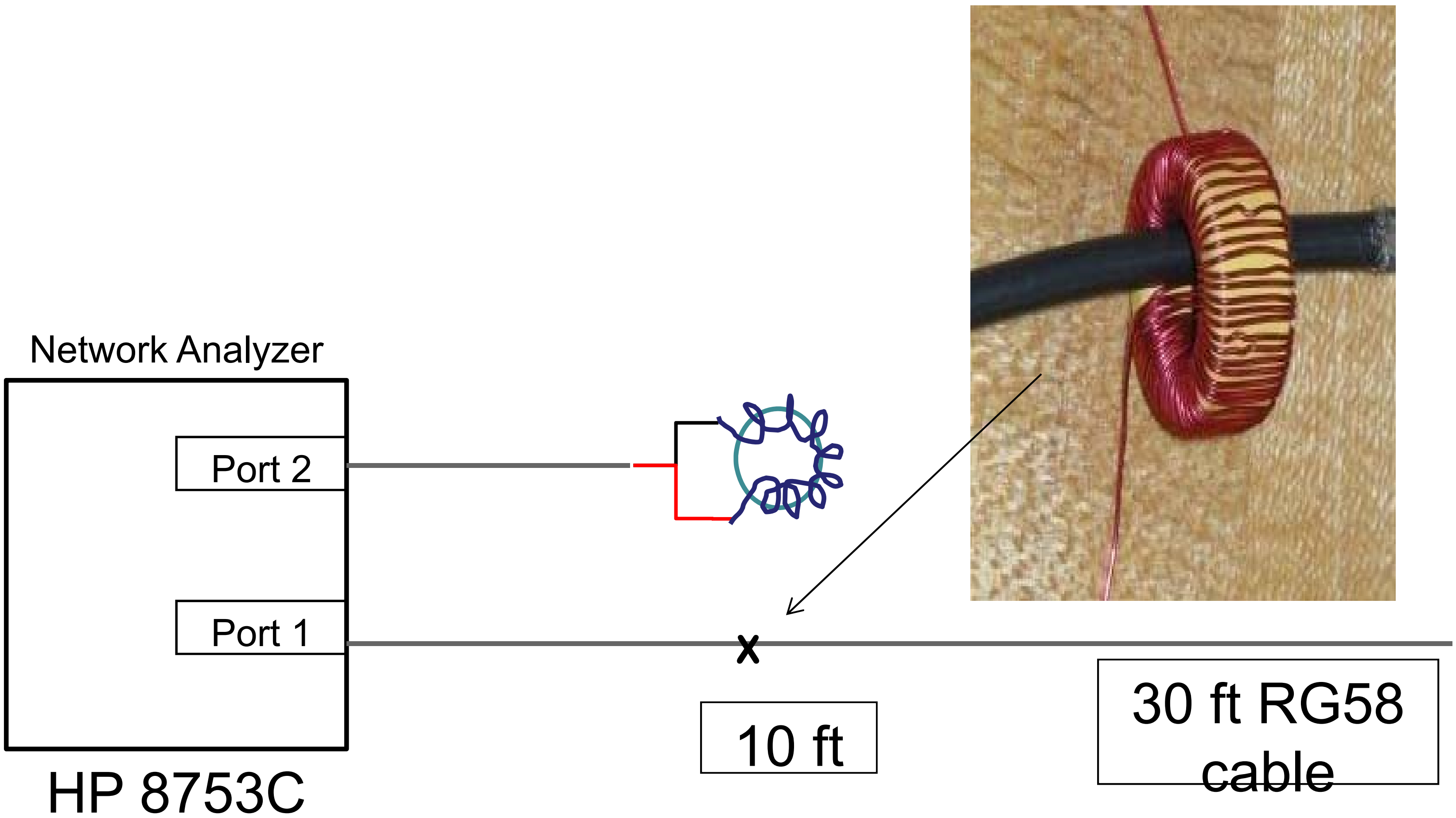
Measured:

1st Order Fit ~ 0.92c

Median ($\frac{\Delta z}{\Delta t}$) ~ 0.9367c

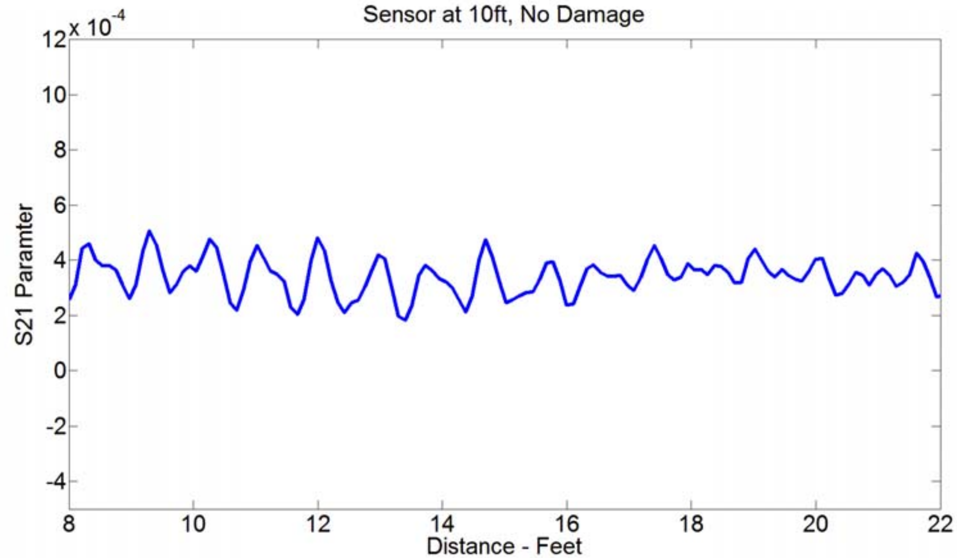


Measurement Setup

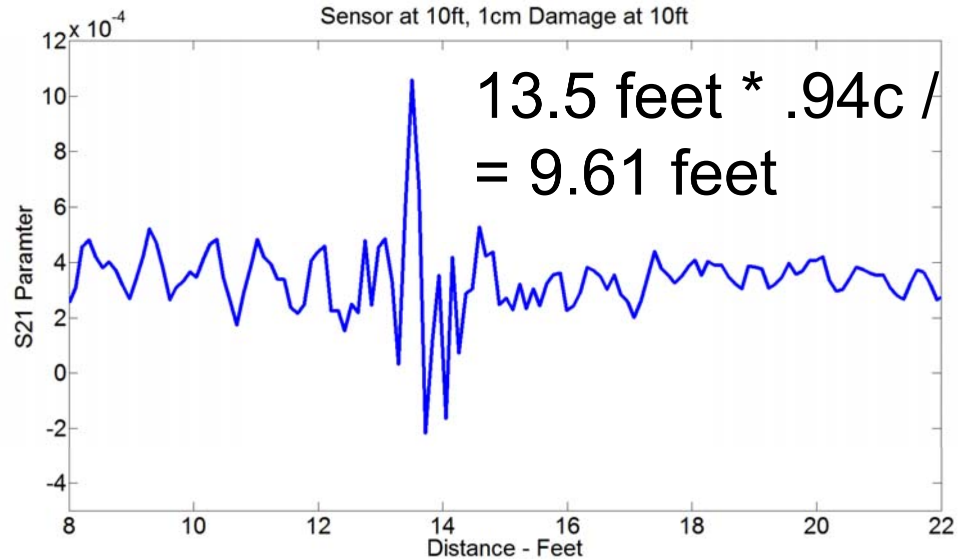


Measurement Results

Baseline measurement at 10ft



1cm damage at 10ft mark



13.5 feet * .94c / .66c /2

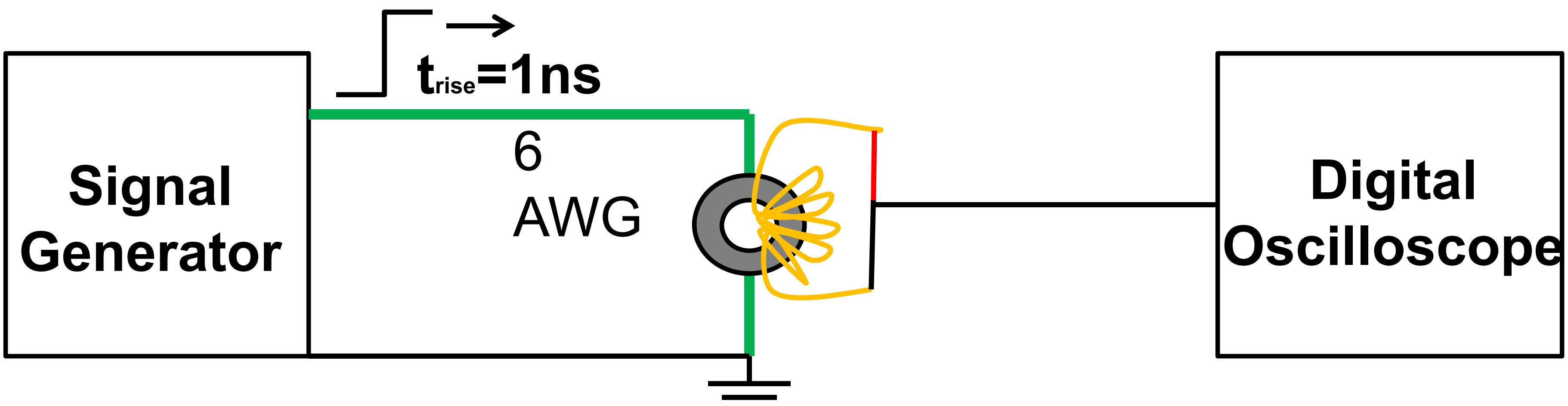
= 9.61 feet

Characterization of Sensor

- Characterize Parameters
  - Windings
  - Wire Gauge
  - Geometry
  - Materials

- Maximize Induced *emf*

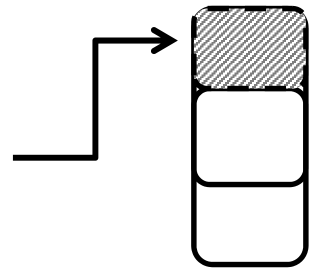
$$Vemf = -NA\mu(\mu' - j\mu$$



Sensor Geometry

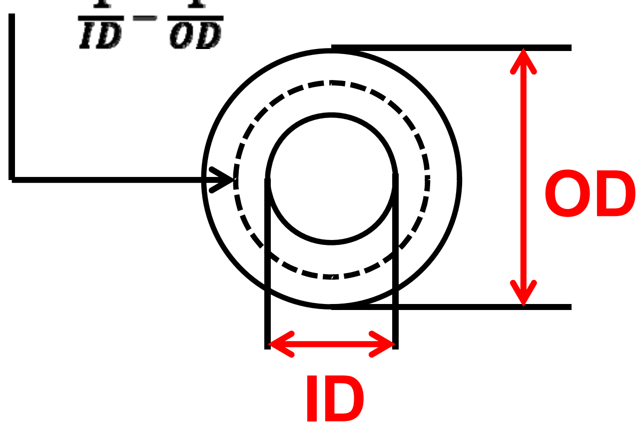
Cross Sectional Area

$$A = h\frac{\ln\left(\frac{OD}{ID}\right)^2}{\frac{1}{ID}-\frac{1}{OD}}$$

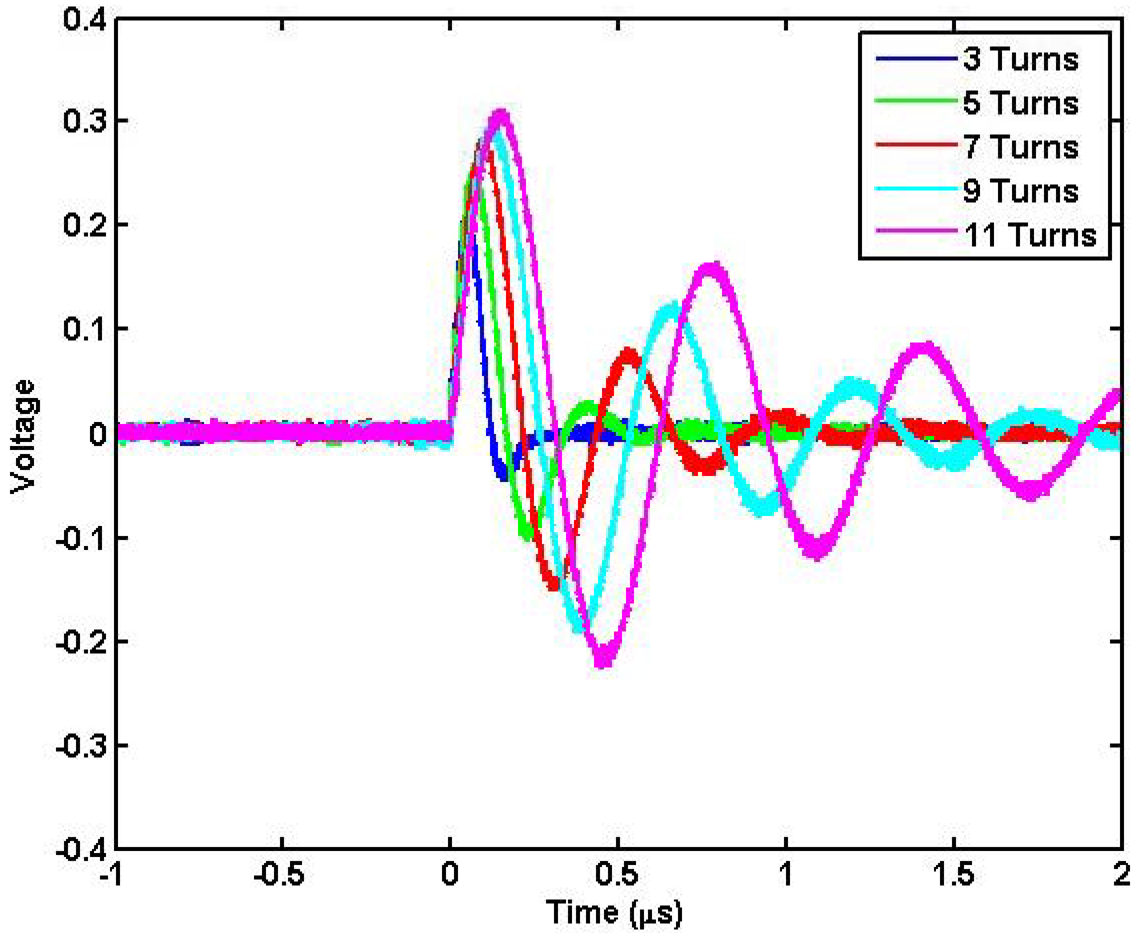


Effective Magnetic Length

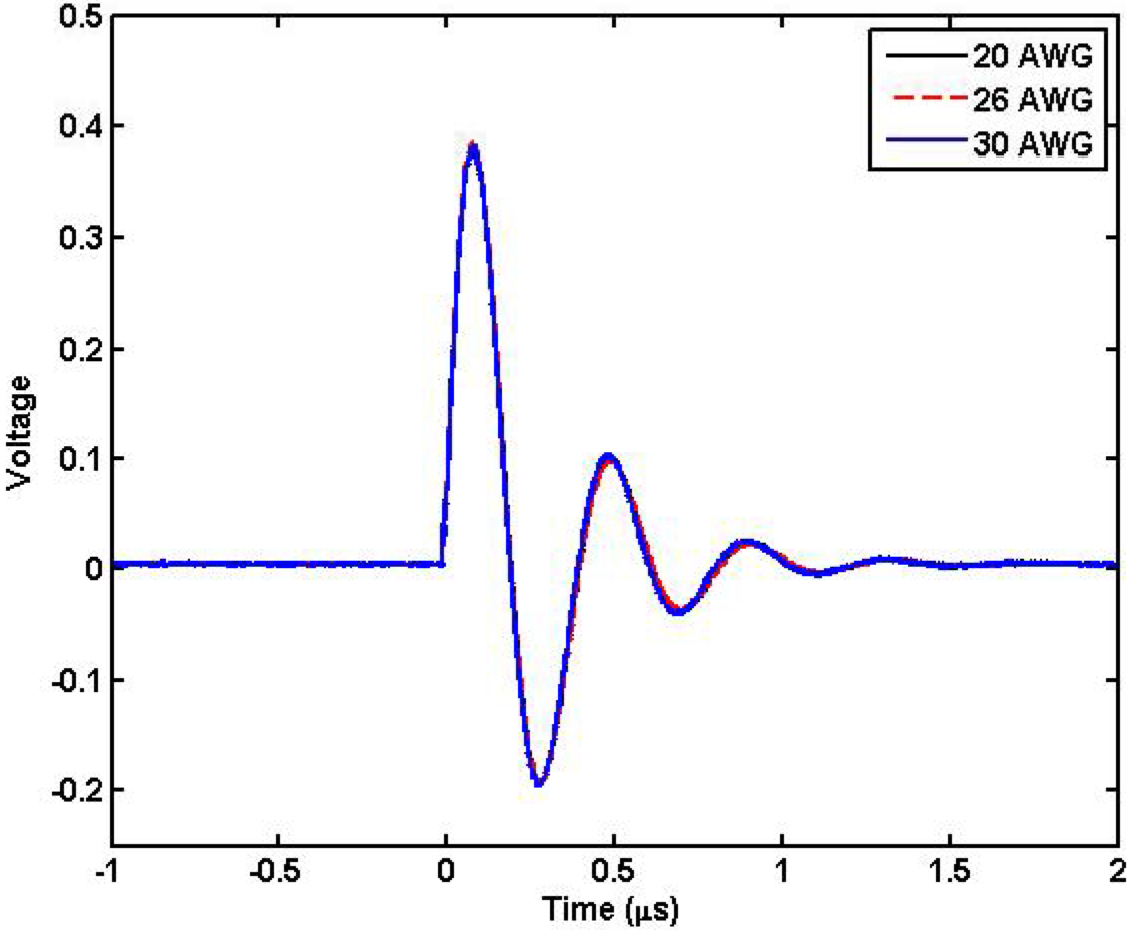
$$l = \frac{2\pi \ln\left(\frac{OD}{ID}\right)}{\frac{1}{ID}-\frac{1}{OD}}$$



Characterization: Number of Windings



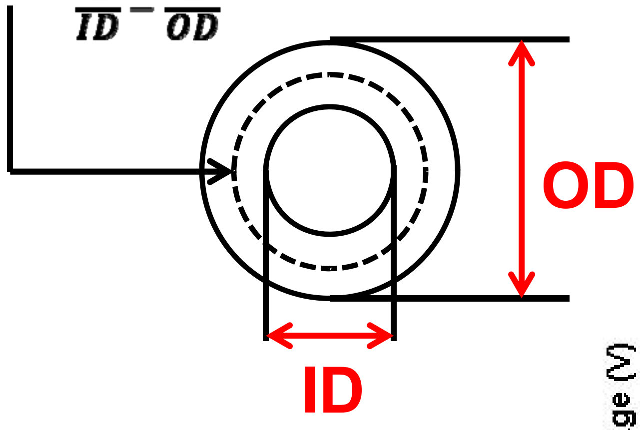
Characterization: Winding Wire Gauge

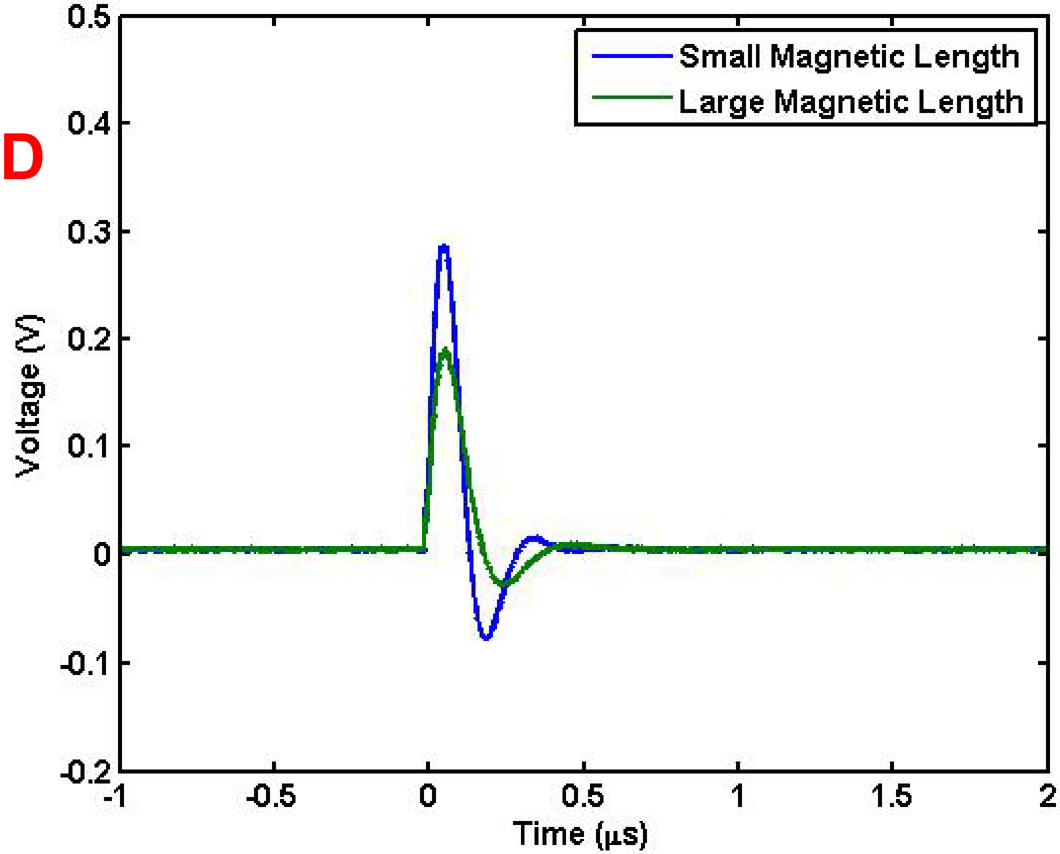


Characterization: Geometry

Effective Magnetic Length

$$l = \frac{2\pi \ln\left(\frac{OD}{ID}\right)}{\frac{1}{ID} - \frac{1}{OD}}$$

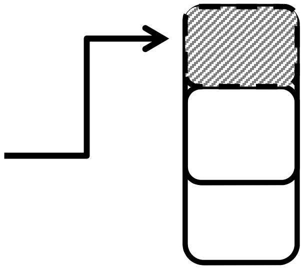


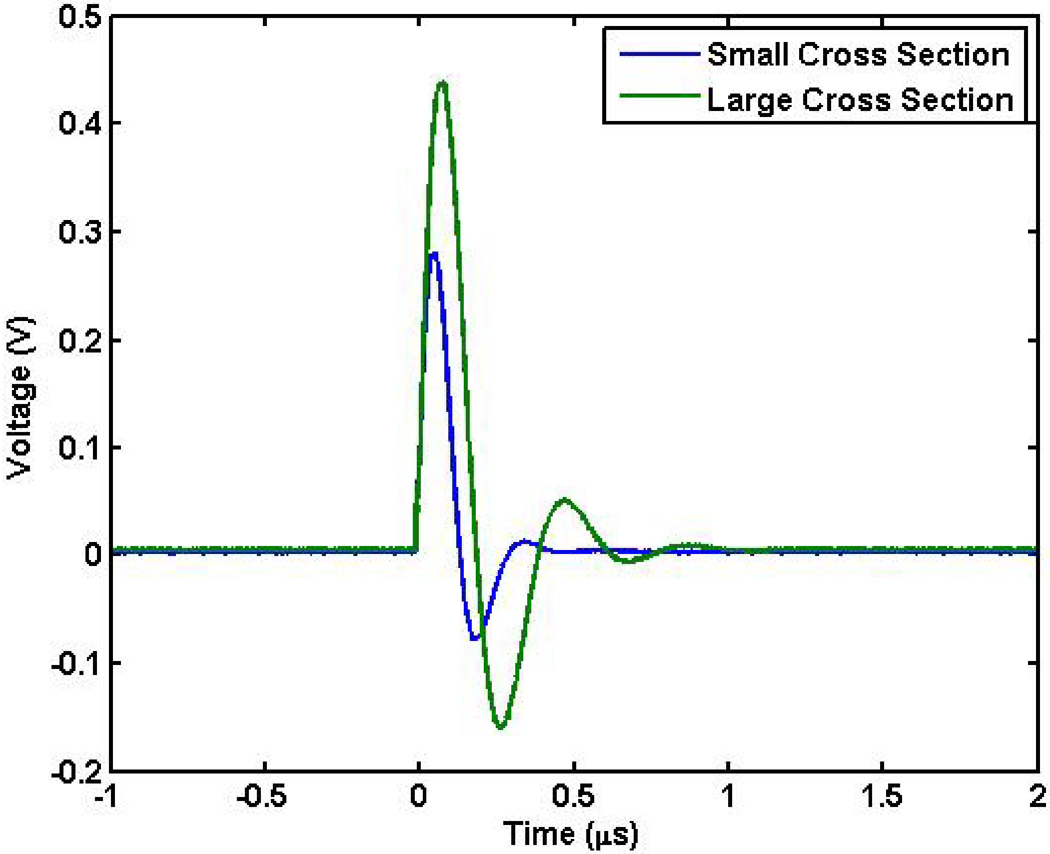


Characterization: Geometry

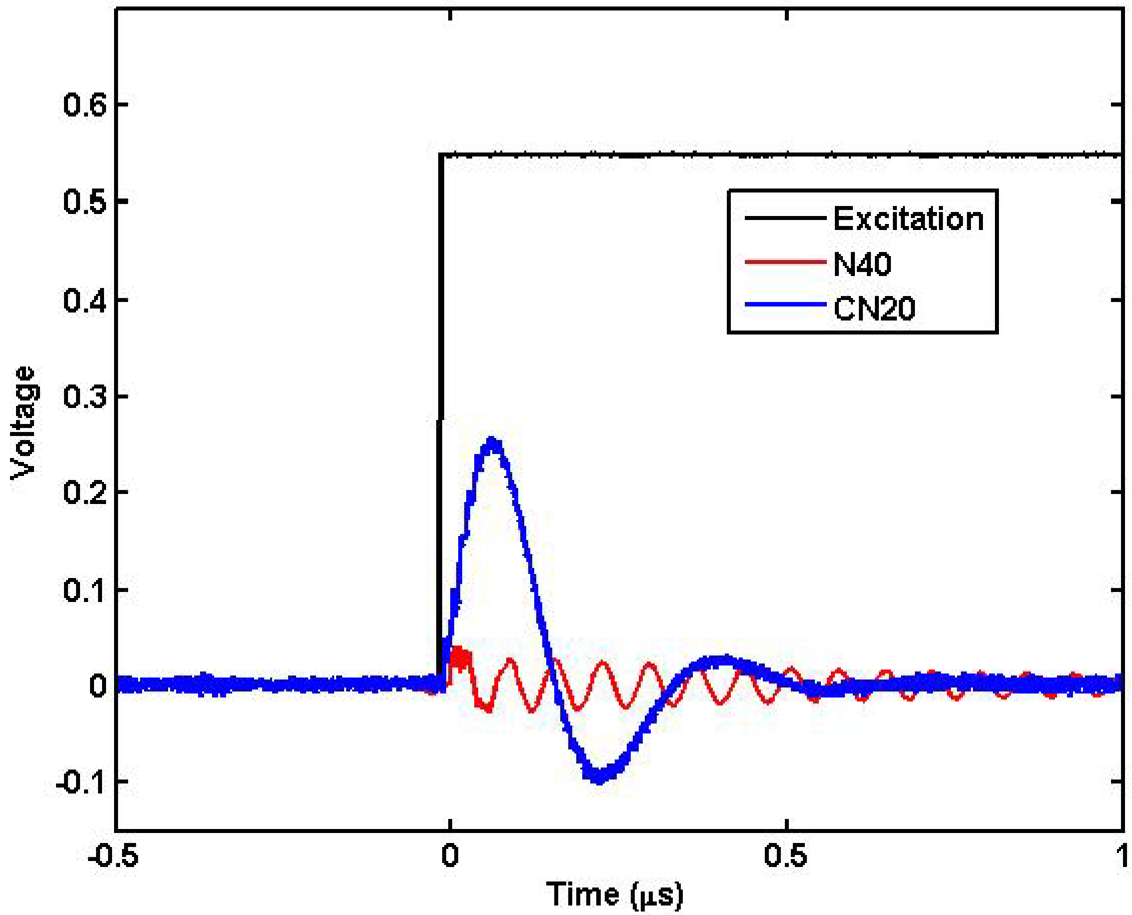
Cross Sectional Area

$$A = h\frac{\ln\left(\frac{OD}{ID}\right)^2}{\frac{1}{ID}-\frac{1}{OD}}$$

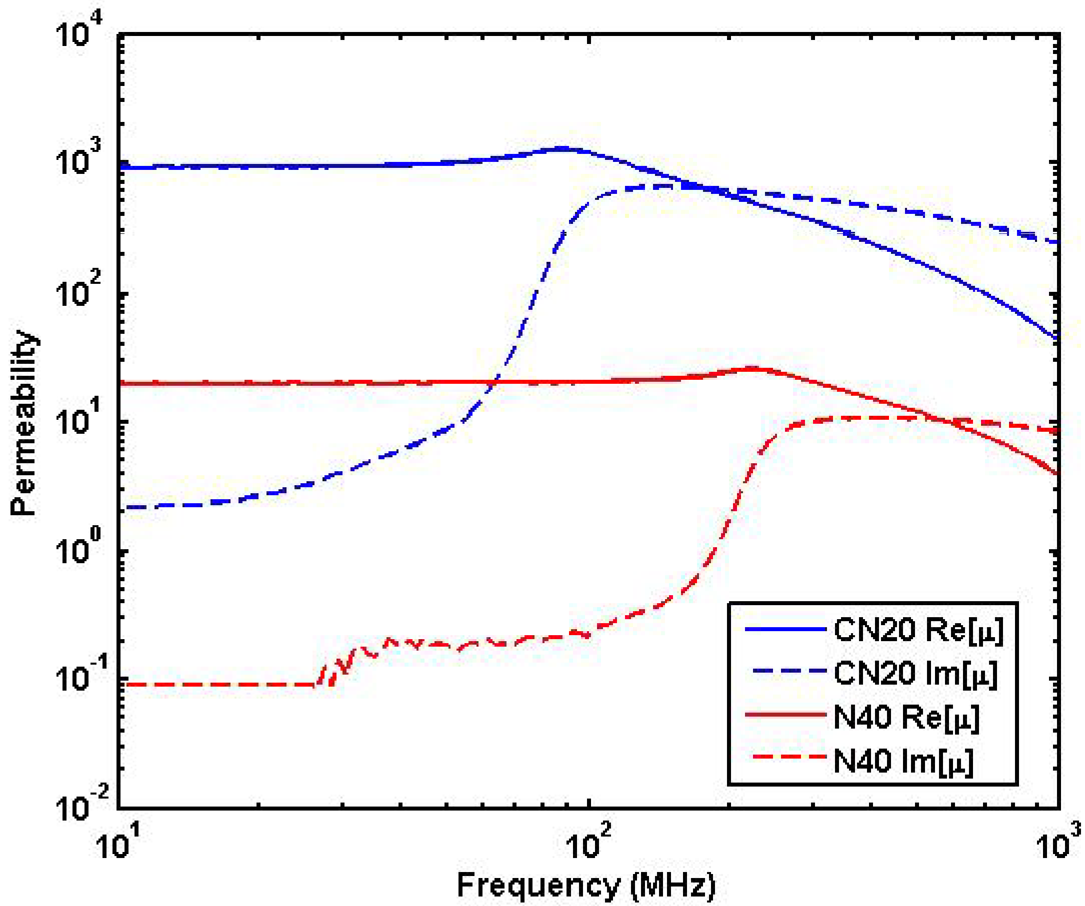




Characterization: Materials



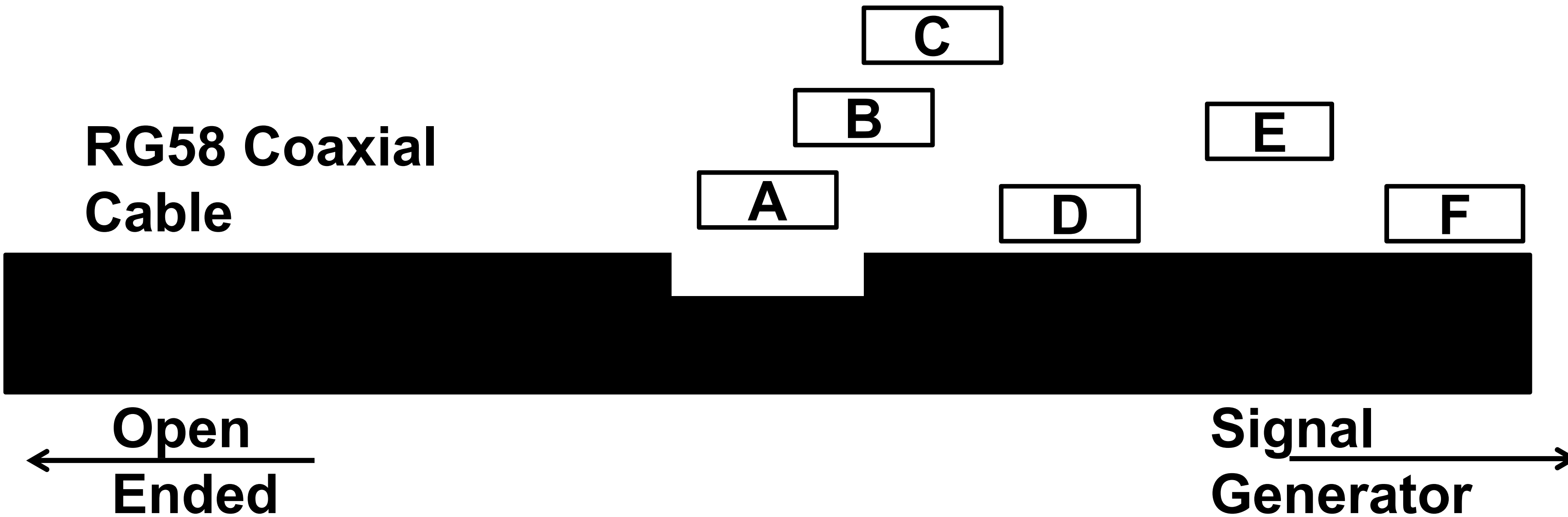
Characterization: Materials



Sensor Characterization

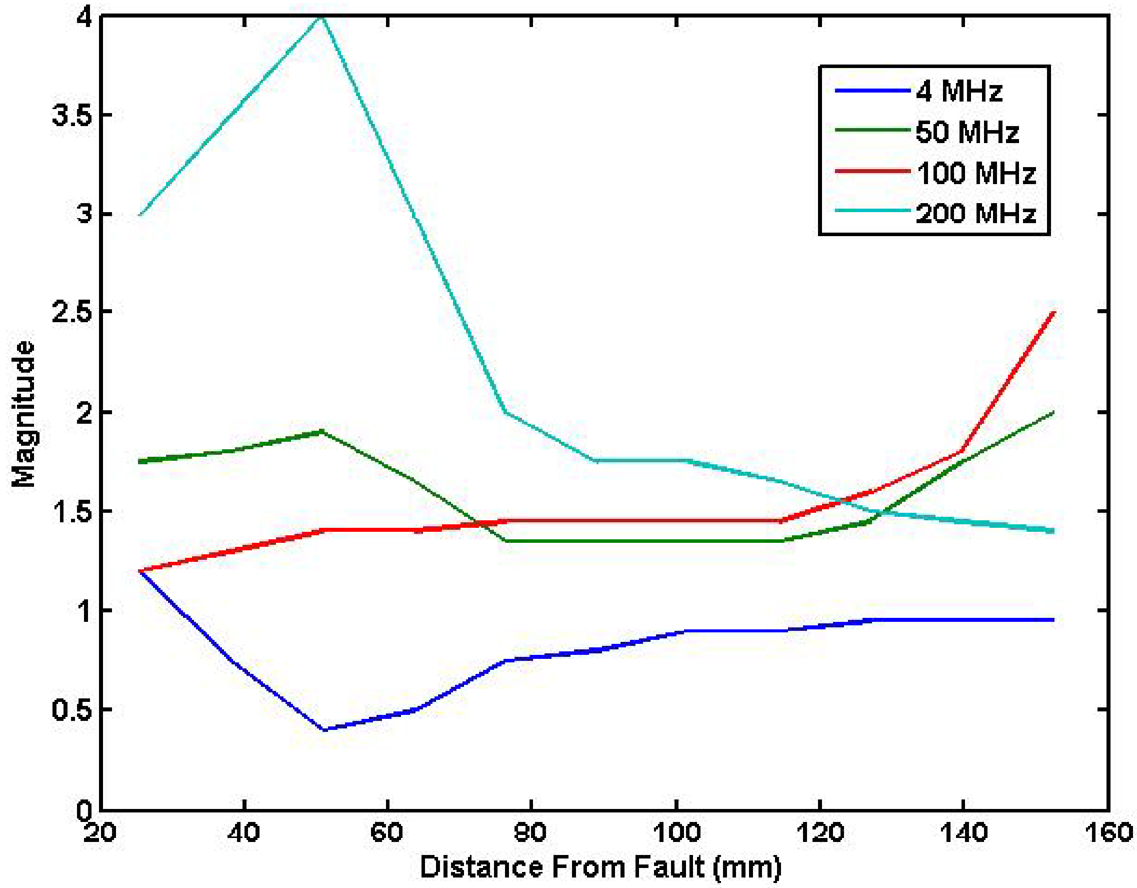
- *Windings*
  - *Keep Low*
- *Wire Gauge*
  - *Larger than 30AWG*
- *Geometry*
  - *Increase Area*
  - *Minimize Magnetic Length*
- *Materials*
  - *N40 (Least Dispersion at 200 MHz)*

Preliminary Measurements



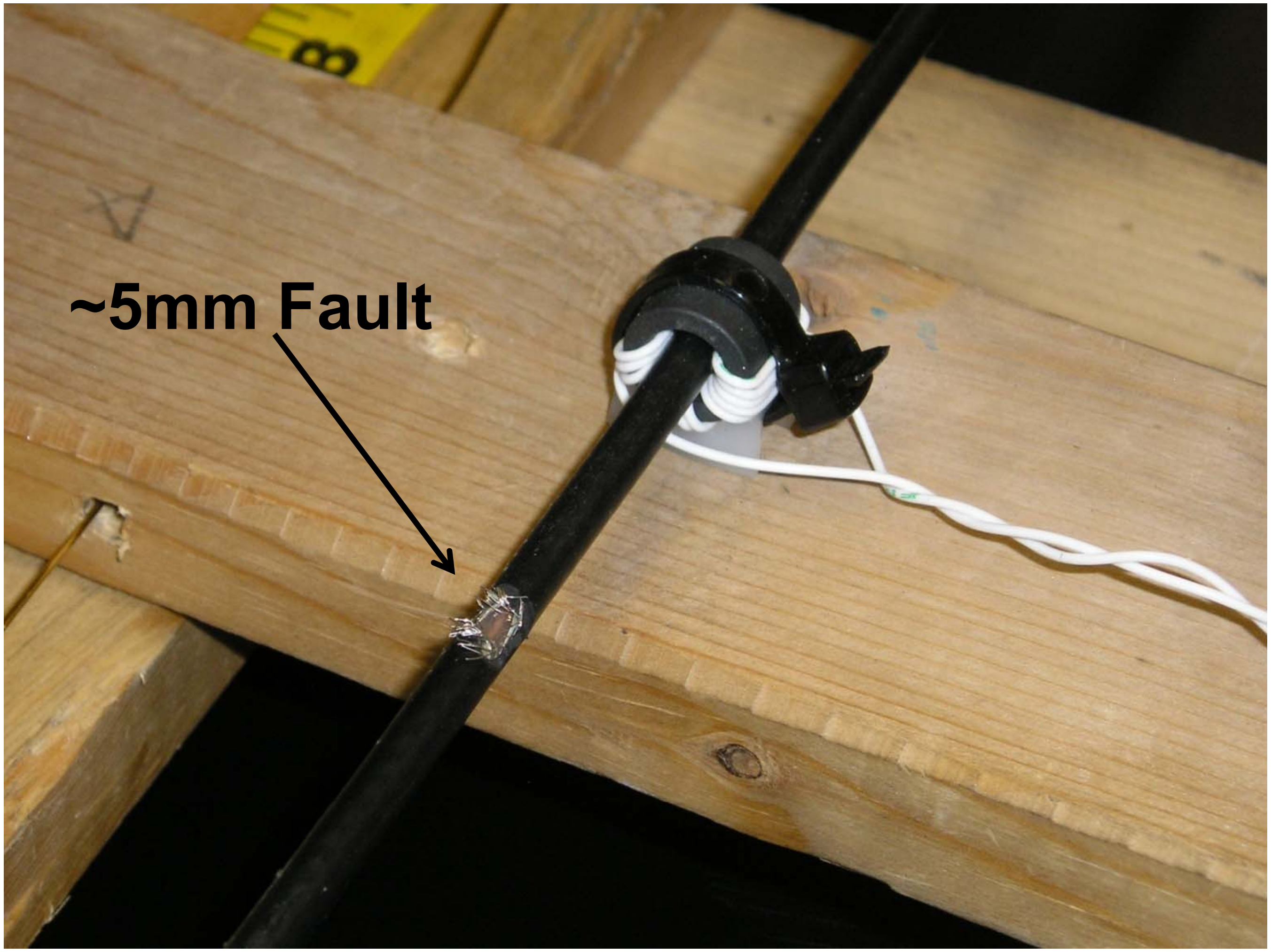
A	B	C	D	E	F
Over Fault	Offset	Off Fault	75mm	150mm	300mm

10mm Fault

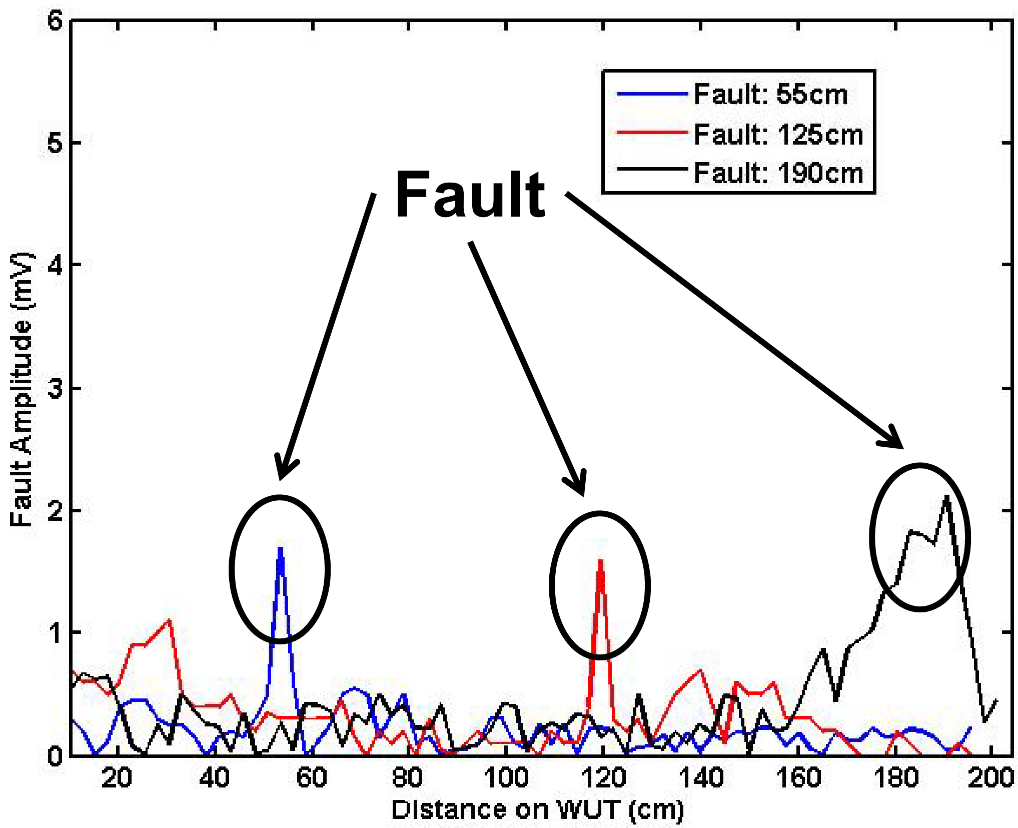


4 MHz
50 MHz
100 MHz
200 MHz
Magnitude
Distance From Fault (mm)
0
0.5
1
1.5
2
2.5
3
3.5
4
20
40
60
80
100
120
140
160

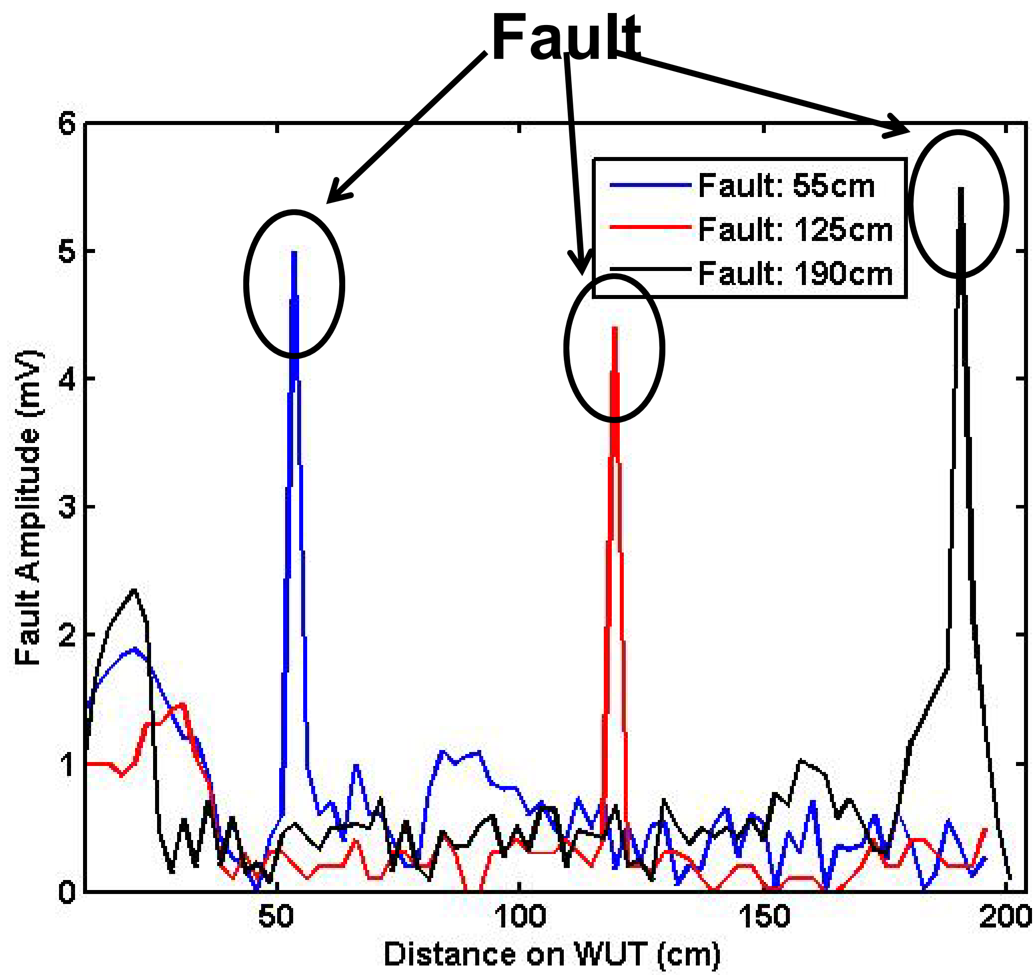
Fault Detection (5 mm)



Fault Localization (5 mm Fault)

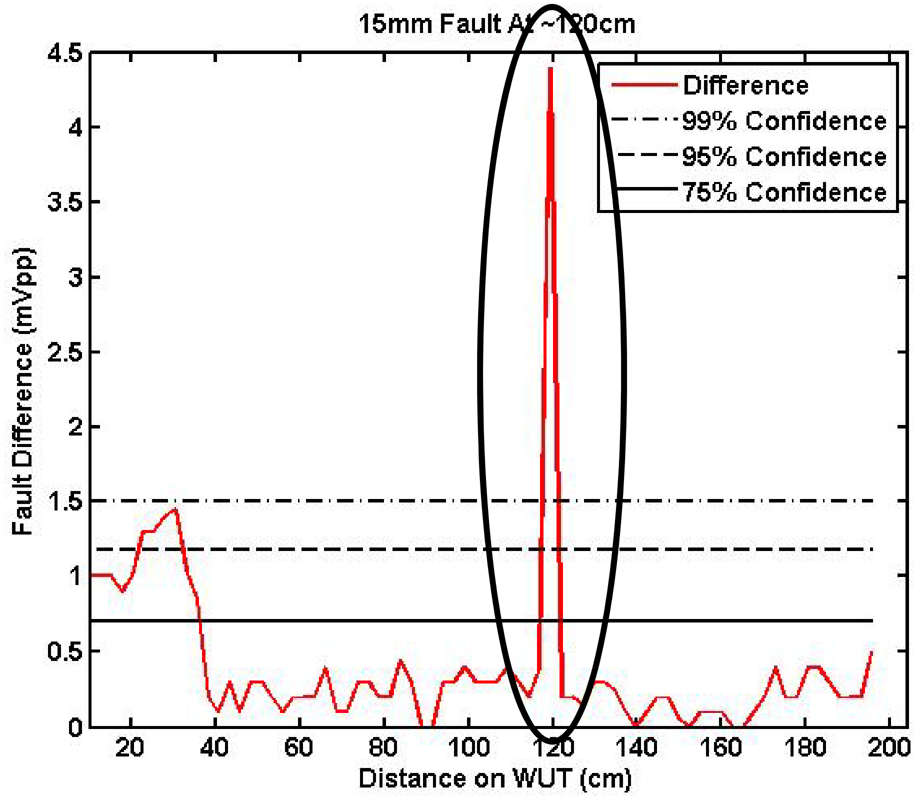


Fault Localization (15 mm Fault)

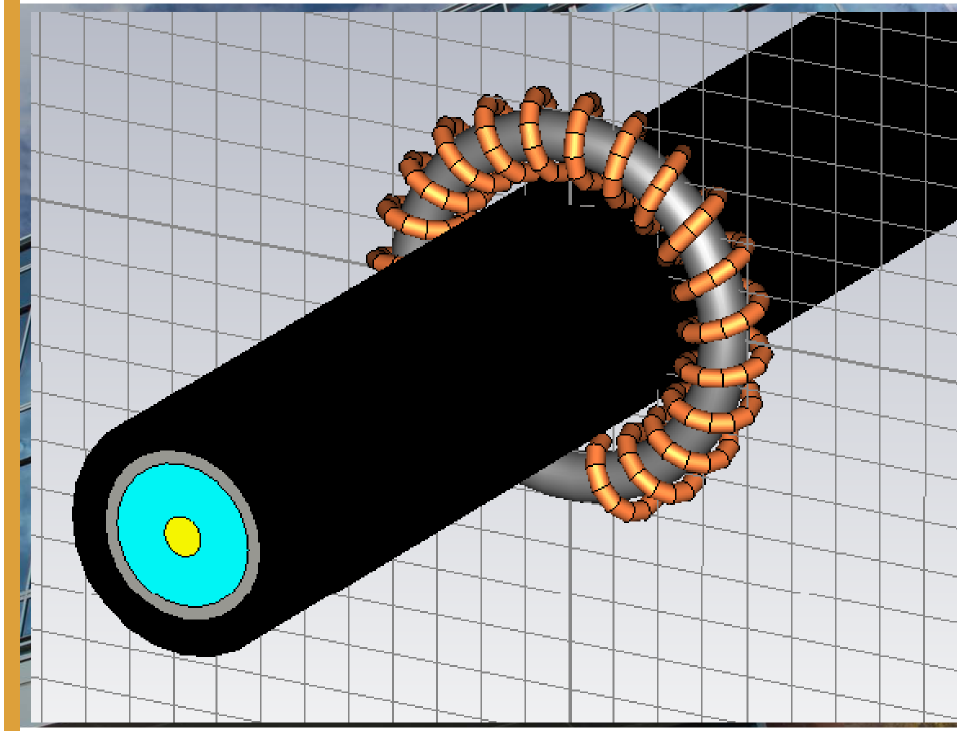


Goals

- *Need to localize and characterize apertures in coaxial shielding*
- *Traditional reflectometry not suited for shield apertures*
- *Accomplished with an external inductive non-contact sensor*



Lucas Thomson
University of Utah



lucas.thomson@utah.edu

www.ece.utah.edu/~cfurse

cfurse@ece.utah.edu