NIOSH Internal Research: UHF, MF, TTE, Tracking Status

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Path to wireless communications

- Communications & Tracking (CT) systems introduced were generally similar to or adapted from surface systems

- Coal mine environment is different from surface
  - No open spaces: restricted spaces, long entries, with cross-cuts
  - Operating environment: restrictions on location and size of antennas or other components
  - Sidewalls, roof, floor are somewhat conducting
  - Permissible system required
  - Different regulations apply in mine

- Radio waves propagate quite differently underground compared to surface systems – mechanisms not fully understood

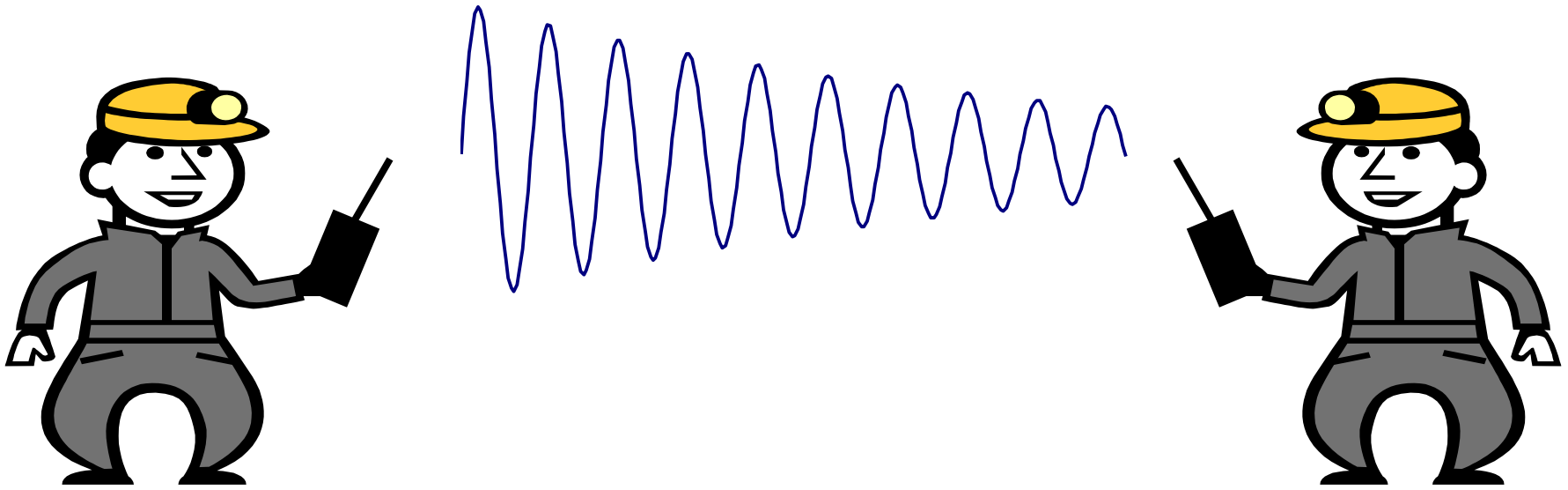
What to expect in these presentations

- Underground radio technologies fall into 3 frequency bands
- Quick description of each (present projects; 4 year effort)
  - UHF
  - MF
  - TTE
- Electronic tracking: related but somewhat different area
- NIOSH/OMSHR research to assist in enhancing performance & reliability & survivability (MINER Act goals)
- Transfer knowledge
- Gap: How does signal vary with distance (path loss) specifically in the mine environment? (mine environment includes specific noise environment)

$$P_r(dB) = P_t + G_t + G_r + path\ loss$$

Importance of Path Loss & Noise

- Degradation and loss favorite radio station when drive out of coverage area



Tx

Rx

Importance of Path Loss & Noise

- Experienced degradation and loss favorite radio station when drive out of coverage area
- Implies quality reception
  - requires certain signal strength to work
  - signal strength decreases with distance

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- From tutorial presentation
  - signal quality depends on adequate signal to noise ratio (SNR)
- Successful radio system design
  - Relies on valid predictions and assumptions about signal propagation
  - Relies on characteristics of signal path
  - Relies on nature of anticipated noise and interference

Why modeling?

- Modeling: use of computer programs to simulate path loss (attenuation) between Tx and Rx

- Interaction of EM wave with environment can be complex
  - From tutorial, each frequency band propagation very different
  - Frequency of operation big effect on performance
  - Behavior likely to depend on characteristics of individual mine
  - Don’t want to perform RF experiments in every mine
  - Need physics to understand and formulas to predict

- Want to develop a tool for users to obtain mine-specific results

Other thoughts on modeling

- Easy to evaluate/understand ‘what if’ scenarios (sensitivity analyses)
- Can’t reasonably measure every mine – need model
- Incredible variety of powerful computational tools available
- Computational tools can be expensive
- Can require extensive computer resources
- Require experience to use
- Models must be validated with measurements
- Enhance understanding and develop modeling tools to make results available to all (webinar)

- Ultimately: a tool for users

UHF Research

CDC Workplace Safety and Health
National Institute for Occupational Safety and Health NIOSH

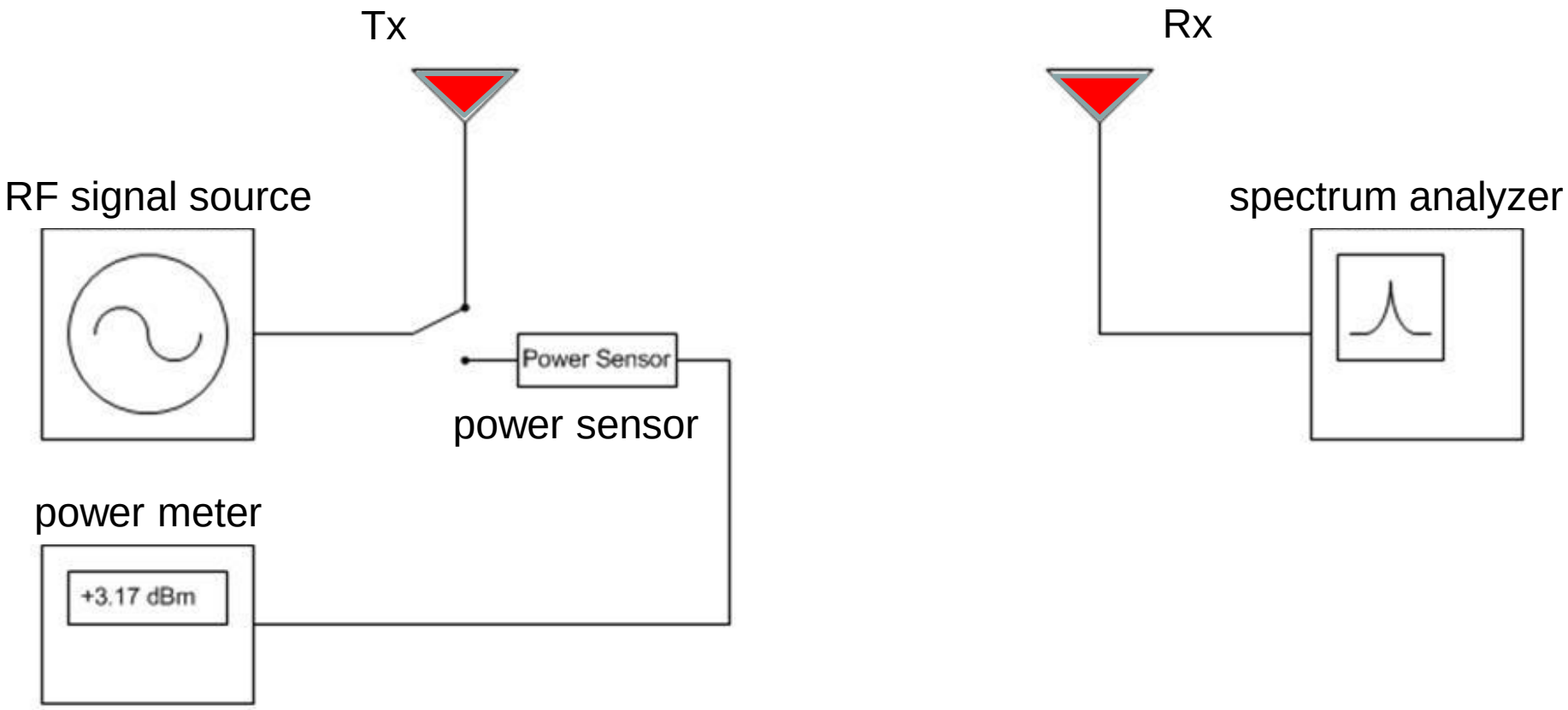
UHF – mine entry propagation

- Research propagation from 450 MHz to 5.8 GHz
  - SHF 3 GHz – 30 GHz
  - Leaky feeder at 150 MHz (VHF)

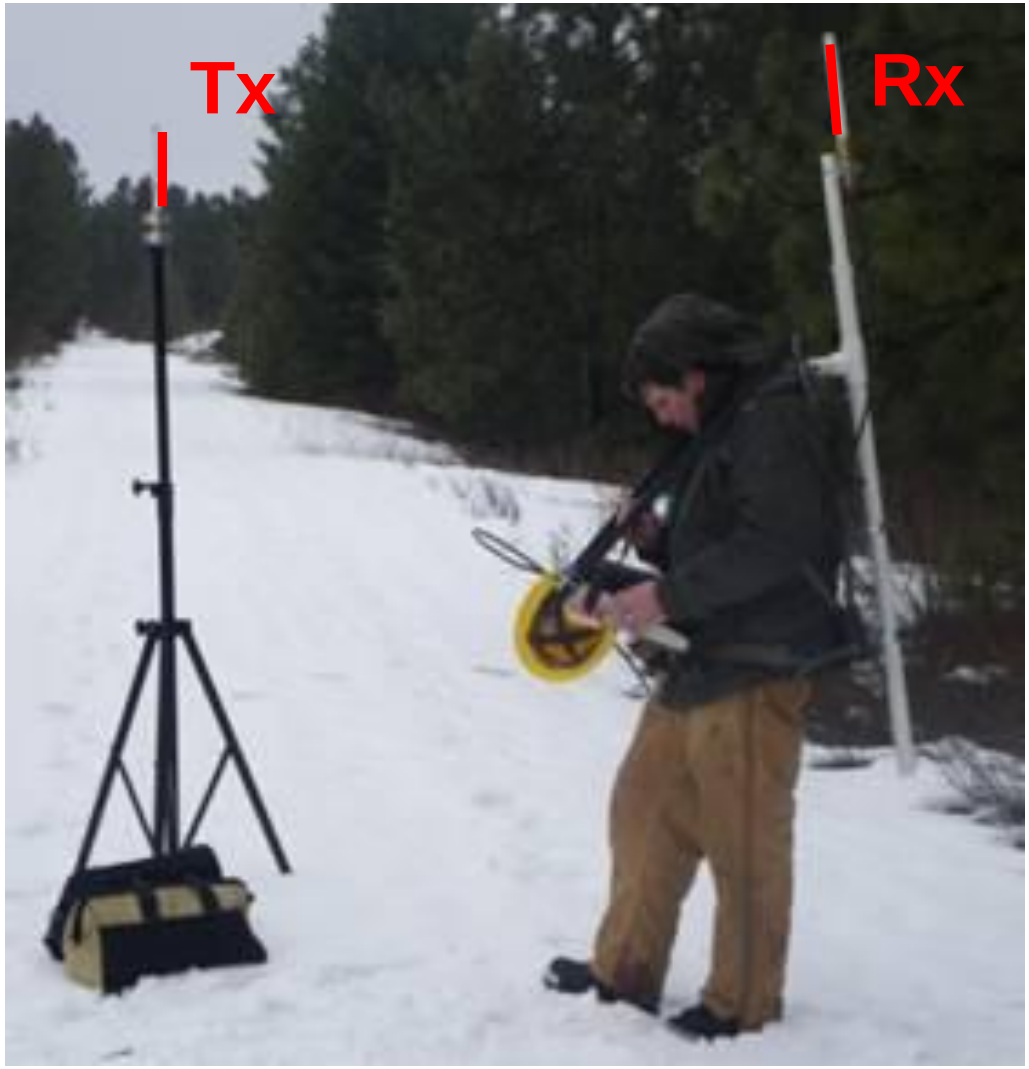
- Path loss or propagation
  - Tunnel
  - Room and pillar
  - Obstructions – stoppings, equipment, people, wires/cables/pipes

- UHF radio wave propagation & attenuation down an entry

UHF measurement block diagram



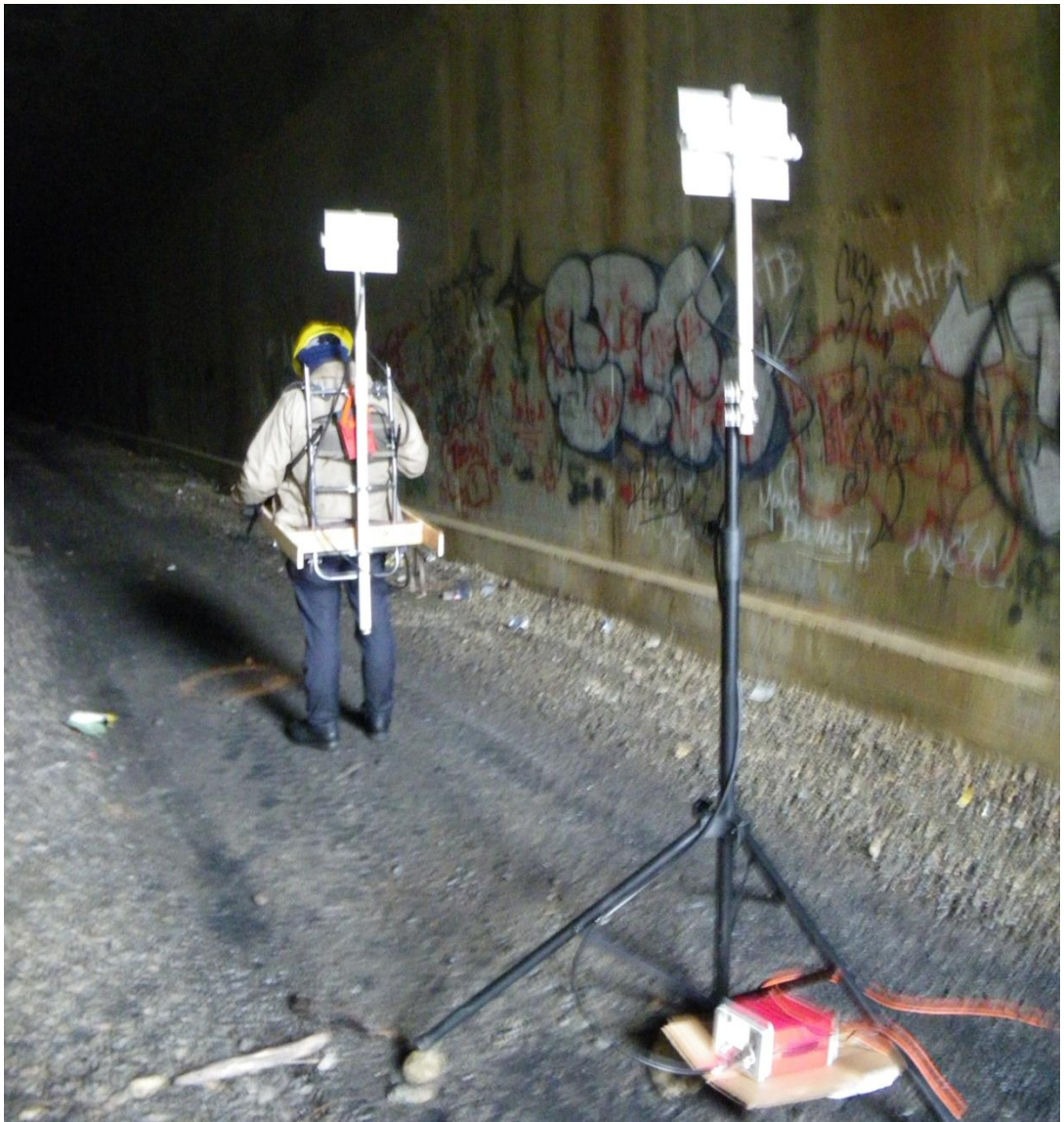
Initial UHF measurements



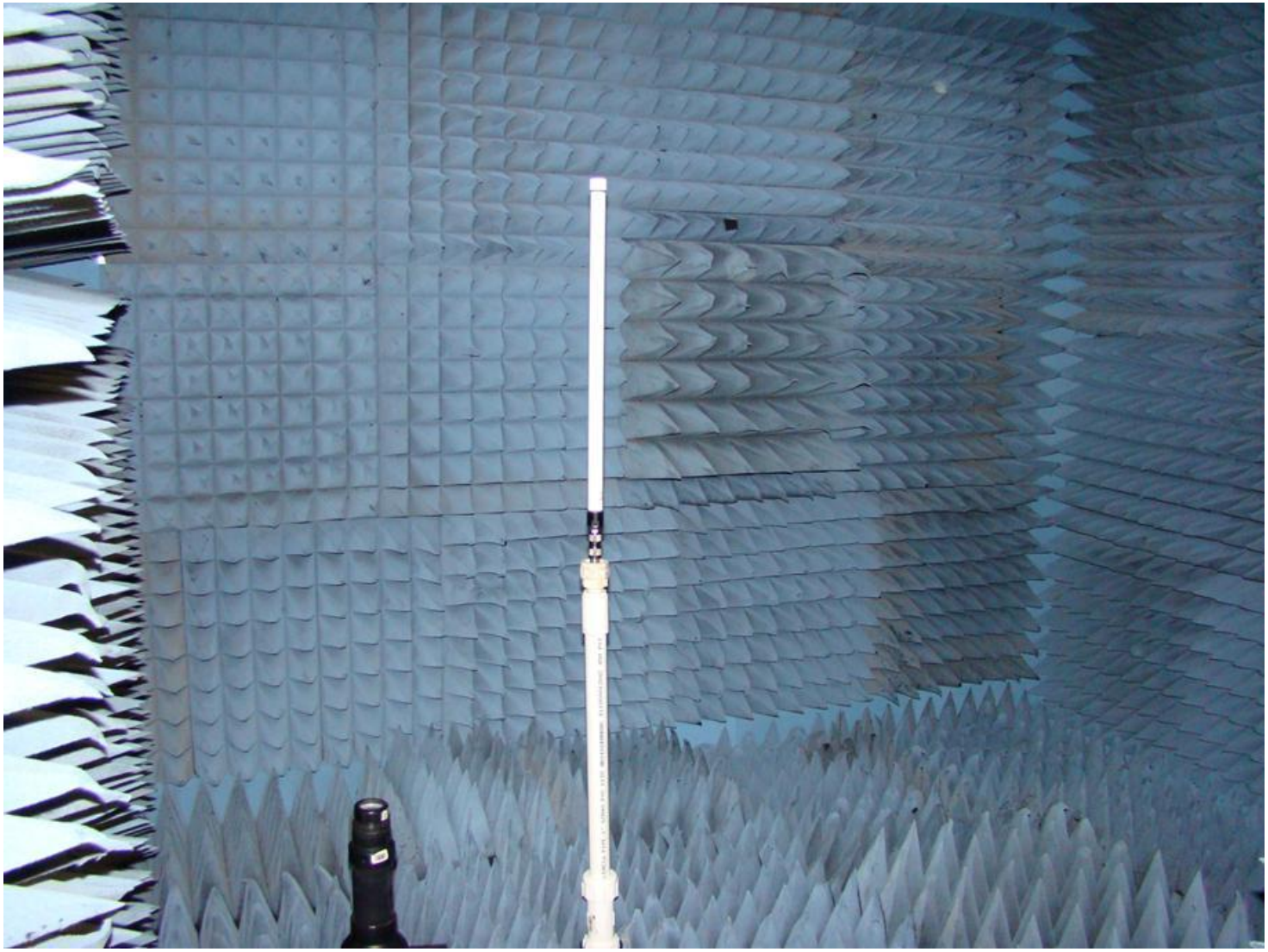
2500 ft Abandoned train tunnel

UHF measurements in tunnel

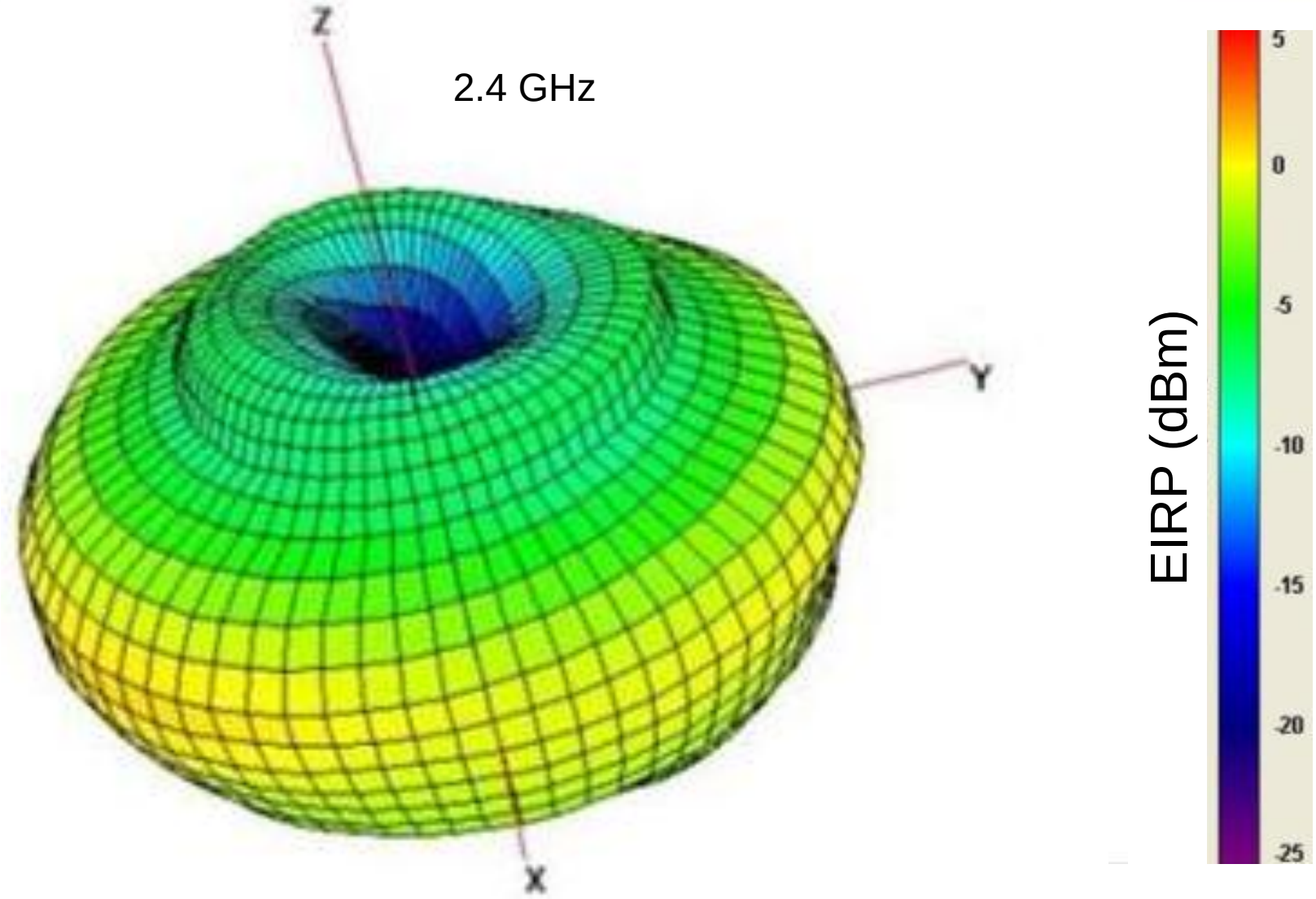
Some measurements with patch antennas



Characterize antenna pattern



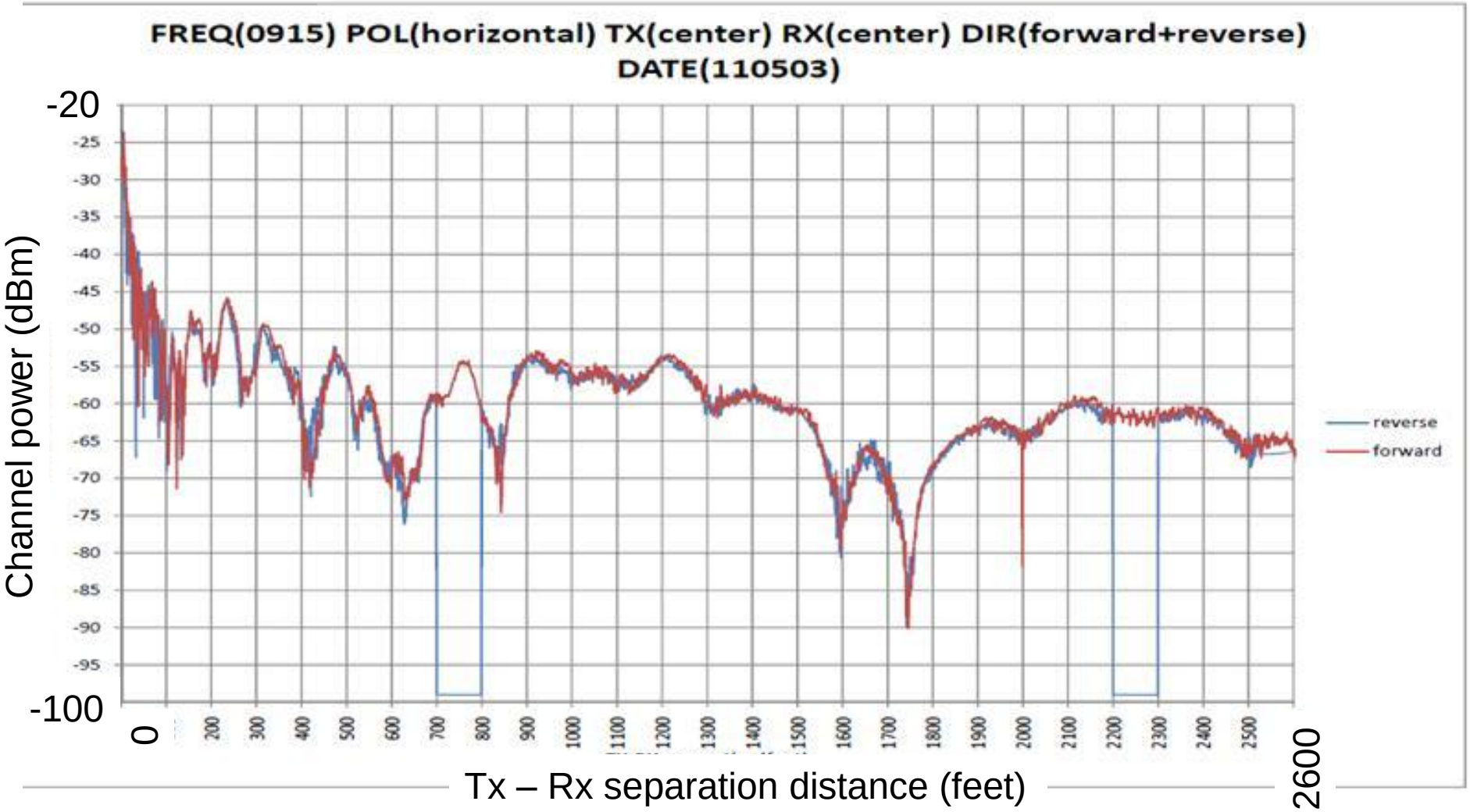
Antenna radiation pattern



UHF Measurements in NIOSH research mines

Mobile Rx antenna

Representative data sample

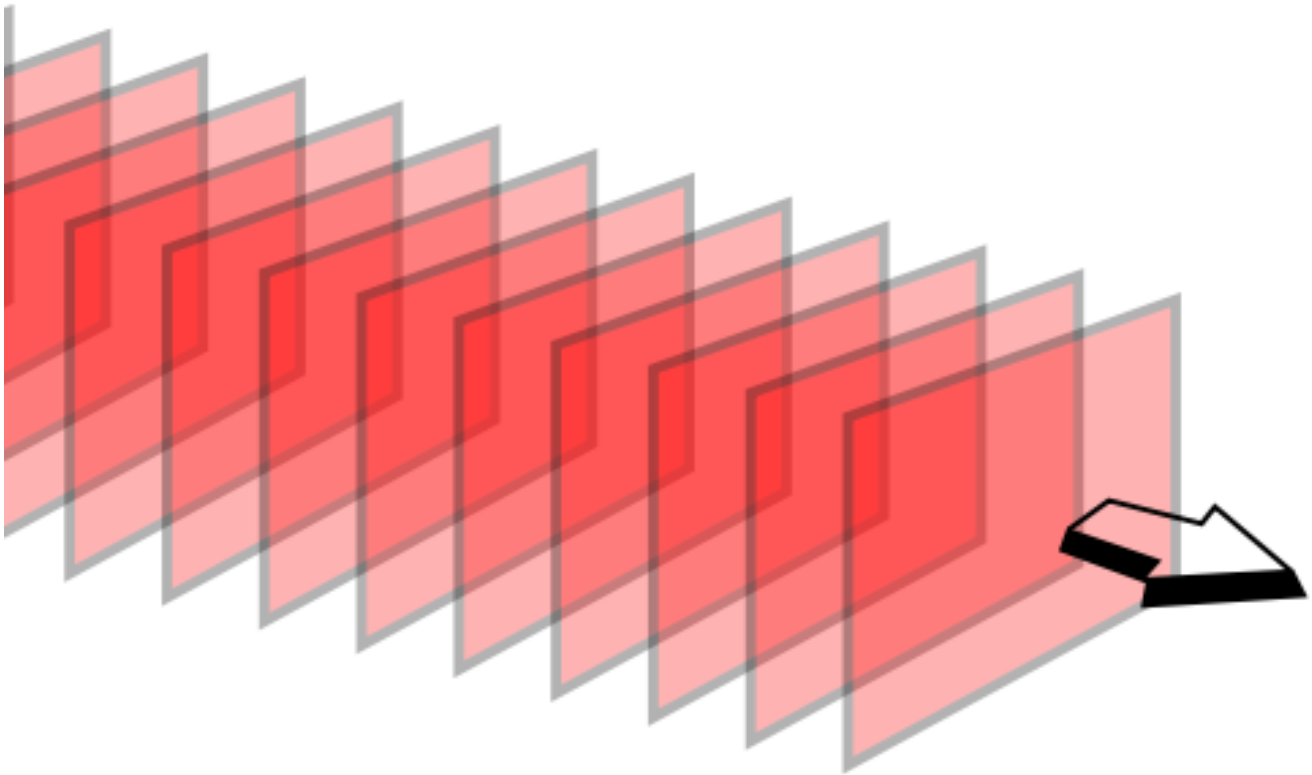


Fundamental wave property: wave front

Series of water waves

Seen from above (series of peaks)

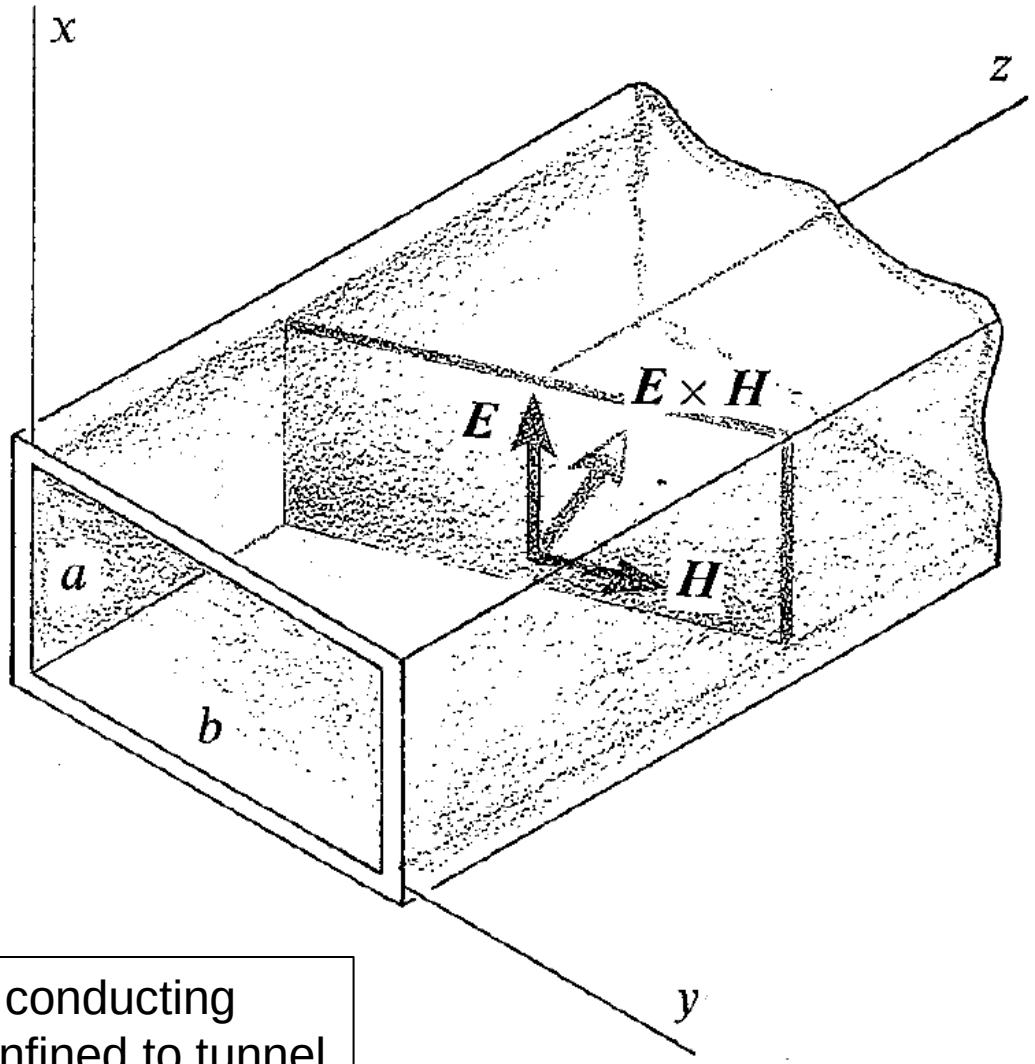
Concept of plane wave



Each plane is at the peak of the wave
Occurs after some distance (about a wavelength) from source

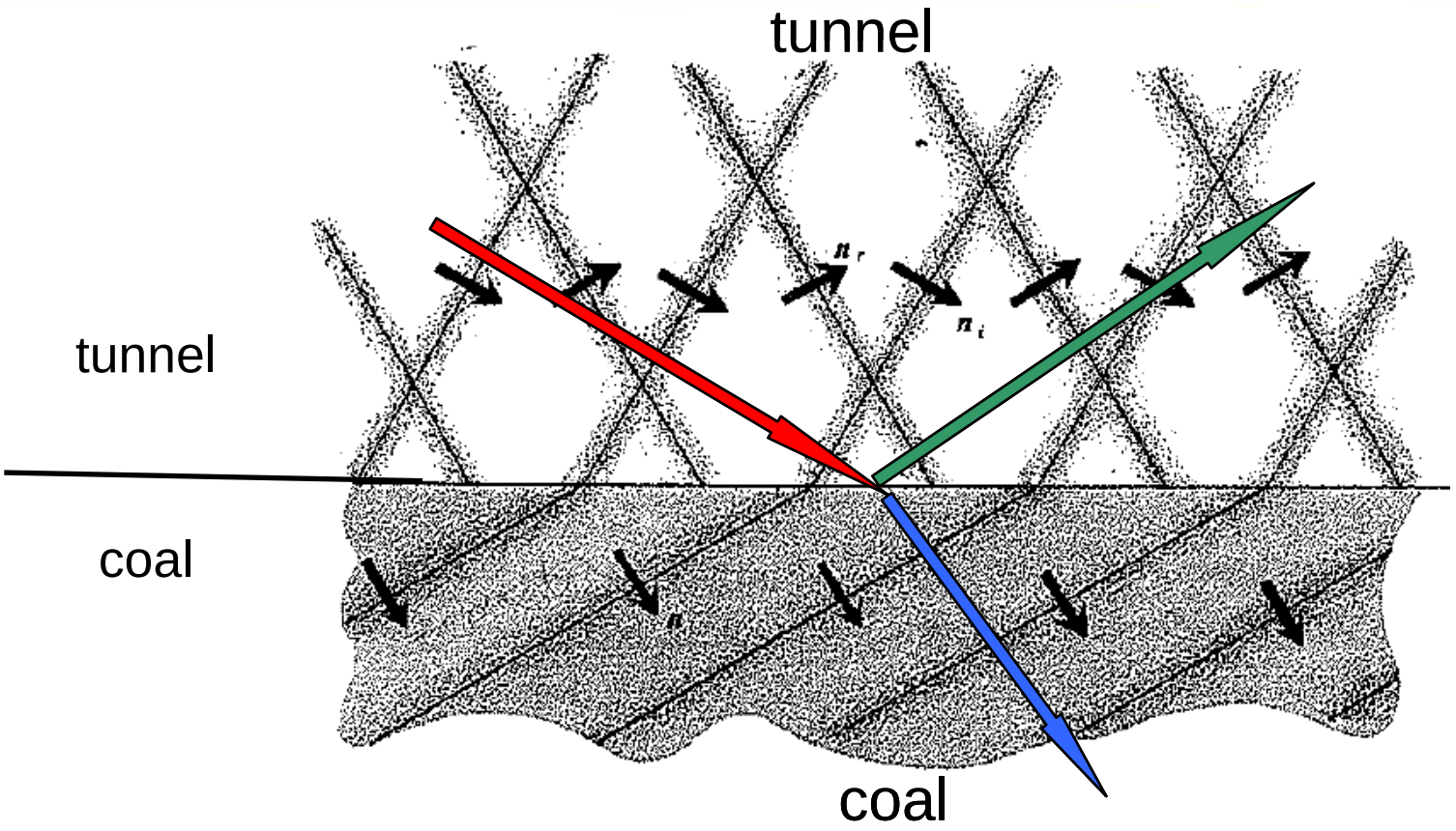
Generally not a consideration with MF or TTE because of such long wavelengths.

Tunnel acts as waveguide



Walls are somewhat conducting
EM (radio) waves confined to tunnel

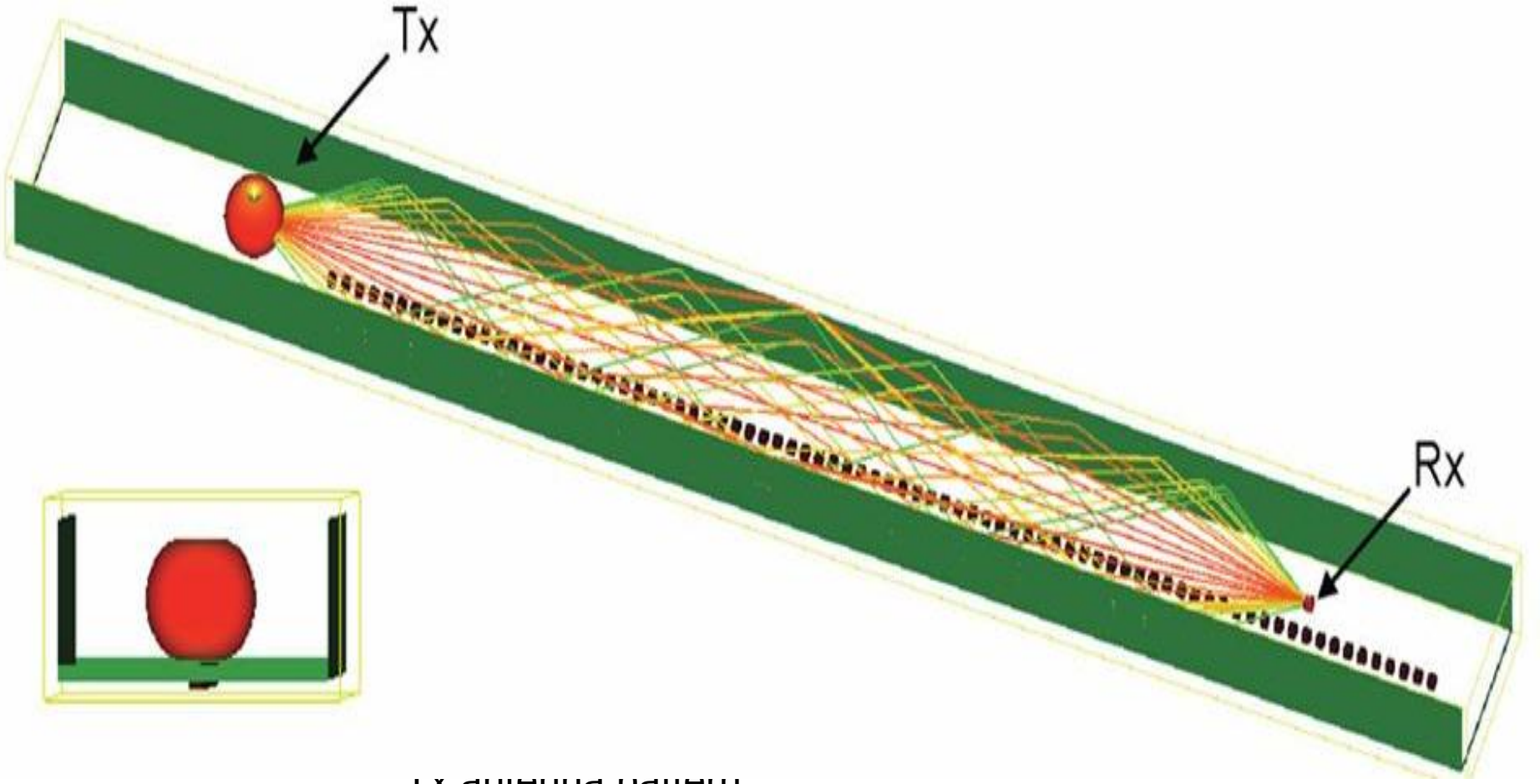
Ray is perpendicular to wave front



Wave strikes wall (red):
Part reflects (green)
Part transmitted (blue) (removes some energy from the ongoing wave)

Ray optics model of UHF in tunnel

Remcom: Wireless InSite



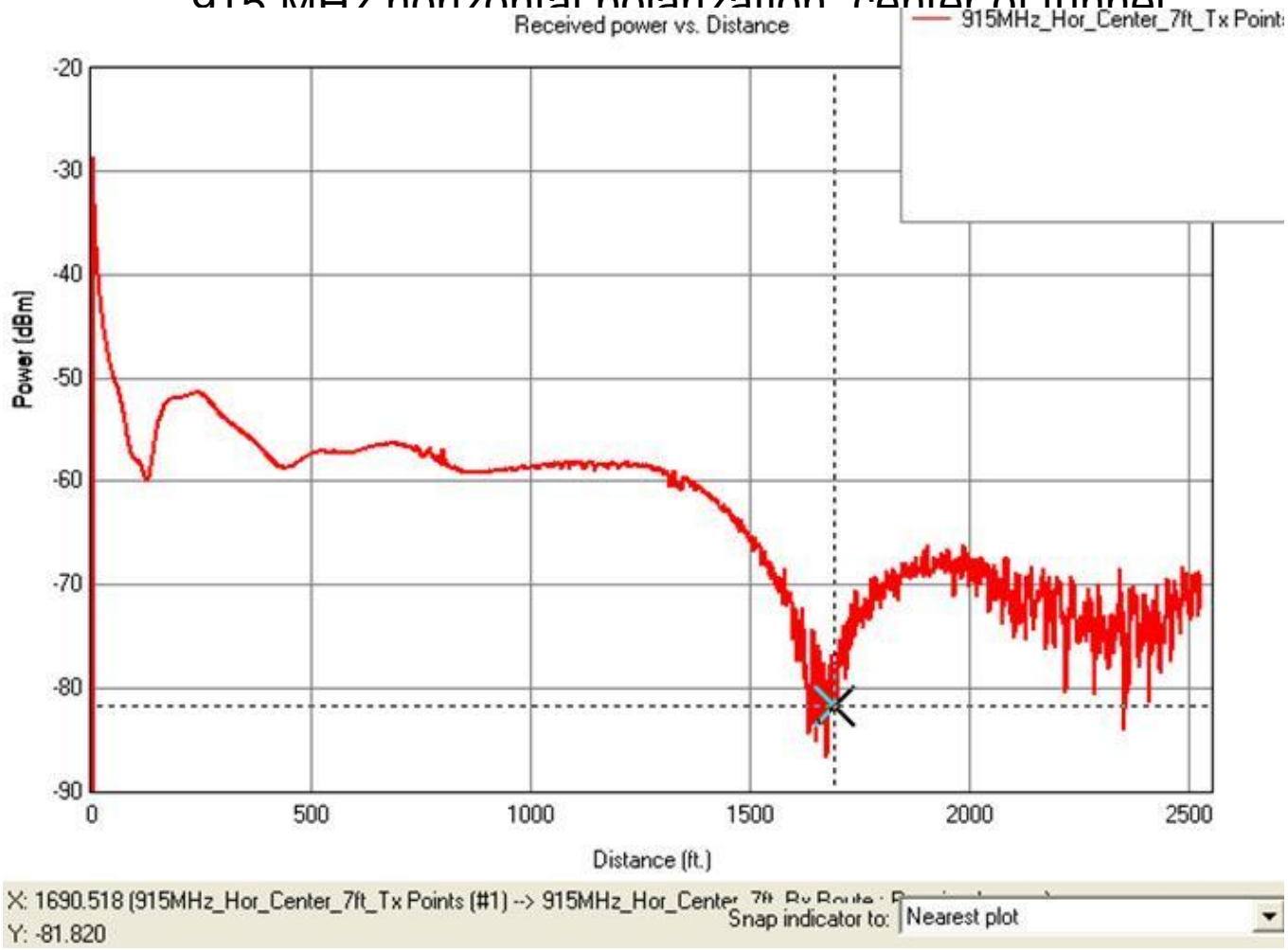
Tx antenna pattern

Model inputs

- Tunnel dimensions: height, width, length
- Electrical properties of each surface material
- Frequency of operation
- Tx and Rx antenna types: dipole, or other, or data
- Location of Tx and Rx antennas (can move)

Sample model results

915 MHz horizontal polarization, center of tunnel



Received power (dBm)

1st year UHF research summary

- Determined/acquired appropriate RF equipment
- Characterized Tx and Rx antennas for 450 MHz – 5.8 GHz
- Made initial path loss measurements
  - Train tunnel
  - NIOSH research mines
  - Several working mines scheduled (next year)
- Developing models (& continue)
  - Ray optics
  - Several analytical models
  - NIST support

MF Research

CDC Workplace Safety and Health
National Institute for Occupational Safety and Health NIOSH

MF Research

- MF radios alone – through air – 50 ft
- Near conductor – can propagate 1000's feet

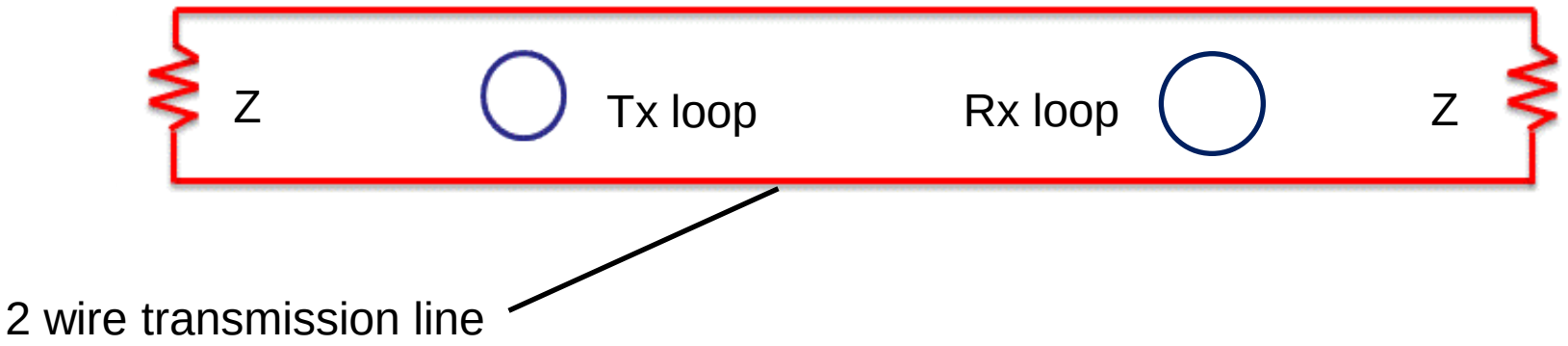
MF Parasitic Coupling

- MF propagates by parasitic coupling to conductors
- Want to start modeling and measurements with simplest configuration (build confidence)
- Relatively easy to model single isolated conductor
- Not so easy to measure/duplicate model geometry in practice
- RF currents can travel multiple paths (different from DC); environment plays big role

Separate coupling from transport

Coupling

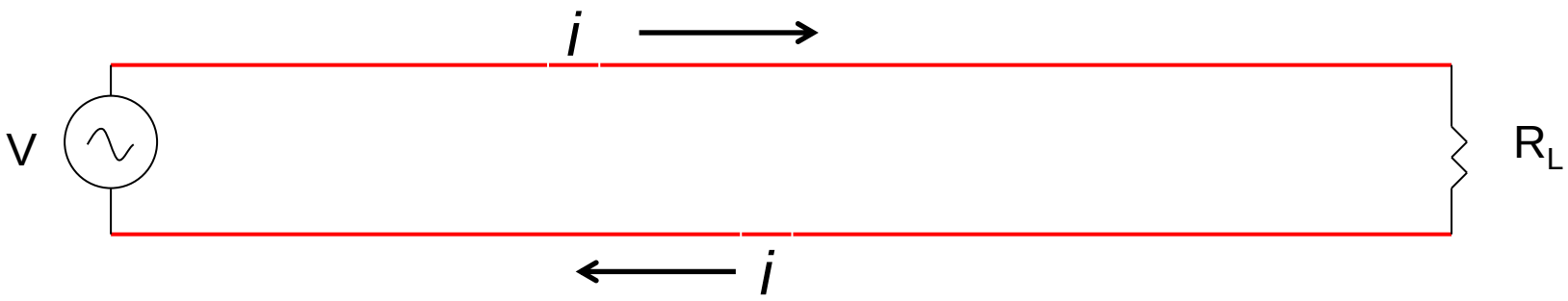
1. How signal inductively couples from Tx/Rx loop to conductors



Separate coupling from transport

Transport

2. How signal propagates down conductor(s)
   - Single conductor, coal return
   - Multiple conductors
   - How transition from one mode to other
   - How signal disperses at intersection/cross-cut

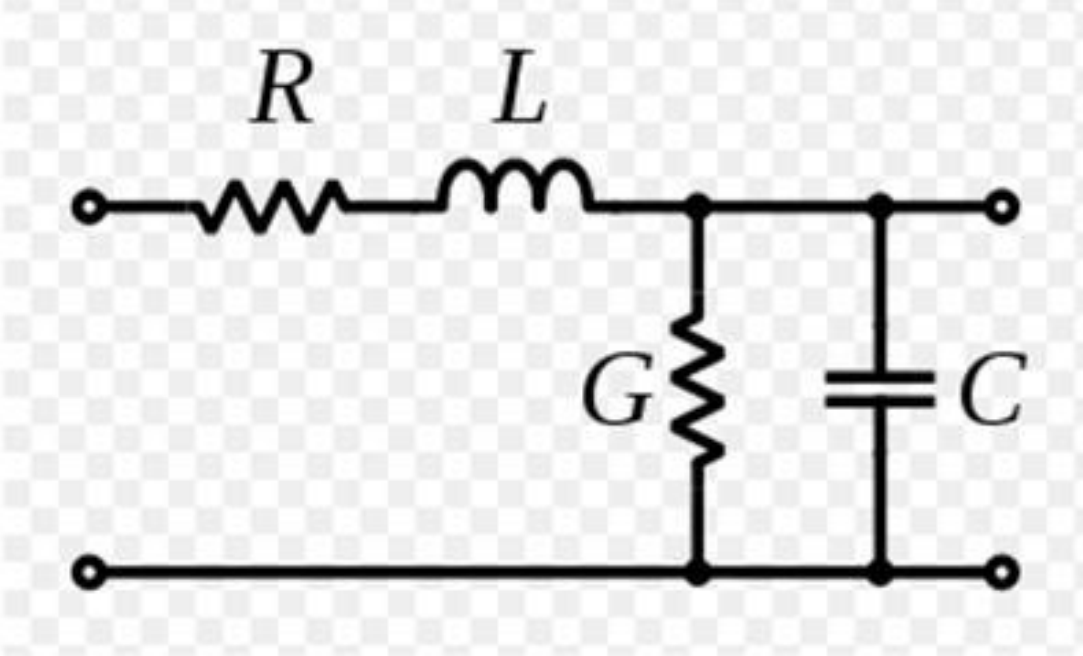


Start simple: measurements & modeling

- Difficult to find mine entry with no conductors or only one conductor

- Easier to do measurements on surface
  - Single conductor
    - earth for return path
    - earth electrical properties
  - 2 parallel conductors
    - reasonably far from surface
    - as determined by model

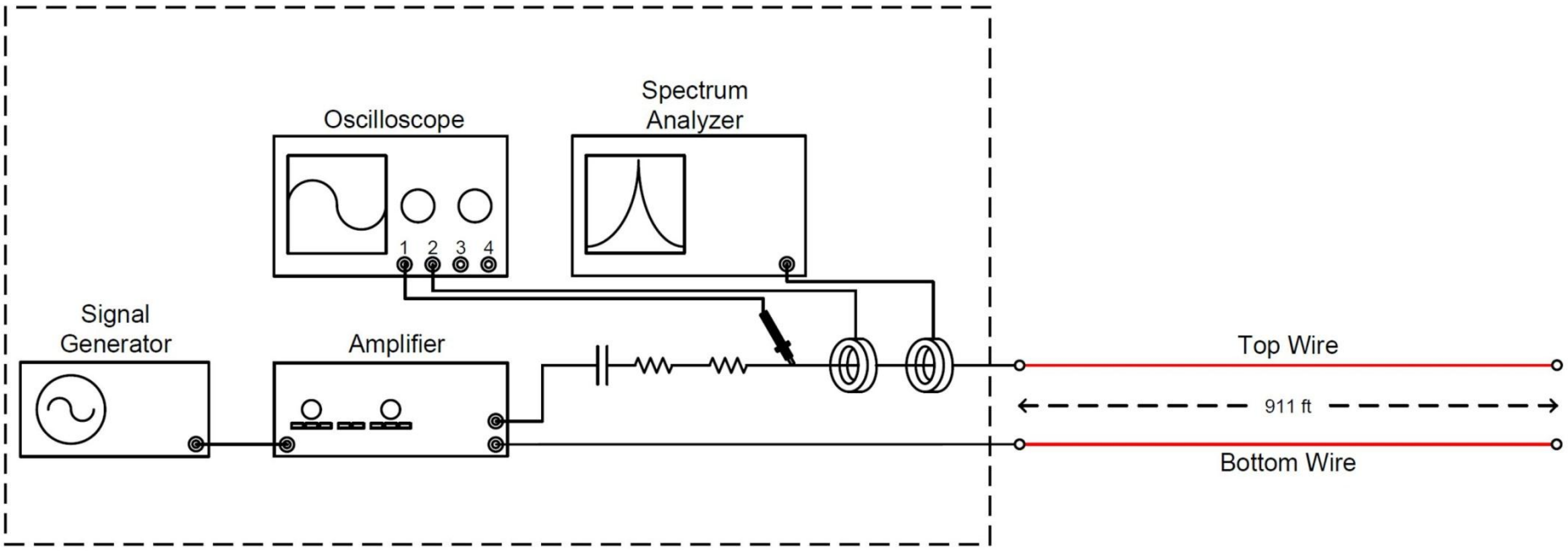
Transmission line model



R = resistance per length
L = inductance per length
G = shunt conductance per length
C = shunt capacitance per length

α = attenuation per length (dB/100 ft)
VF = velocity factor (fraction of speed of light)
Z_o = characteristic impedance (ohm)

MF measuring equipment

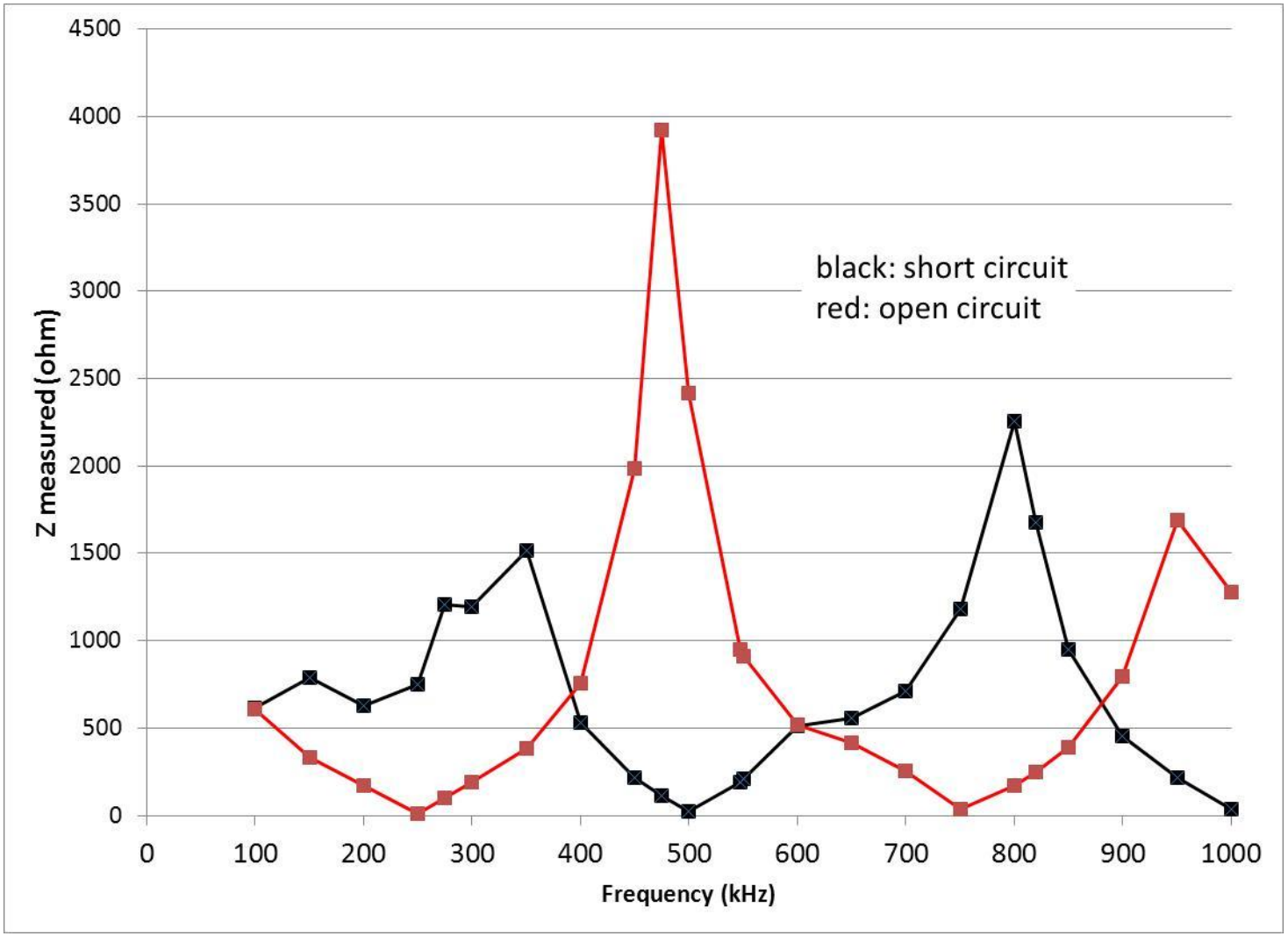


Surface MF Experiments

- Two wire transmission line
- Single wire – earth return transmission

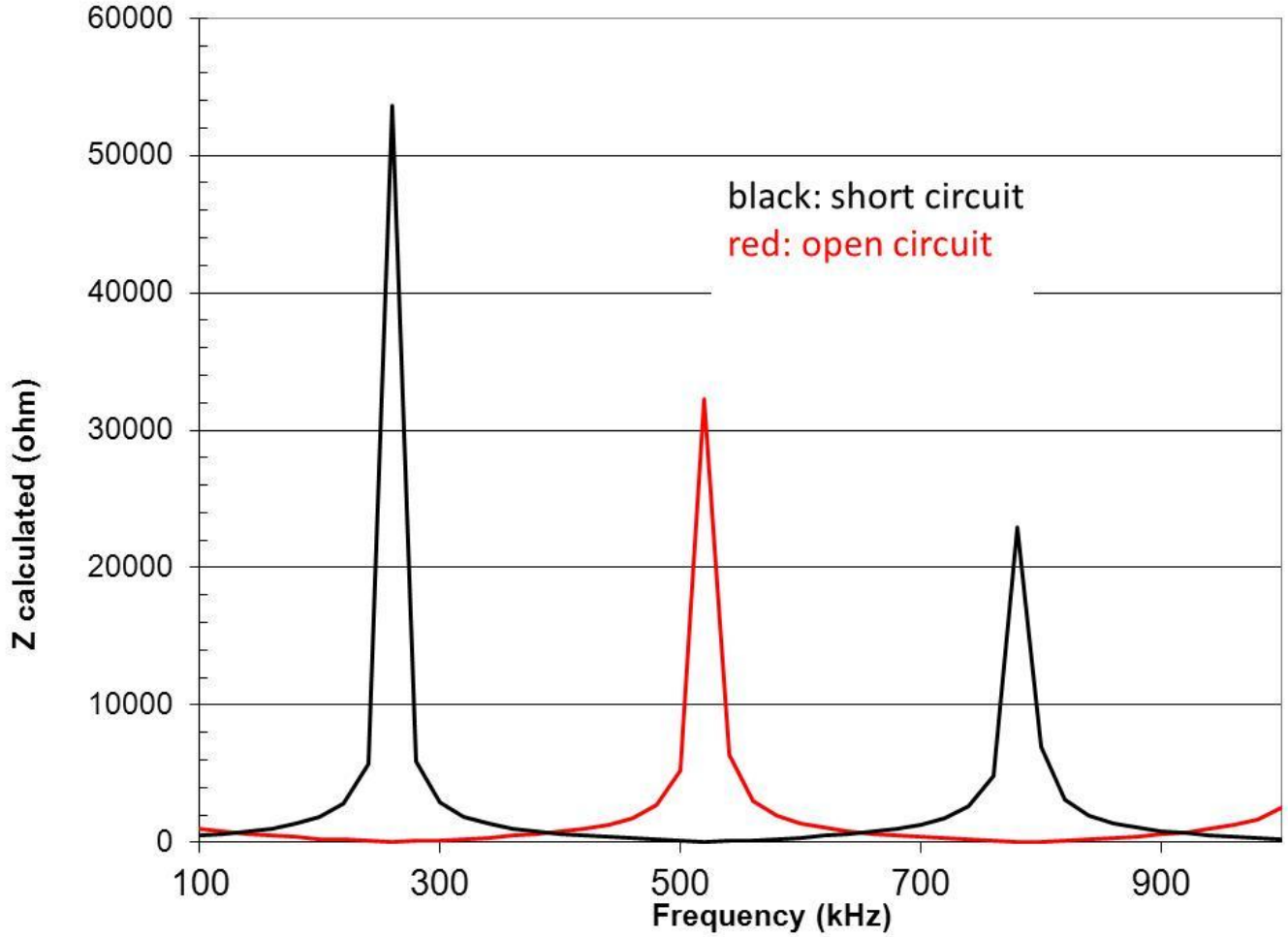
Rare nice day

MF impedance measurements

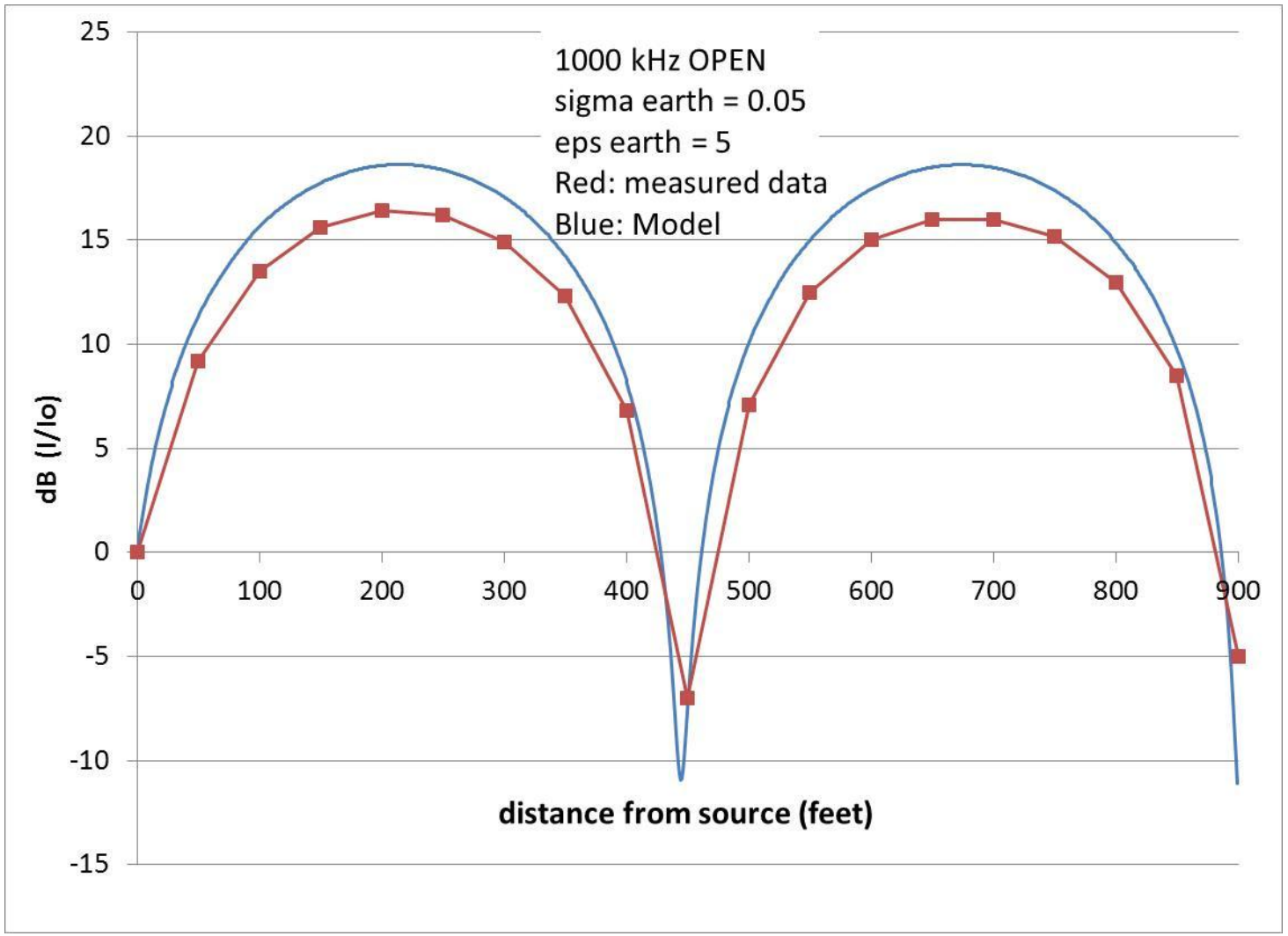


MF impedance modeling

FEKO: method of moments

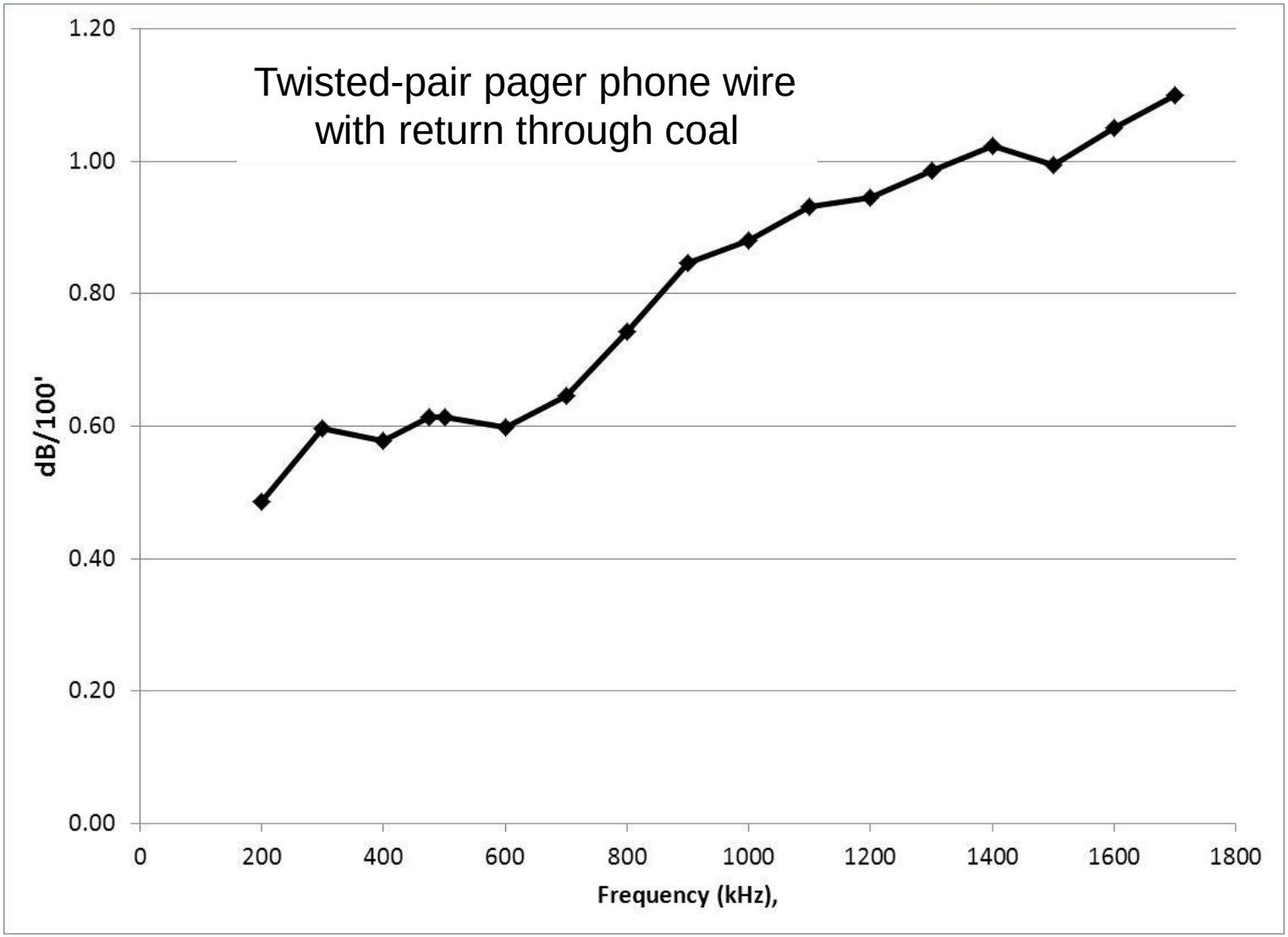


MF current distribution modeling



MF in NIOSH mine

Attenuation determination



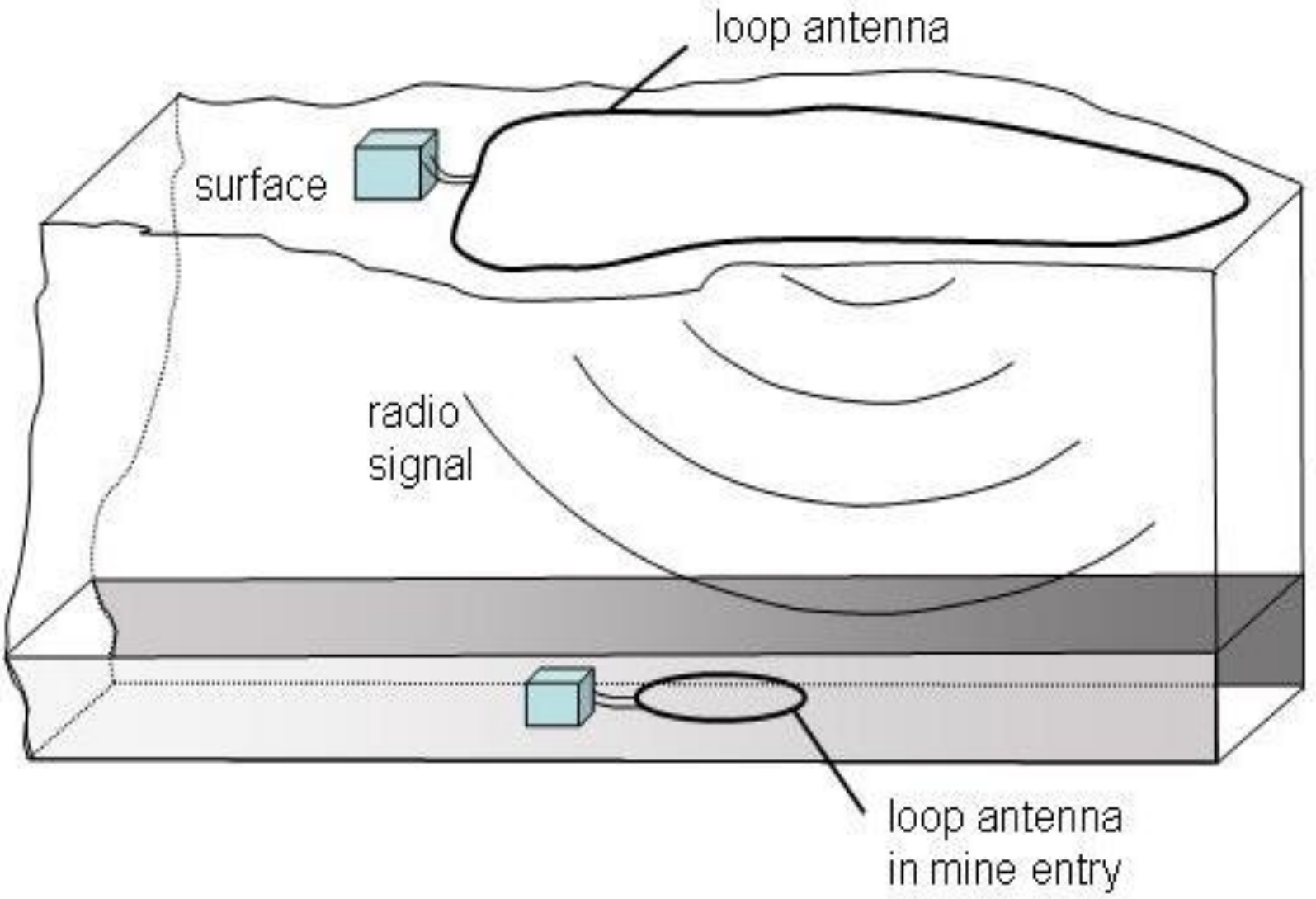
1st year MF research summary

- Determined/acquired appropriate RF equipment
- Made initial path loss measurements
  - Surface
  - NIOSH safety research coal mine
  - Several working mines scheduled (next year)
- Developing models (& continue)
  - Method of moments
  - Several analytical models
  - Working with Penn State University
- Initial comparison of models and measurements is encouraging

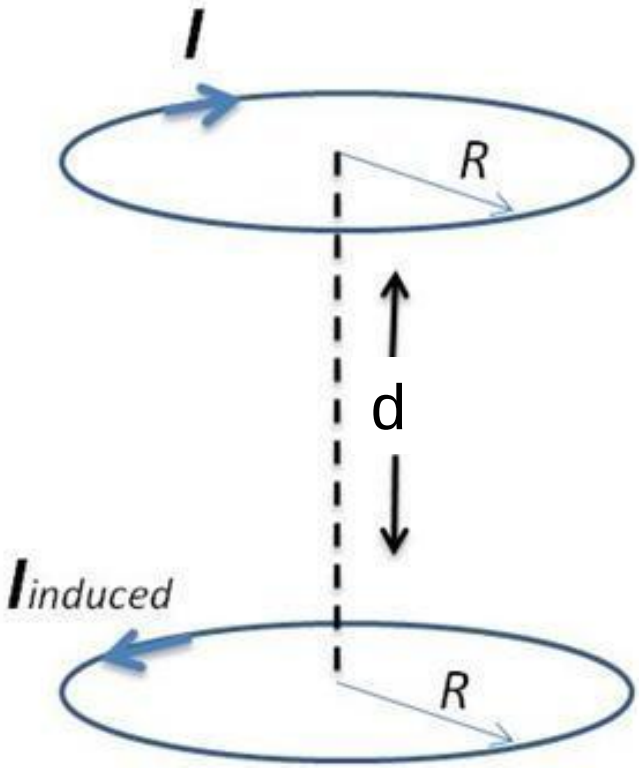
TTE Research

CDC Workplace Safety and Health
National Institute for Occupational Safety and Health NIOSH

TTE Research



Coupling between loops



Generate RF current in one loop

Induces RF current in other loop

Free Space loop coupling

Important parameters:

- I_{tx} = Current (total is N turns X current per turn) in Tx loop
- R_{Tx} = Radius of Tx loop
- R_{Rx} = Radius of Rx loop
- d = Separation distance
- f = frequency

Voltage induced in R_X loop

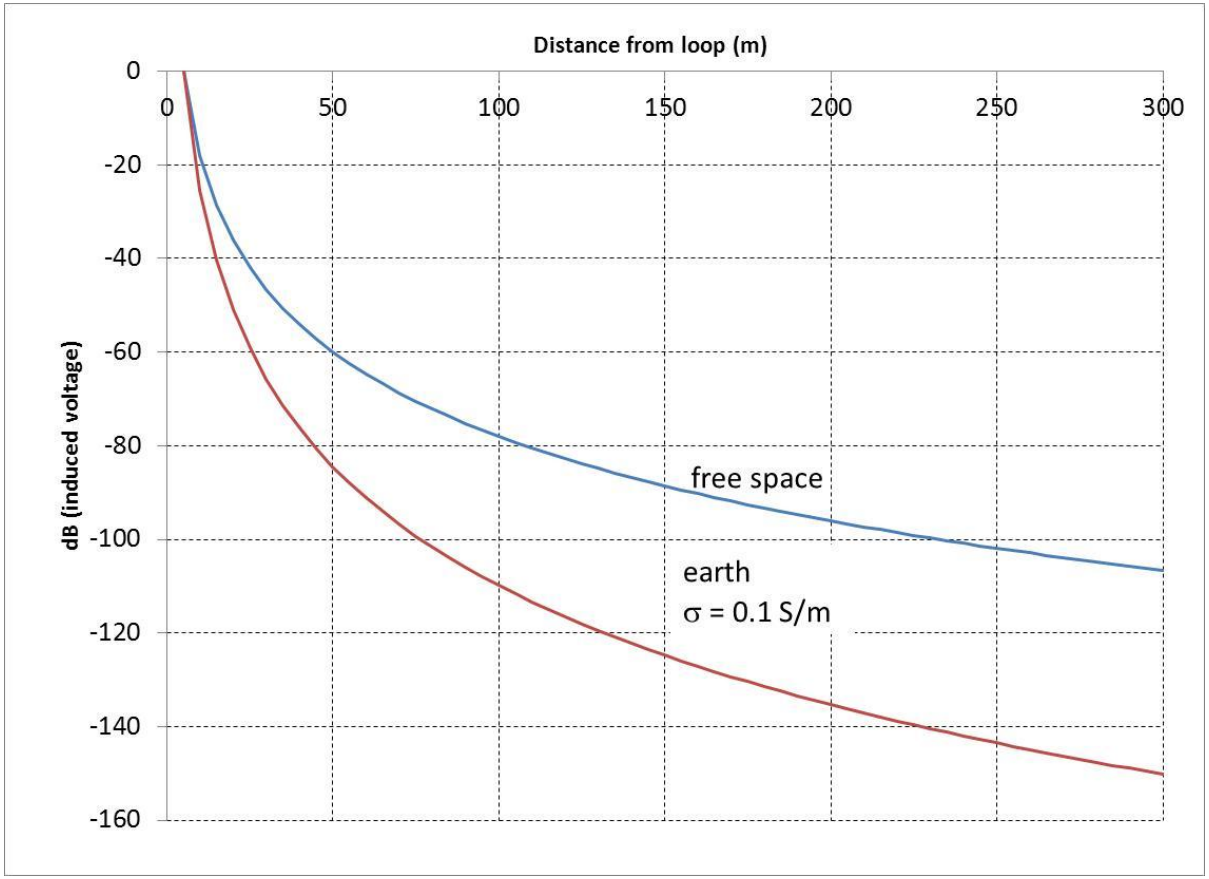
$$V_{Rx} = 1.1 \cdot 10^{-5} \frac{I_{Tx} R_{Tx}^2 R_{Rx}^2 f}{d^3}$$

M = magnetic moment $M = N I_{Tx} (\pi R_{Tx}^2)$

Loop coupling through earth

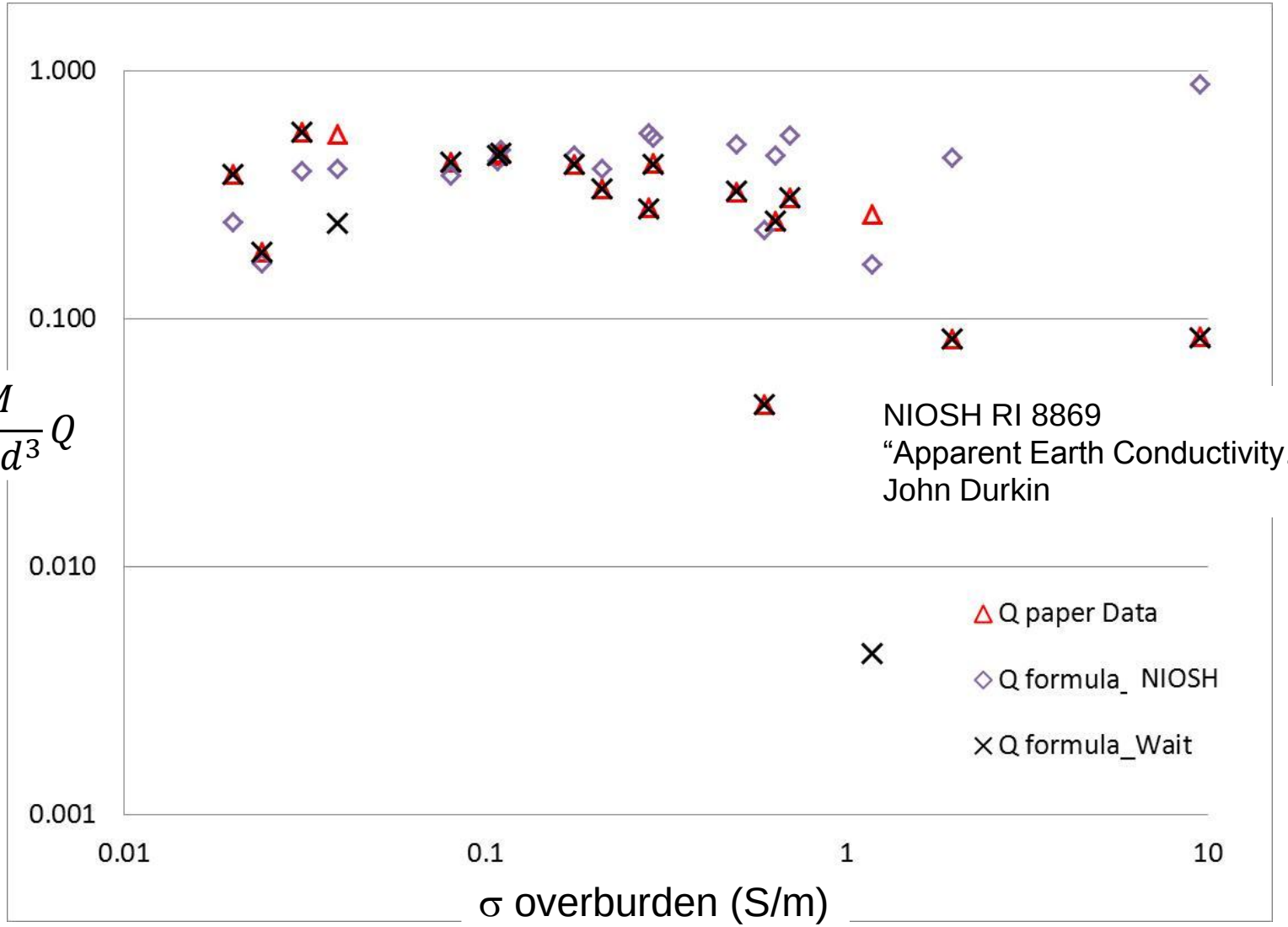
$$V_{Rx\ with\ earth} = V_{Rx\ free} \frac{0.022}{d^{1.22} f^{0.58} \sigma^{0.363}}$$ One approximation

σ = conductivity of earth



Use coupling to determine apparent/effective σ

$$H_z = \frac{M}{2\pi d^3} Q$$



NIOSH RI 8869
"Apparent Earth Conductivity…"
John Durkin

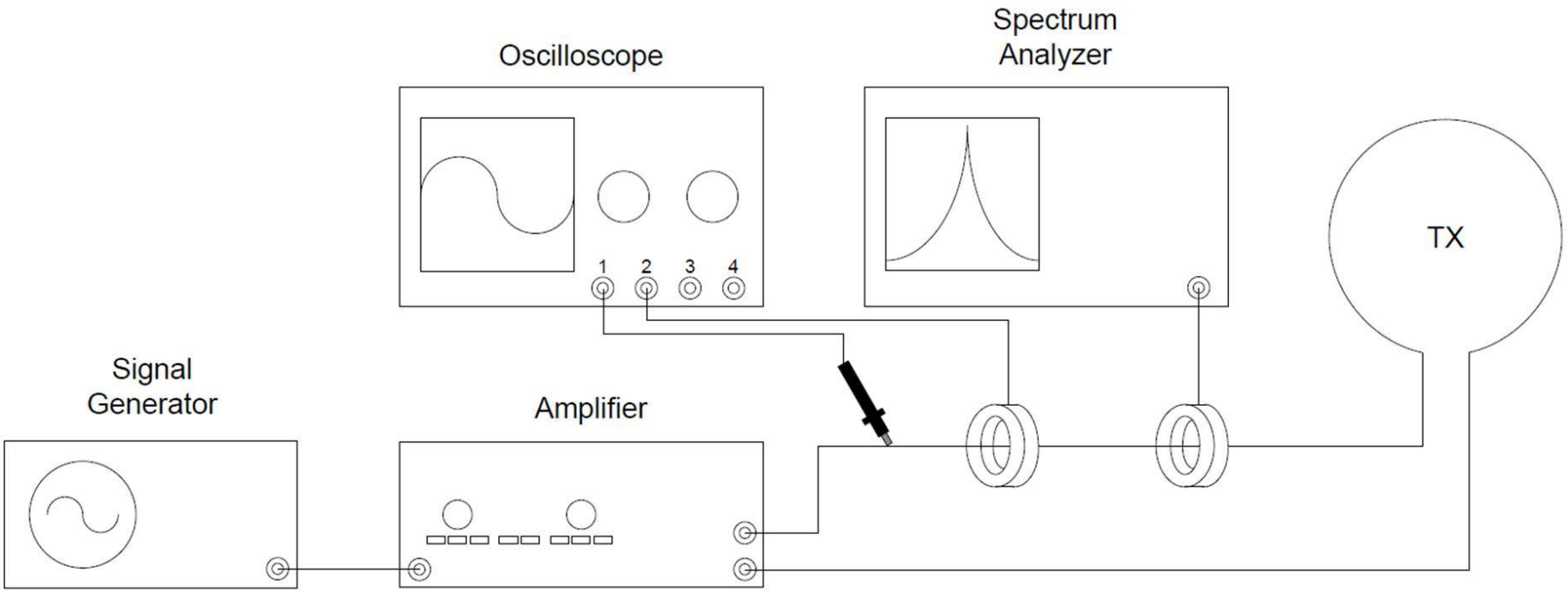
TTE Measurements

7.5 ft radius
10 turns

Transmit:
10 amps
100 Hz to 10 kHz

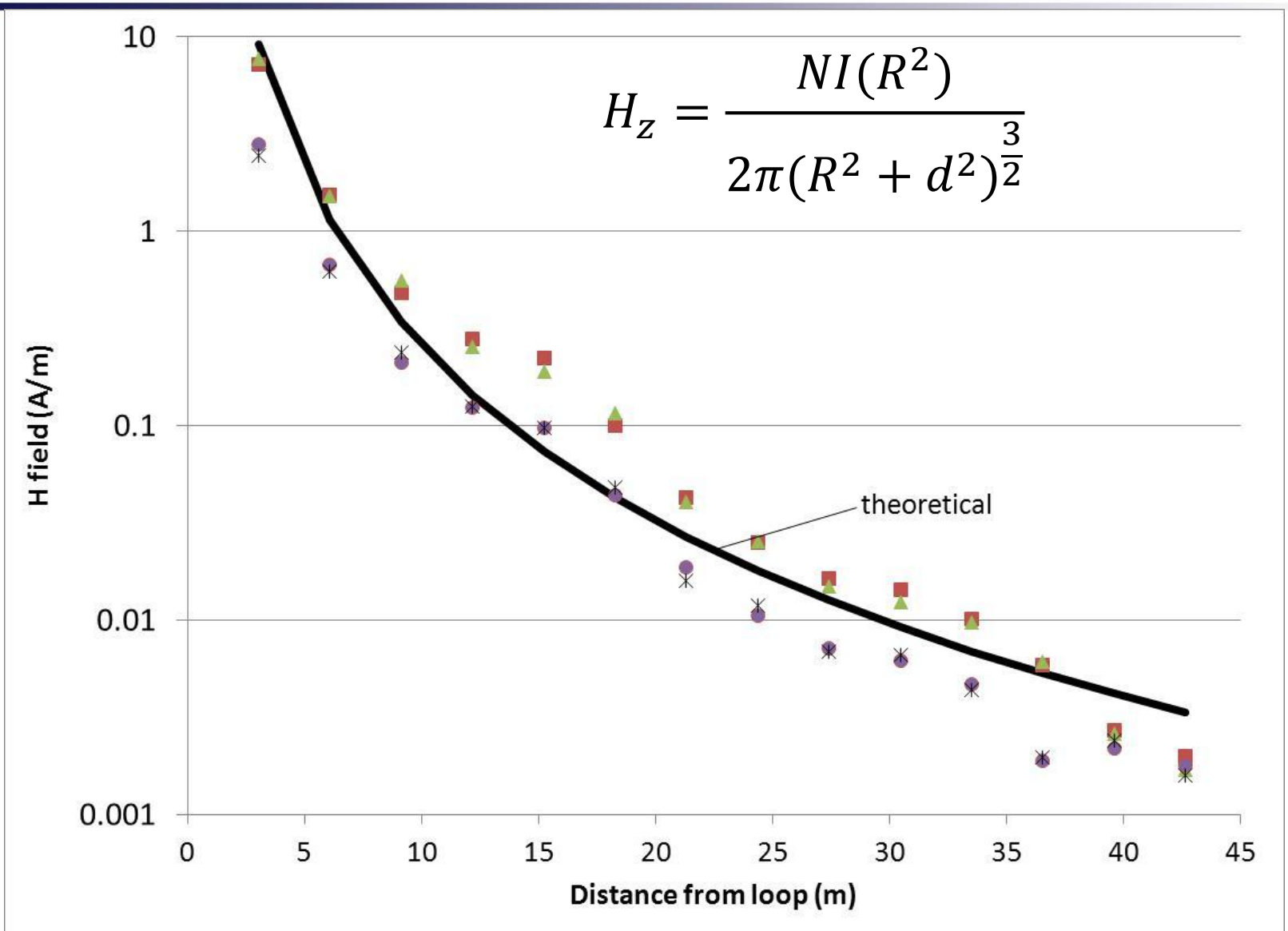
Built two: Tx and Rx

Tx block diagram



Use spectrum analyzer to measure Rx antenna signal

Field Strength in air



1st year TTE Research Summary

- Initial investigation of loop coupling models
- Evaluation of Bureau of Mines TTE data & comparison to models
- Determined/acquired appropriate TTE RF equipment
- Built two TTE loop antennas
- Optimized coupling to antennas
- Measured field from loop in air & compared to prediction
- Preparing for TTE measurements in mines
- Developing more sophisticated models (& continue)

Tracking Research

CDC Workplace Safety and Health
National Institute for Occupational Safety and Health NIOSH

Electronic Tracking Research

Reduced powered infrastructure ➡ more survivable

- Two main areas
  - Inertial tracking
    - Potentially reduced system infrastructure
    - Potentially high accuracy
  - Passive RFID
    - Potentially high accuracy
    - Potentially easy installation

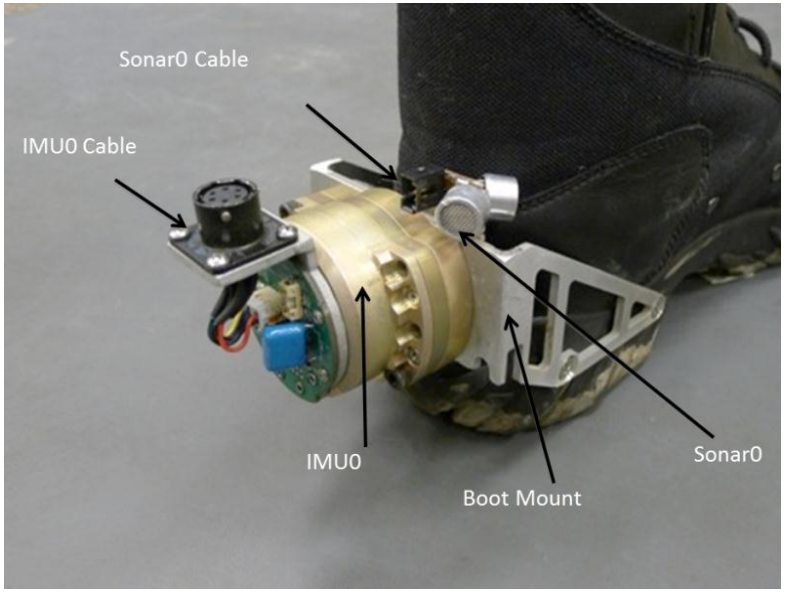
Inertial tracking

- Inertial navigation unit (INU)
- Inertial measurement unit (IMU)
- Sensors
  - Detect linear, and angular acceleration
  - Integrate to get displacement
  - No external reference required (in theory, only need starting location)
- MicroElectroMechanical Systems – MEMS
  - Used in game consoles, automobile air bag systems, guided missiles, aircraft

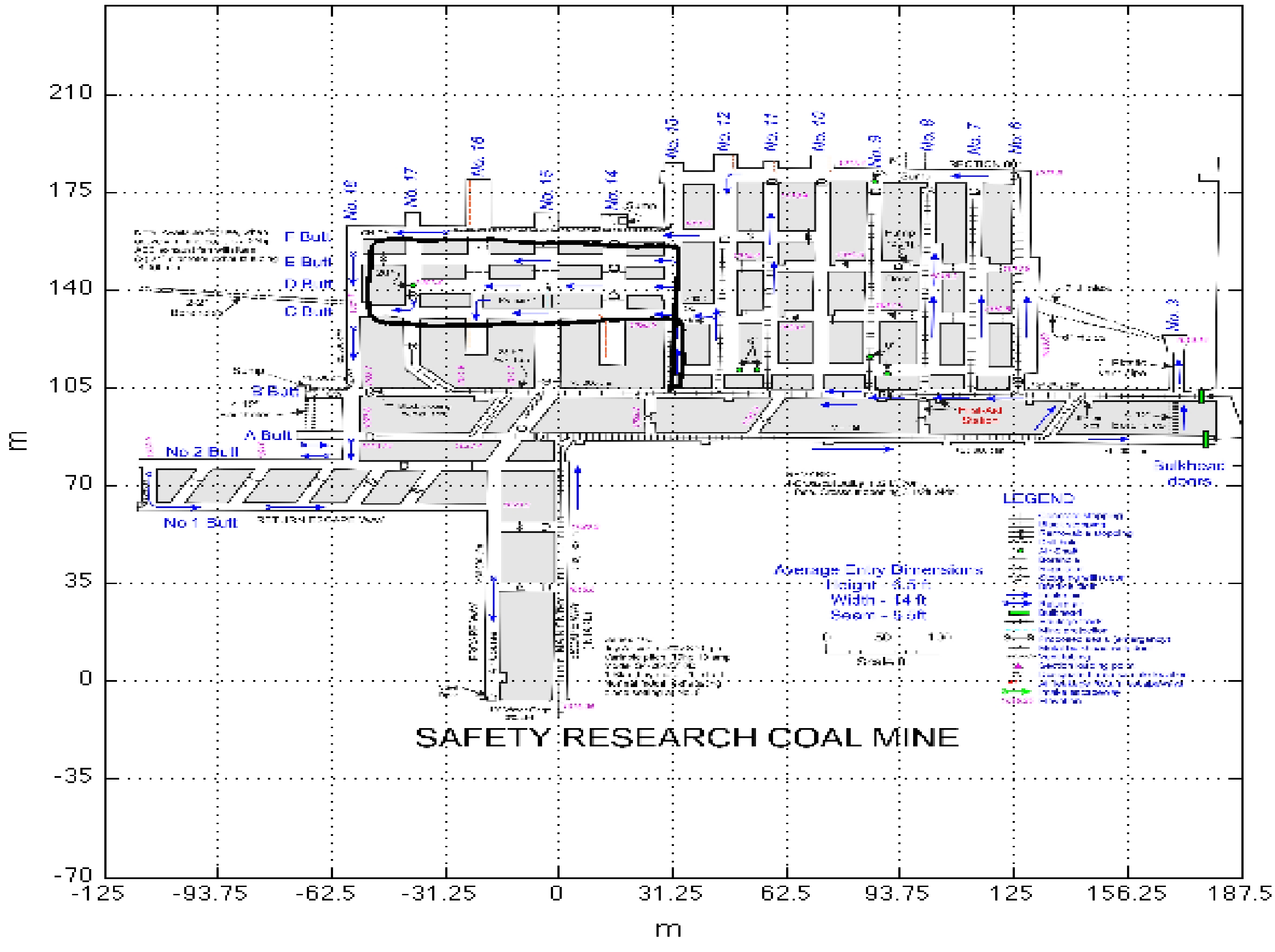
IMU prototype testing

Carnegie Mellon University

- MEMS on boot
- MEMS drift offset
- Multiple sensor data to re-zero IMU
  - Ultrasonic range measurement between boots
  - RFID and readers throughout mine



IMU testing in NIOSH mine



IMU results

- Drift still an issue
- Too much data fusion required
- IMU research expensive & specialized
- Significant commercial (non-mining) interest in improving IMU; especially for GPS denied environments
- NIOSH will continue to monitor progress
- In future, may resolve drift

Passive RFID investigations

- Presently RFID underground uses ‘active’ tags
  - Whether tags are on miner or on mine walls – battery operated
  - To achieve significant read range need active tag
  - Passive has limited read range
- Passive tags
  - Inexpensive
  - Short read range
  - If closely spaced could increase accuracy at low cost
  - Working with Univ of Pittsburgh RFID Research Center
  - Attempt to achieve adequate read range

Presently establishing requirements

RFID reader

passive tag

1st year Tracking Summary

- Investigated several inertial tracking systems
  - Drift still an issue
  - Will monitor commercial progress
- Passive RFID
  - Working with Univ of Pittsburgh RFID Research Center
  - Establishing performance requirements
  - Will procure several systems and evaluate in near future

UHF, MF, TTE, Tracking Research Summary

- Communications research focus is on path loss
- Major initial effort in evaluating equipment for specific frequency range of operation and for required measurements
- Obtained initial measurement data of path loss for each band
- Completed initial modeling efforts in each frequency band
- Near term efforts:
  - Acquire RF data in several mines
  - Enhance models
  - Validate models with measurement data
- Tracking mainly focused on passive RFID

The findings and conclusions in this presentation are those of the authors and do not necessarily represent the views of NIOSH. Mention of company names or products does not constitute endorsement by the Centers for Disease Control and Prevention

Questions?

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