INTELLIGENT FREQUENCY MODULATED CONTINUOUS WAVE (IFMCW) TECHNICAL OVERVIEW

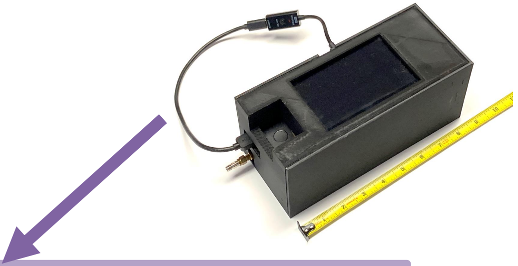
RAM Training Summit XIV

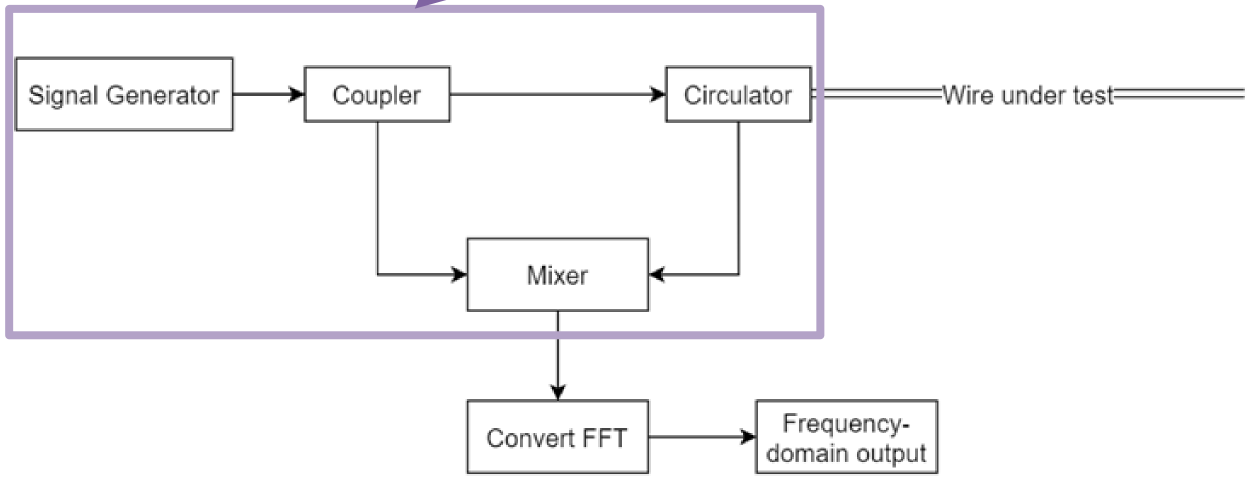
2022-11-01

AVNIK Defense Solutions

- The iFMCW Device
- Time Domain Reflectometry
- Frequency Domain Reflectometry
- Where We Are, Where We Are Going
  – Current lab and prototype states (technology readiness level [TRL] 4)
  – Future plans and designs
- Summary

- Compact cable testing tool
- Detects, locates, and characterizes faults
  - **Uses frequency domain reflectometry (FDR)**
  - Cables tested: Coaxial, CAT5, twisted shielded pairs
- Can replace large and heavy legacy wire checking devices
  - Handheld, lightweight instead of a two man lift
  - Streamlines depot workflow, can be used at all maintenance levels





- iFMCW V1.0
  - Detect, locate, and characterize wire faults
  - Simultaneously detect multiple faults
  - Predictive analytics
  - Smaller form factor (large cellphone)
  - Improved signal

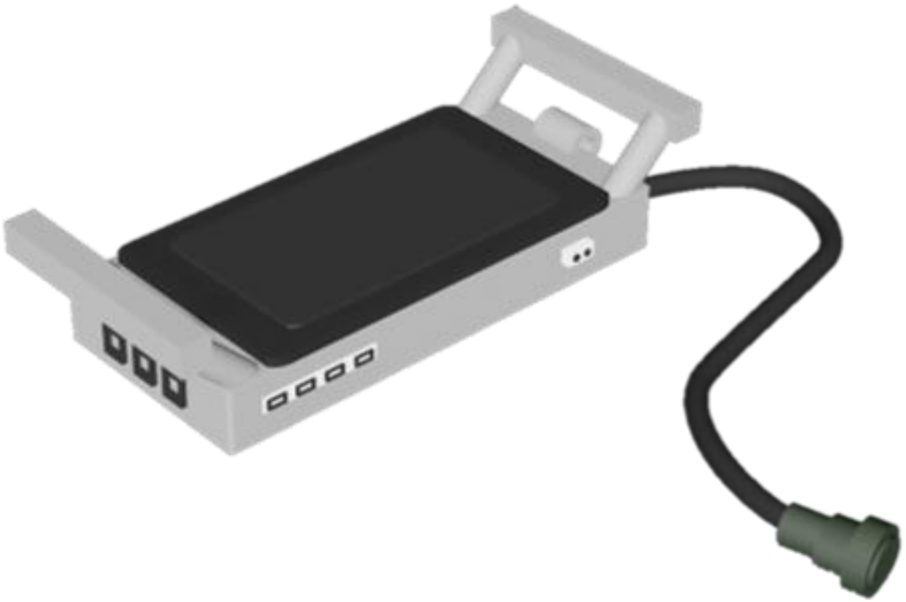


Image depicting proposed design of V1.0 device

- Basic Premise of Operation:
  - Inject a pulsed signal into cable
  - Measure reflection time of faults (on order of nanoseconds)
  - Calculate length (given the velocity factor)
- Harder to distinguish noise from reflections if reflections are small
- High power is required to produce results if noise is overwhelming
- Determining correct pulsewidth for distance measurement and resolution can be difficult
  - Shorter pulse yields higher resolution, but less range and vice versa for longer pulses

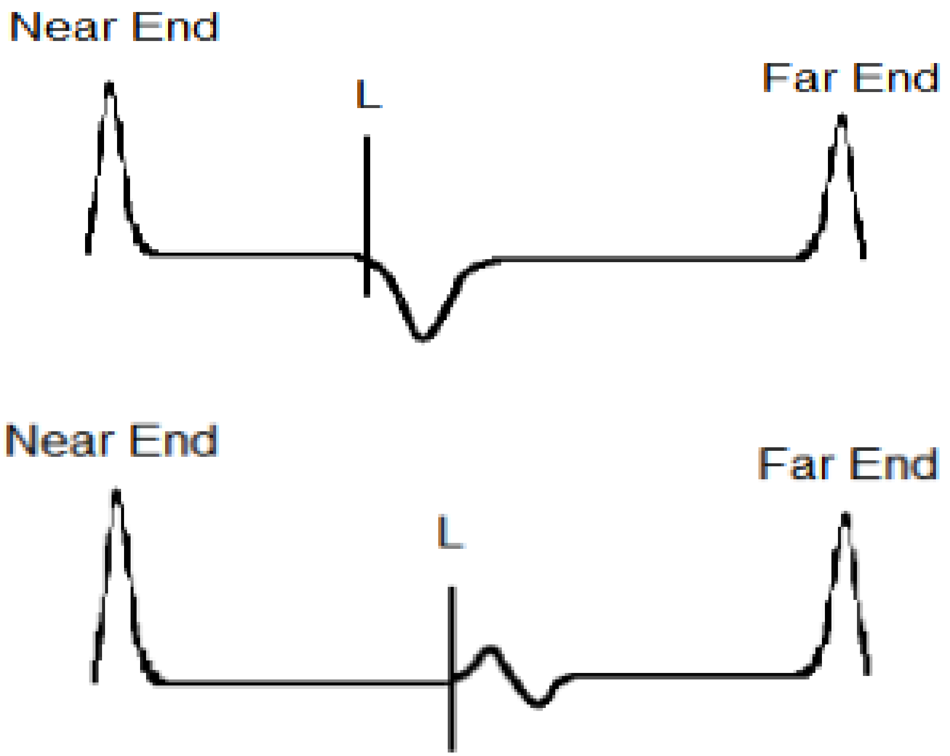
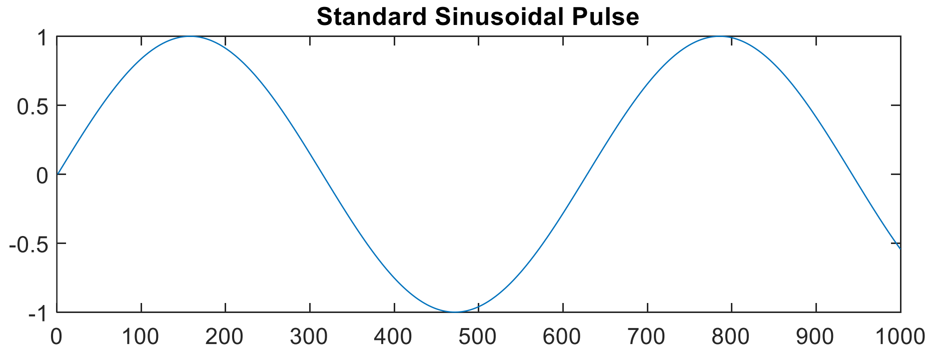


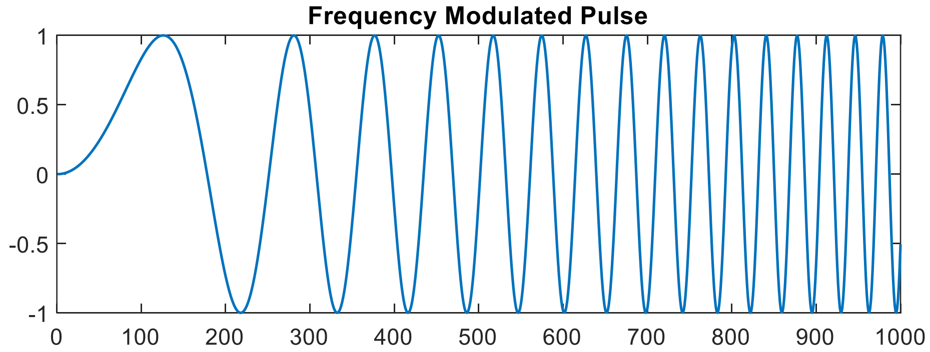
Illustration of interpreted reflections for various cases in TDR

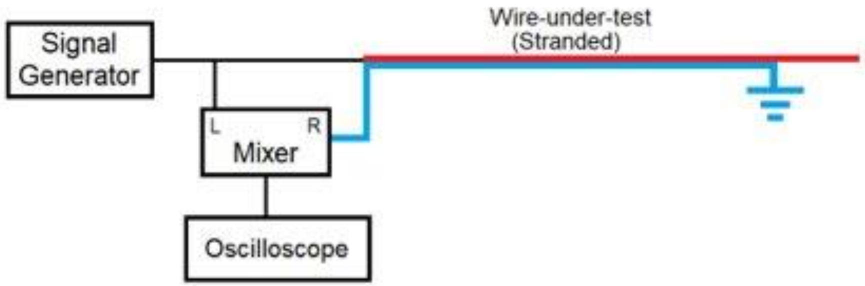
Image: https://www.neetrac.gatech.edu/publications/CDFI/5-TDR_17_with-Copyright.pdf

FREQUENCY DOMAIN REFLECTOMETRY (FDR) OVERVIEW

- Basic Premise of Operation:
  - Injects a linearly frequency-swept pulse
  - Combine reflected signal with baseline signal in mixer
  - Calculate cable length from FFT of resulting data (given the velocity factor)
- Spectral patterns are less susceptible to noise at the same power
- Resolution is a function of the bandwidth







- High Resolution:
  - Resolution is a function of the signal bandwidth
- Mathematical aspect:
  - Initial signal processing relies on fast Fourier transform (FFT) of signal
- Detect various types of interference
- Resistance to noise
  - Higher signal to noise ratio (SNR) is more easily achieved than in TDR
  - FDR encodes information in the frequency domain which is less susceptible to degradation from signal spikes
- Low Power (order of milliwatts)

- Reflection Coefficient Γ is defined as:

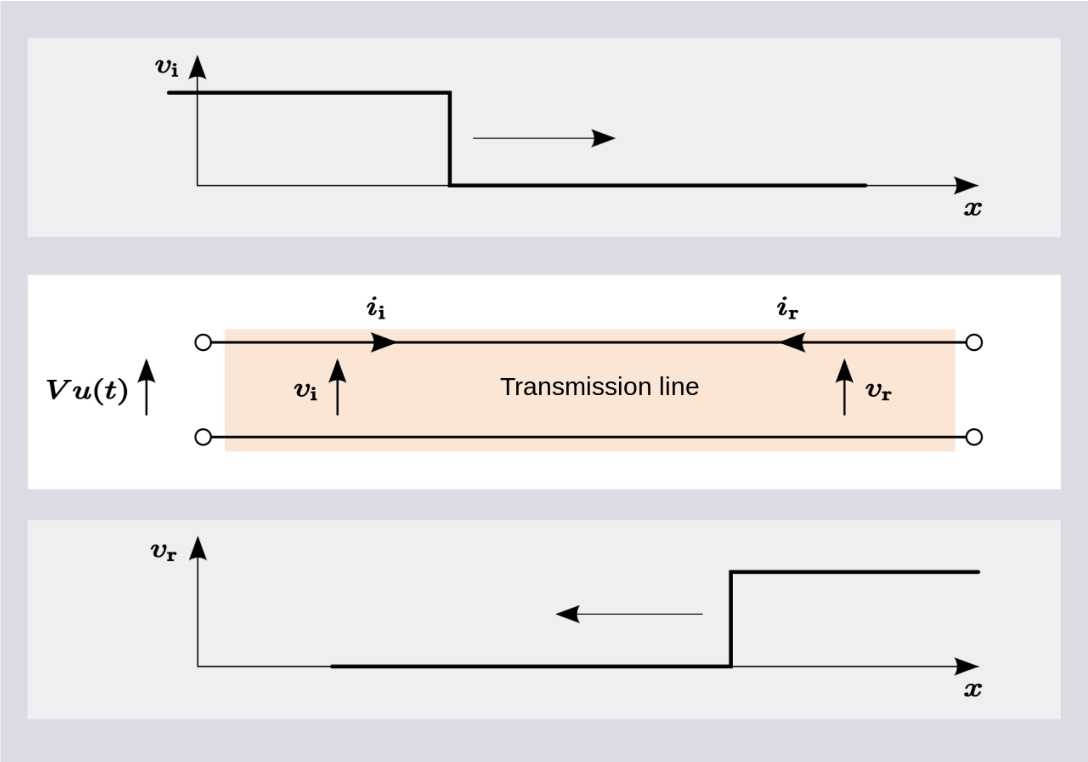
$$\Gamma = \frac{Z_L - Z_O}{Z_L + Z_O}$$

- Imperfections in the cable cause deviations in the characteristic impedance from the expected value of Z_O
- In the simplest cases:

  $\Gamma = 0$ when impedance (i.e. $Z_L = Z_0$).

  $\Gamma = 1$ at open circuits ($Z_L \rightarrow \infty$)

  $\Gamma = -1$ at short circuits ($Z_L = 0$)



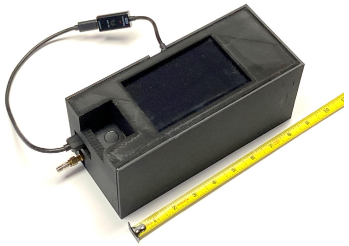
Example: impedance mismatch ($\mathcal{Z} \neq \mathcal{Z}_o$) causes standing wave ratio to become nonzero, causing reflection seen from the left side

Image: https://en.wikipedia.org/wiki/Reflections_of_signals_on_conducting_lines

DEFENSE SOLUTIONS, INC.

WHERE WE'VE BEEN, WHERE WE ARE

- Current V0.1 Handheld Prototype
  - Technological Readiness Level TRL **4**
  - Validation in laboratory environment
- Future V1.0 Handheld Product



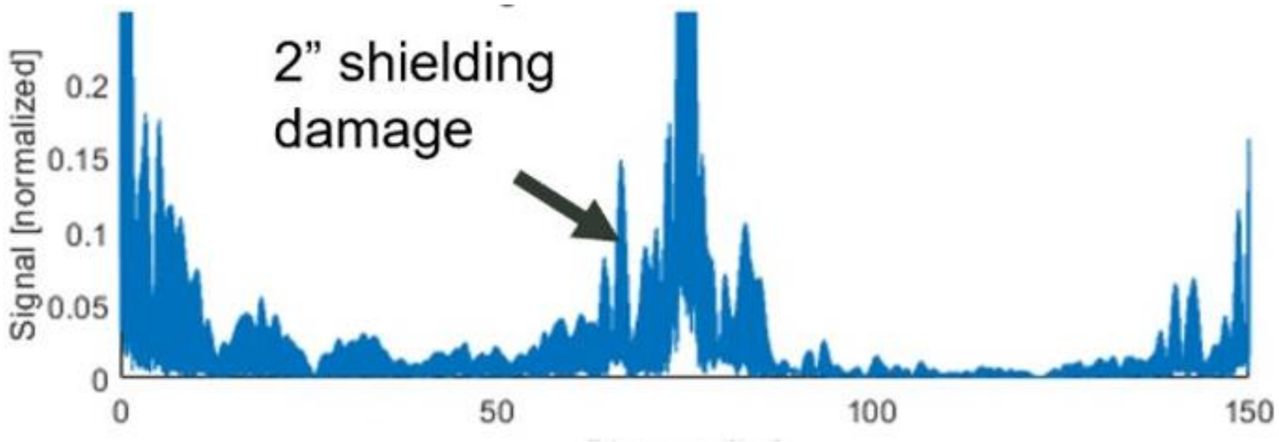
Prototype v0.1

PCB Signal Generator

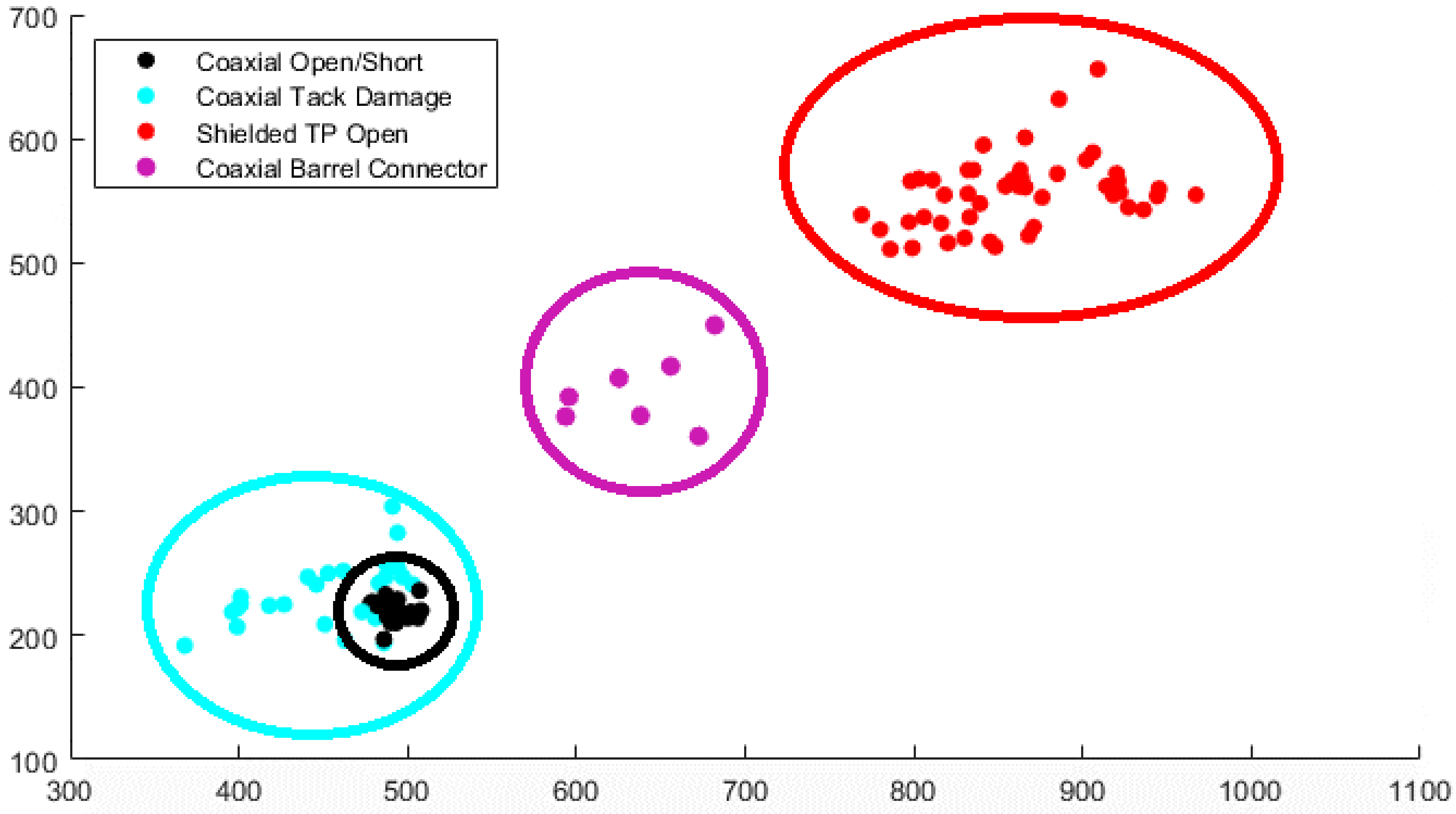
Breadboard Signal Generator

External Signal Generator (HP 63640B)

v0.1
Lab Prototype
• Handheld
• Raspberry Pi
• Batteries only
• Touchscreen
v0.1
PCB Signal Generator Module
• Small
• 9V batteries
• 5V power supply
• Oscilloscope
Pre-v0.1
Breadboard Signal Generator
• Large
• 9V batteries
• 5V power supply
• Oscilloscope
v0.00
Baseline
Laboratory External Signal Generator
• Very large
• AC power
• Oscilloscope

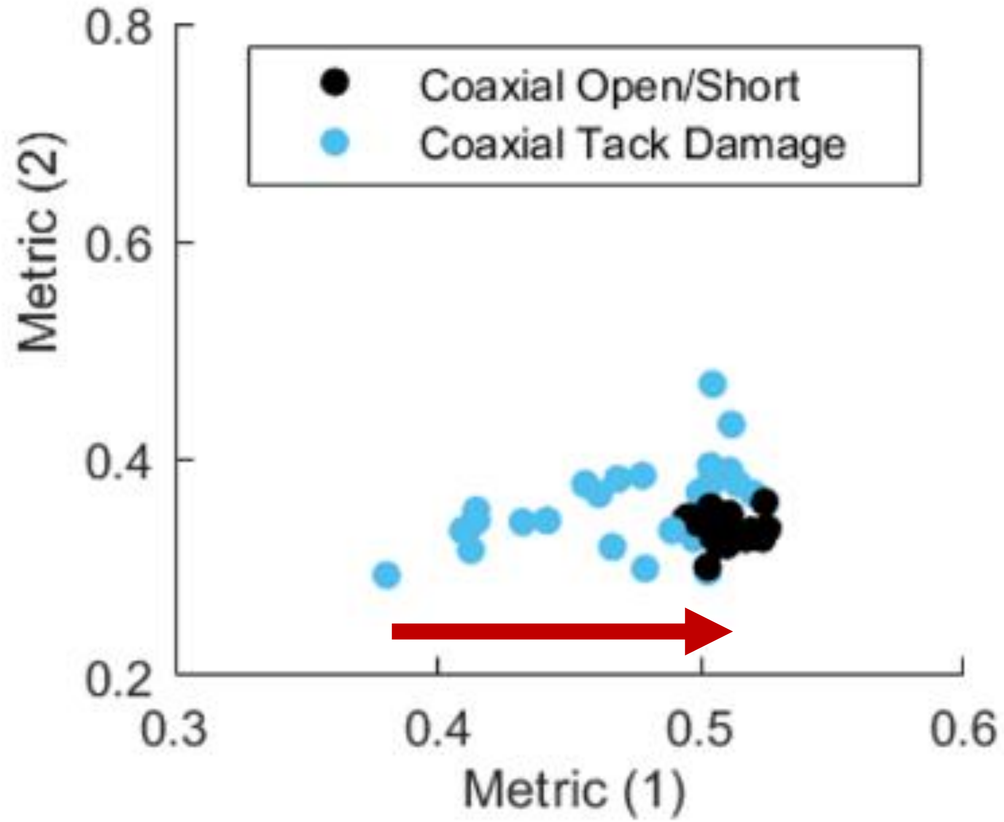


- Achieve better signal fidelity for:
  - Fault detection (>30 dB from noise)
  - Localization
  - Characterization
- Preliminary remaining useful life prediction
  - Mechanical and thermal stresses
- Intermittent and incipient faults: Detection, location, and characterization
- Multiple faults simultaneously
- Transitioning these capabilities to the handheld device

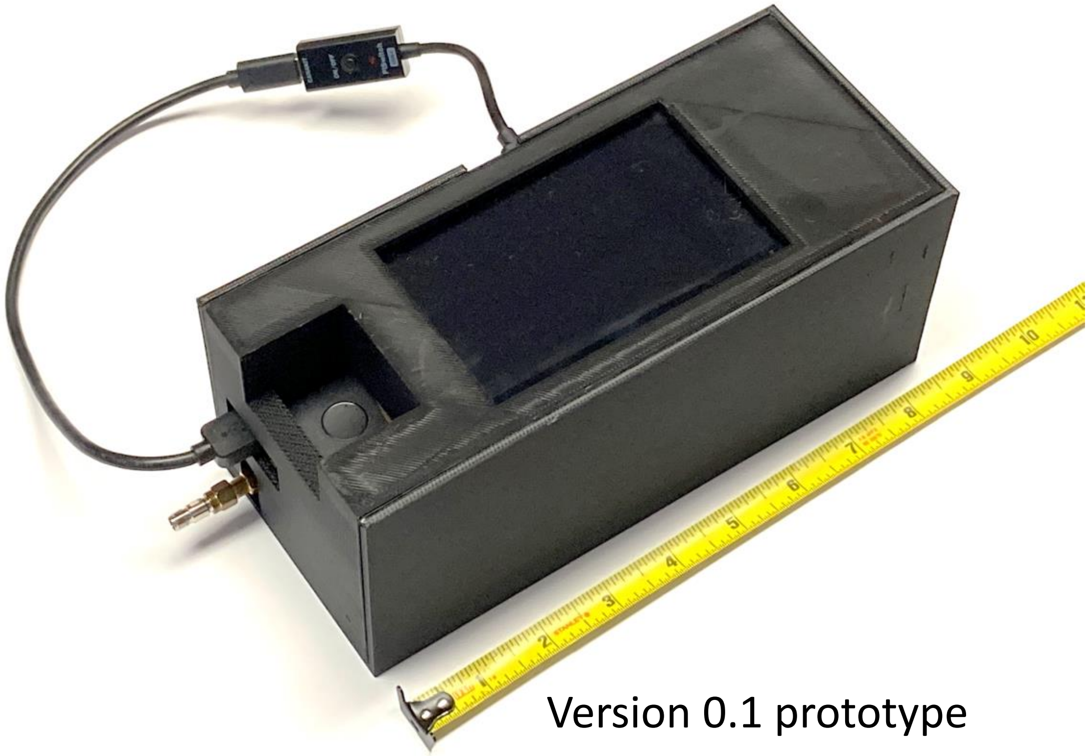


Graph depicting clustering of various fault types based on particular metrics

- The image on the right depicts damage induced by inserting a tack into coaxial cable
- Showcases ability to quantify incipient faults
- Deeper tack insertions migrate from left to right on graph as faults approach complete short (red arrow)
- ***Tack damage is still detectable even after tack removal (not shown)***

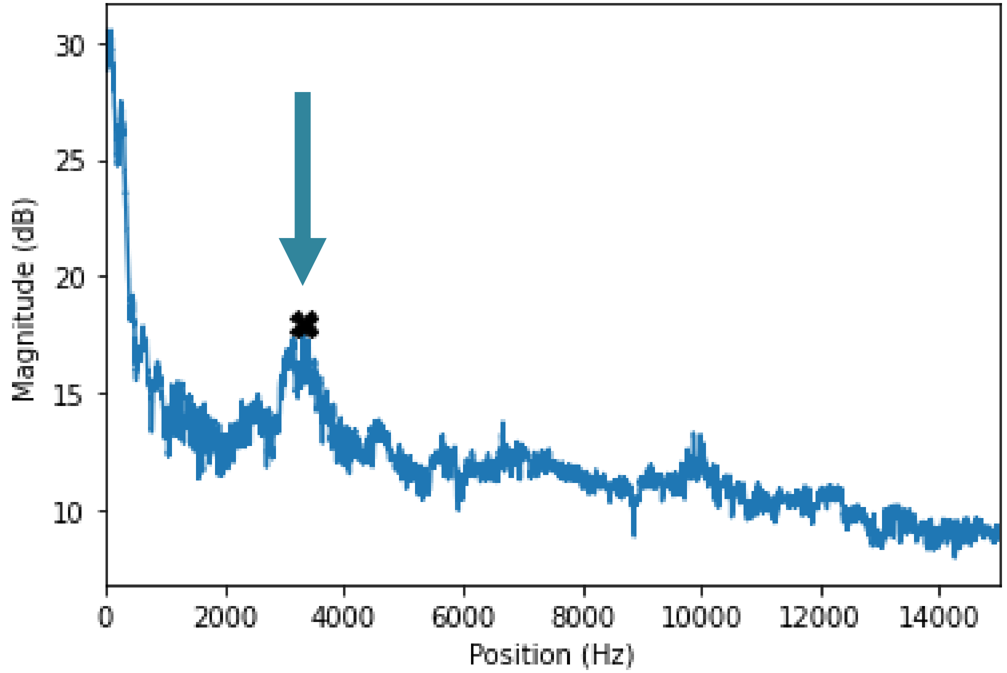


- **iFMCW V0.1** w/FDR Results:
  - Detect and locate faults with accuracy to within 1 inch
  - **Cables Types Tested**: Coaxial, CAT5, twisted shielded pair
- Footprint
  - Hand-held and lightweight
  - 2.19 lbs.
  - 9” × 9” × 5”
  - 4x 9V batteries and power bank



Version 0.1 prototype

- Image depicting V0.1 Prototype data output for the detection of CAT5 cable termination ~5 dB signal above noise
- Lower SNR is due to early stages of development
  - Higher frequency and power components will be added to increase value



80” CAT5 cable termination detected with 3300Hz output

VISION: DEVELOPMENT DIRECTION TO V1.0

- Detect, locate, and characterize multiple faults simultaneously
- Further Characterization Capabilities
  - Open, short, intermittent fault types for more cables
  - Chafing, bending, and other types of mechanical/environmental damage such as corrosion and thermal damage
- Predictive Capabilities
  - Anticipate incipient deteriorating cables
- Smaller Form Factor (< 1/2 current footprint)
  - Currently has a large power bank, 9V batteries powering separate modules
  - Simplification to only one small power supply
- Higher Signal Power into Test Cable
  - Currently only 5 mW
  - Provide higher SNR for faults to detect smaller faults and longer cables

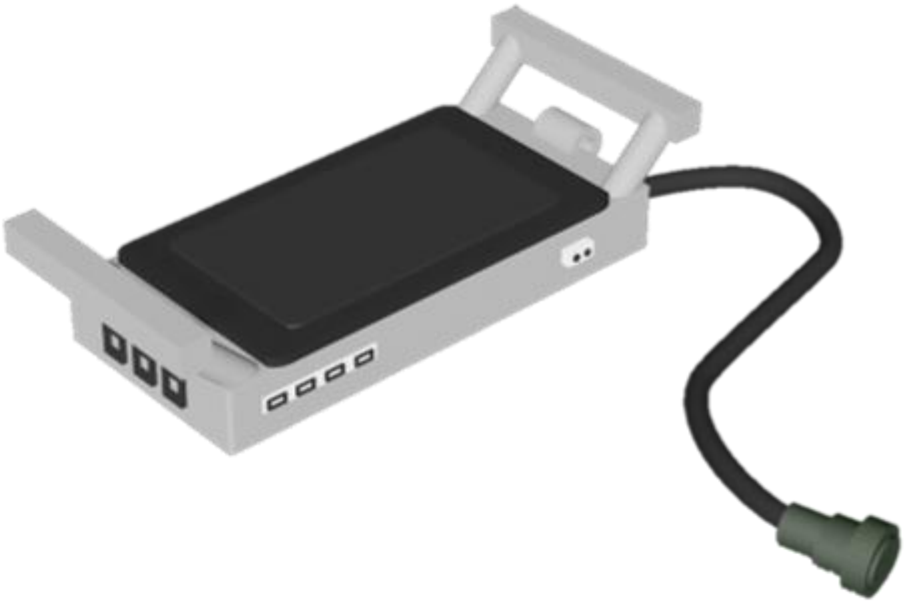


Image depicting proposed design of V1.0 device

SUMMARY

- iFMCW device leverages FDR analysis to detect, locate, and characterize faults
- Handheld
- Low power (< 1W)
- In a lab environment has demonstrated the ability to detect, locate, and characterize a variety of faults on multiple cables
- V0.1 prototype has shown technology can be miniaturized, with further improvements allowing the lab capability integrated into a handheld device

POINTS OF CONTACTS

- Jeff Craven
  jeffery.craven@avnikdefense.com
- Wai Tai Chan
  wai.chan@avnikdefense.com
- Michele Platt
  michele.platt@avnikdefense.com
- Morgan Evans
  morgan.evans@avnikdefense.com
- AVNIK website
  www.avnikdefense.com