CHAR SYSTEM
OPERATION & TRAINING

Module 2
Basic Measurement Theory

AT CONCLUSION OF THIS MODULE, THE STUDENT WILL BE EXPECTED TO:

- Calculate capacitance, inductance, and resistance of basic circuits
- Describe a traveling wave transmission line
- Calculate characteristic impedance
- Calculate velocity of propagation
- Recognize standing wave effects on capacitance measurements

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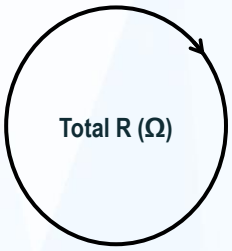
LOOP RESISTANCE

..... is the total series resistance in a circuit



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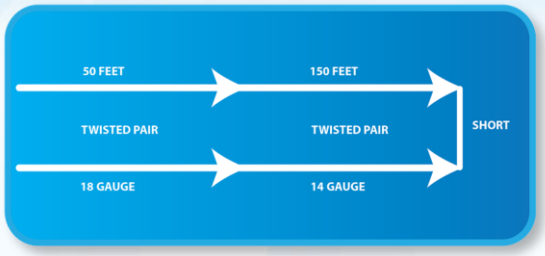
LOOP RESISTANCE OF CABLE TERMINATED IN SHORT CIRCUIT



From wire table 18 gauge: 0.00659 ohms/foot
14 gauge: 0.00258 ohms/foot
(18 gauge wire) + (14 gauge wire)
R= 2 x 50 ft x 0.00659 ohms/ft + 2 x 150 ft x 0.00258 ohms/ft
R= 1.433 ohms total resistance

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CIRCUIT IMPEDANCE

The LCR Meter measures impedance at 100 Hz, 1 kHz, and 10 kHz, calculating:

Rac (AC Resistance)

and

C (Capacitance)

or

L (Inductance)

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CIRCUIT CAPACITANCE

- Capacitance is Linear for parallel plates:
  C = 8.854 A/D picoFarads
  A = area of plate, meters
  D = separation between plates, meters
- Capacitance is NON-Linear for parallel wires:

$$C = Ln\frac{27.8}{\frac{D}{r}}$$ picoFarads/meter (D>>r)

D = Conductor Separation, cm

r = conductor radius, cm

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CONDUCTOR SEPARATION

- The TDR and FDR will show a capacitive change. This can be seen with cable going from conduit to cable tray, and changes within a multiple conductor cable, and moisture intrusion.

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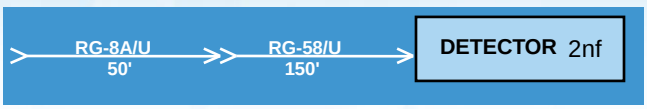
DETERMINING TOTAL CAPACITANCE OF A CIRCUIT



RG-58/U = 28.8 pF/ft x 150 ft = 4320 pF

RG-8A/U = 29.8 pF/ft x 50 ft = 1490 pF

Detector = 2000 pF

Total = 7810 pF

(Obtain cable capacitance by measuring sample or from mfg's specifications)

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SAMPLE APPLICATIONS

- Capacitance calculations can be used for verification of the presence of moisture in a cable
- Typically used for verification of the condition of nuclear instrumentation (NI) detectors

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DETERMINING TOTAL CAPACITANCE OF A CIRCUIT

- The cable manufacturer provides the unit resistance and capacitance per foot for the cable
- By determining the length of the field cable and multiplying this length by the capacitance per foot, you can calculate the total cable capacitance
- The detector manufacturer provides the capacitance of their detector

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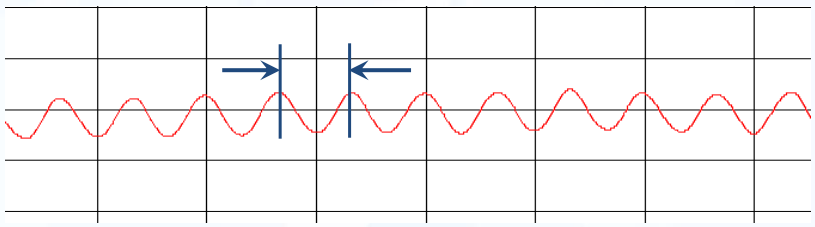
WAVELENGTH

Wavelength is the distance between identical points on a periodic signal



To calculate wavelength:

$$\text{Wavelength} = \frac{\text{Velocity of Propagation (Meters/Sec)}}{\text{Frequency (Hz)}}$$

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WHEN MEASUREING IMPEDANCE OF LONG CABLES (> 1,000 FT)

- Consider cable length
  - To prevent radiated emissions, cable length must be < 1/8 signal wavelength
- CHAR System measures capacitance at 100 Hz, 1 kHz, and 10 kHz.
  - Wavelength @ 100 Hz = 6,481,728 ft
  - Wavelength @ 1 kHz = 648,172 ft
  - Wavelength @ 10 kHz = 64,817 ft

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FREQUENCY vs. WAVELENGTH

Frequency may affect capacitance:

- If the cable is long.
- If the frequency is high.

Line resonance is not a problem if the cable length is less than 5% of the wavelength.

– Critical frequency is 10kHz, so 5% of the wavelength is 3,241 ft.

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RESONANT CIRCUIT

Reactive loads at the end of a line may create a resonant circuit even on short transmission lines – this may create errors.

$$F_r = \frac{1}{2\pi\sqrt{LC}} = \text{resonant frequency}$$

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TIME DOMAIN REFLECTOMETRY (TDR) FREQUENCY DOMAIN REFLECTOMETRY (FDR)

- TDR/FDR is used to locate circuit problems
- Operator needs to understand where reflectometry signal is traveling
- Operator needs to understand limitations of TDR/FDR testing
  - Over 4 kΩ looks like an open to TDR

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GENERAL DESCRIPTION OF REFLECTOMETRY (TDR/FDR)

- A measurement technique that sends a traveling wave down a radio frequency transmission line
- The signal is guided between the two conductors, and the reflections are observed to determine the integrity of the transmission line.
- The reflections are caused by changing circuit parameters along the transmission line, i.e., impedance and permittivity
- Any two adjacent conductors, separated by a dielectric, have the capability to guide a traveling wave

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GENERAL DESCRIPTION (CONT'D)

- The cable dielectric will determine the speed of the traveling wave and the losses of the traveling wave
- The surface resistance and incremental capacitance and inductance of the transmission line will affect the losses of the traveling wave
- Maximum speed of the traveling wave would be the speed of light in an air dielectric
- Distance between reflections along the transmission line is determined by measuring the time delay between points
- Frequency Domain Reflectometry (FDR) is more sensitive than TDR to changes in dielectric permittivity that correspond to thermal and radiation aging

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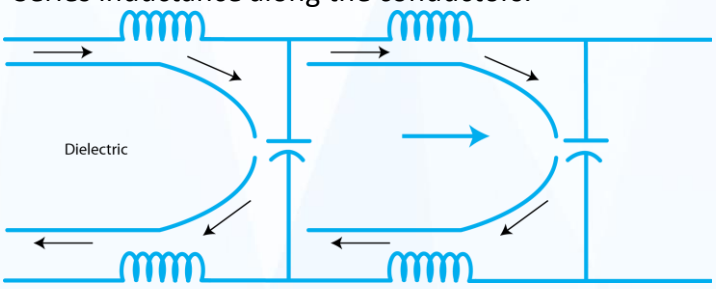
TDR/FDR USES GUIDED WAVE OF ENERGY

As energy moves down the line, it is impeded by losses to the incremental inductance and capacitance.

- Parallel capacitance between the conductors
- Series inductance along the conductors.



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GUIDED WAVE TRANSMISSION LINE

- Consists of two conductors separated by a dielectric
  - Coaxial cable or triaxial cable
  - Parallel insulated conductors
  - Insulated conductor over a ground plane or in conduit
- Also called Radio Frequency or RF transmission line

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CHARACTERISTIC IMPEDANCE

Characteristic Impedance:

- What the line looks like to the guided wave of energy
- What the guided wave would see if the line were replaced with a resistive load
- Ratio of Voltage to Current on infinitely long transmission line

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VELOCITY OF PROPAGATION

A traveling wave travels in a cable at a velocity determined by L and C of the dielectric.

$$Vp = \frac{1}{\sqrt{LC}}\ meters/sec$$

Where L is the inductance per unit length and C is the capacitance per unit length.

If the wave is traveling across an air dielectric, it will travel at the speed of light.

$V_c \approx 3 \times 10^8$ meters/sec

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RELATING VELOCITY OF PROPAGATION TO DIELECTRIC

Material	Relative Dielectric	Velocity of Propagation (ft/nS)
Air	1.0	1.0
Polypropylene	2.25	0.667
Water	81	0.111

Velocity of Propagation can range from 0.2 (mineral filled cable) to 1.0 (AIR) in feet per nanosecond.

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APPLICATION OF TDR/FDR

- Measure reflection coefficients
- Determine the characteristic impedance of a cable
- Measure transmission line delay
- Recognize the difference between resistive and reactive transmission line discontinuities
- Trend changes in dielectric permittivity

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REFLECTION COEFFICIENT

$$\rho_V = \frac{Z_T - Z_C}{Z_T + Z_C}$$

Z_T = Termination (load) impedance

Z_C = Cable (source) impedance

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SAMPLE REFLECTION CALCULATION

Using equation:

$$\rho_V = \frac{Z_T - Z_C}{Z_T + Z_C}$$

$$rho = \frac{(76.58\ ohms\ - 50\ ohms)}{(76.58\ ohms + 50\ ohms)}$$

$$rho = \frac{(26.58\ ohms)}{(126.58\ ohms)}$$

$$rho = 0.21 \text{ (unitless ratio)}$$

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CALCULATE CABLE LENGTH

Cable Length = Time Delay multiplied by velocity of propagation

For example:

- L(ft.) = TD (nS) x Vp (ft./nS)
- L(ft.) = TD (100 nS) x Vp (0.67)
- L = 67 feet

TD = Time Delay (read from TDR) (1/2 round trip time)

TD = 200 nS/2 = 100 nS

(Vp = Velocity of Propagation for the cable tested)

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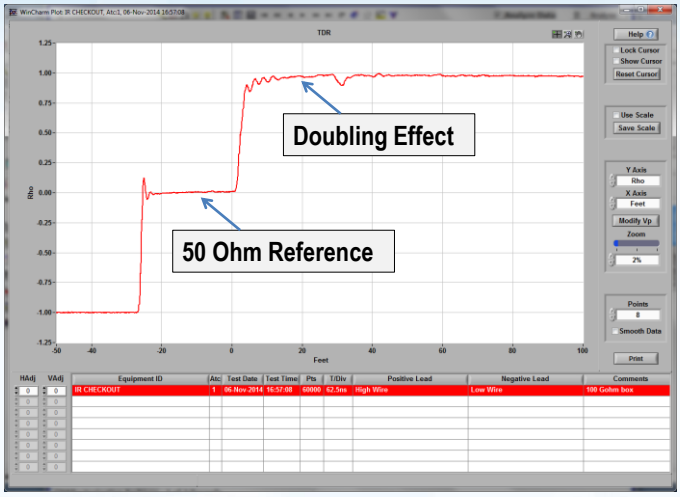
TDR/FDR REFLECTION WILL DOUBLE AT AN OPEN CIRCUIT MEASUREMENT



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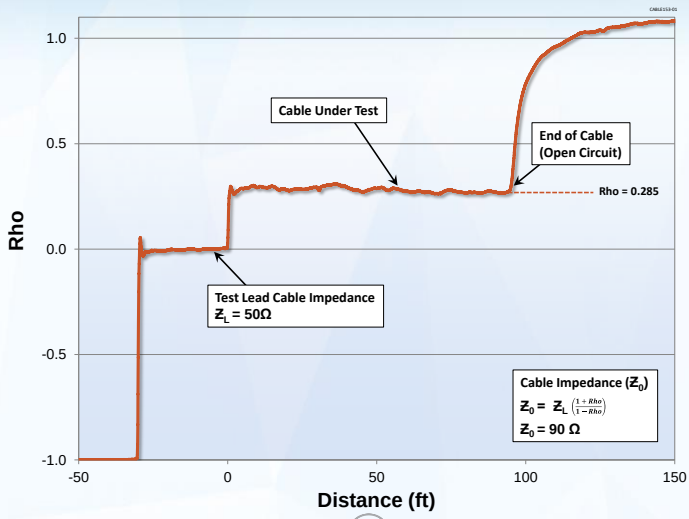
CALCULATING REFLECTION COEFFICIENT AND LOAD IMPEDANCE



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SAMPLE CALCULATION FOR IMPEDANCE

Use formula:

$$Z_T = Z_C\left(\frac{1+\rho_V}{1-\rho_V}\right)$$

Z_T = (50 ohms) * (1 + 0.285) / (1 – 0.285)

Z_T = (50 ohms) * 1.285 / 0.715

Z_T = 50 ohms * 1.797

Z_T = 89.86 ohms

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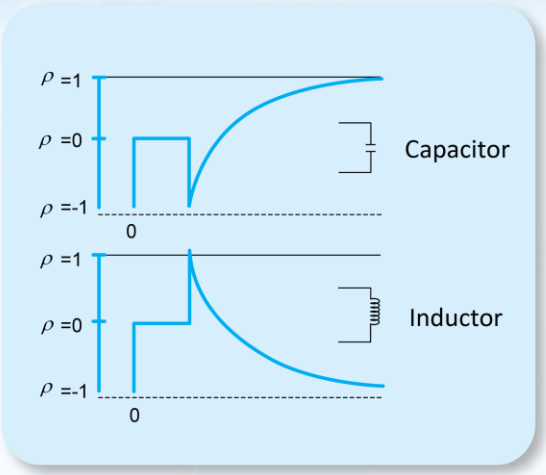
REACTIVE LOAD REFLECTIONS



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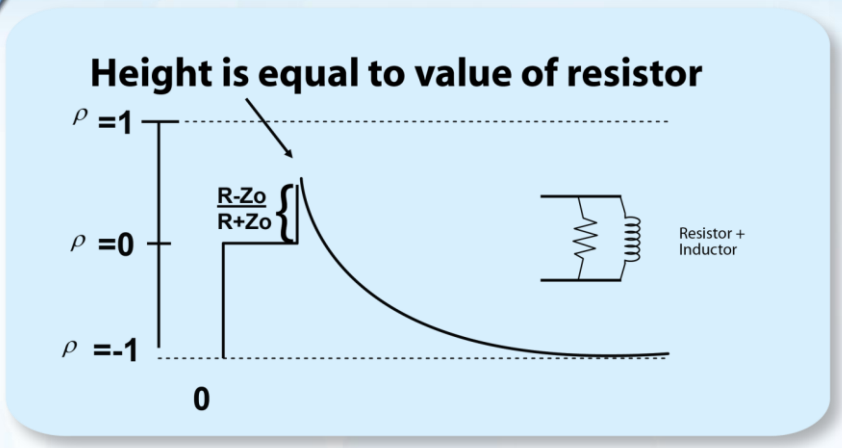
METHODS TO RESOLVE COMPLEX REFLECTIONS (CONT'D)



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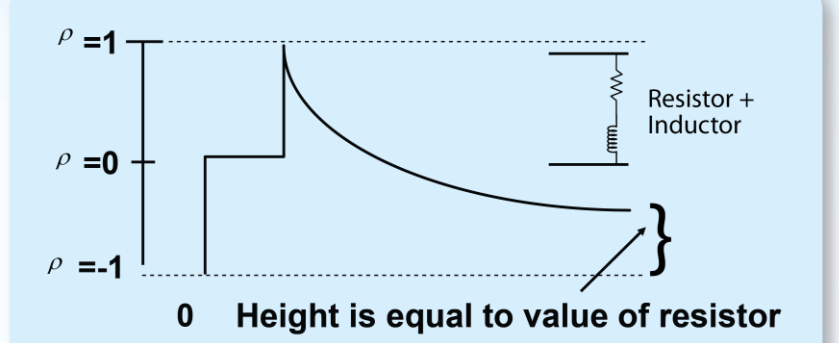
METHODS TO RESOLVE COMPLEX REFLECTIONS (CONT'D)



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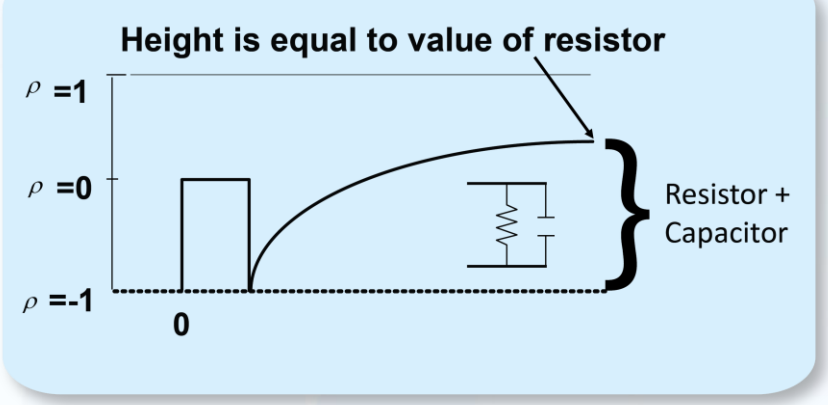
METHODS TO RESOLVE COMPLEX REFLECTIONS (CONT'D)



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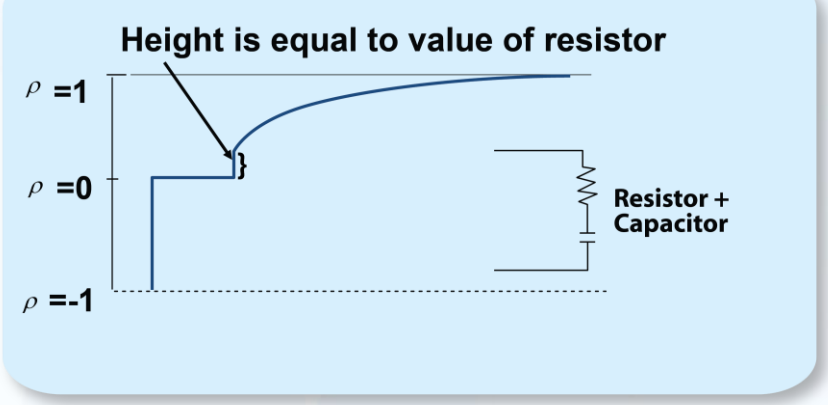
METHODS TO RESOLVE COMPLEX REFLECTIONS (CONT'D)



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ANALYZING CHAR TDR DATA

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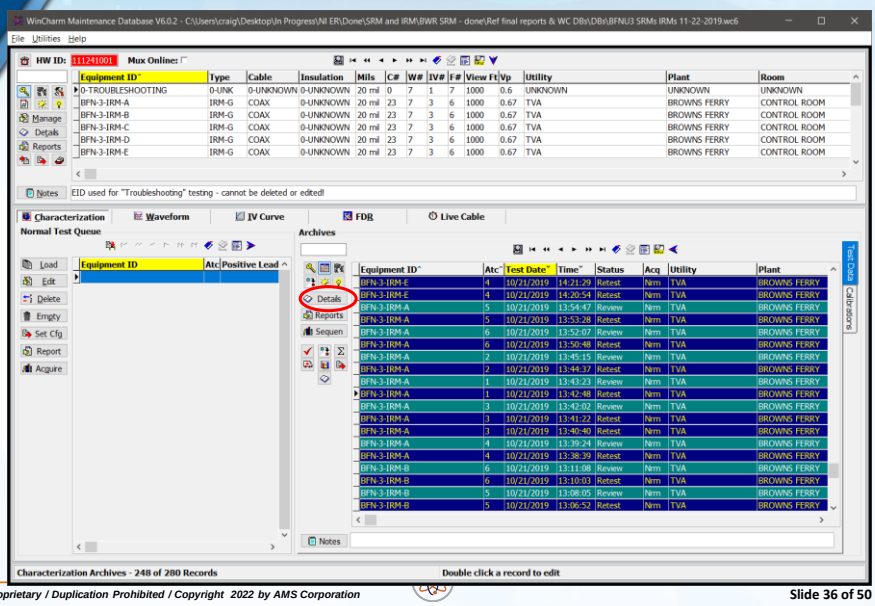
TO DISPLAY THE TDR PLOT, IN ARCHIVES, SELECT "DETAILS" TO SHOW PLOT



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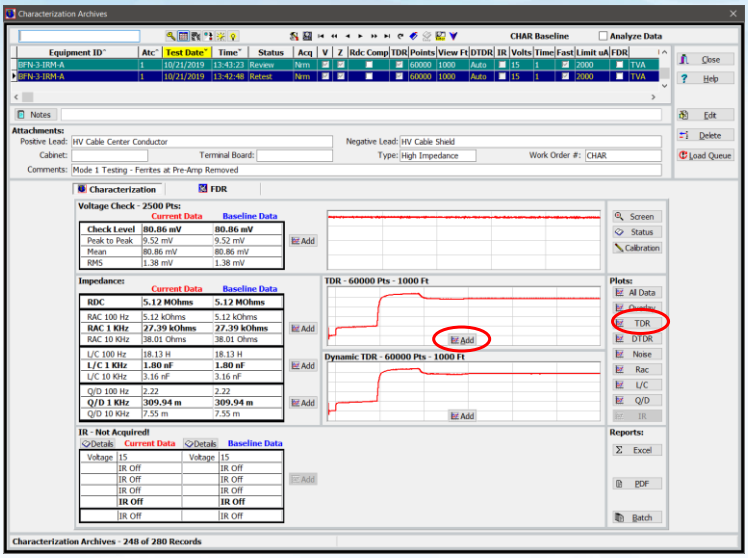
NOW SELECT "TDR" TO DISPLAY TDR PLOT



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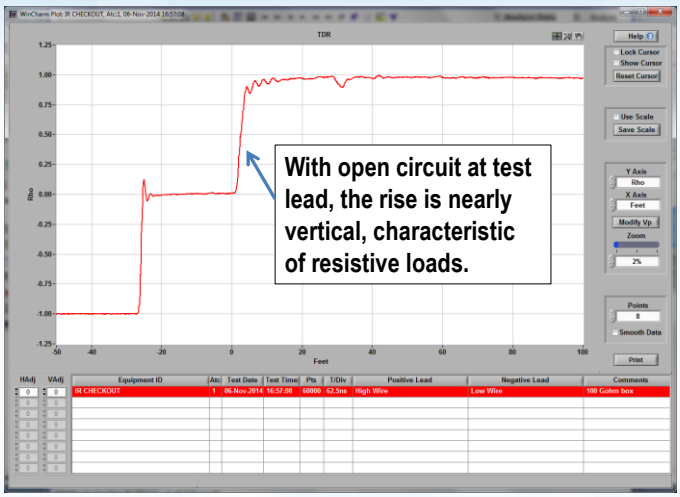
TDR PLOT DISPLAYED



With open circuit at test lead, the rise is nearly vertical, characteristic of resistive loads.

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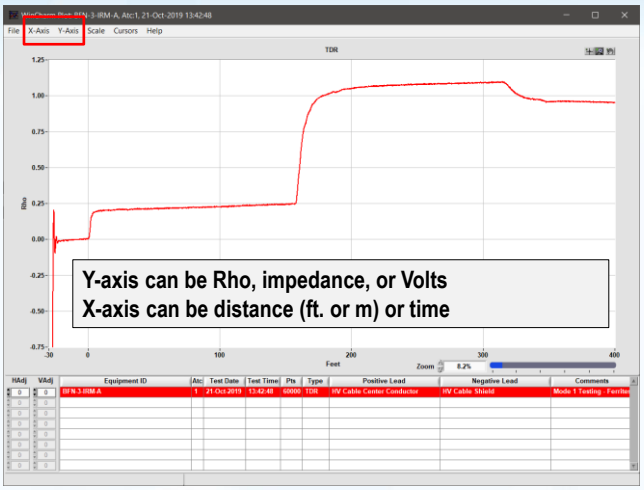
TDR PLOT CAN BE DISPLAYED IN DIFFERENT FORMATS



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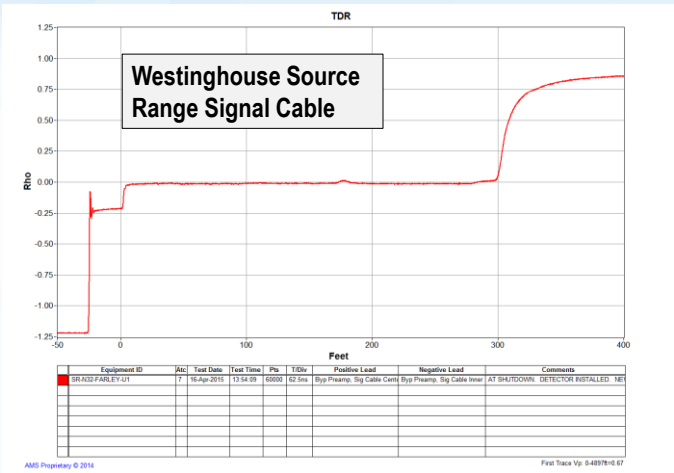
HOW MANY CHANGES IN REFLECTION ARE IDENTIFIED FROM THIS PLOT?



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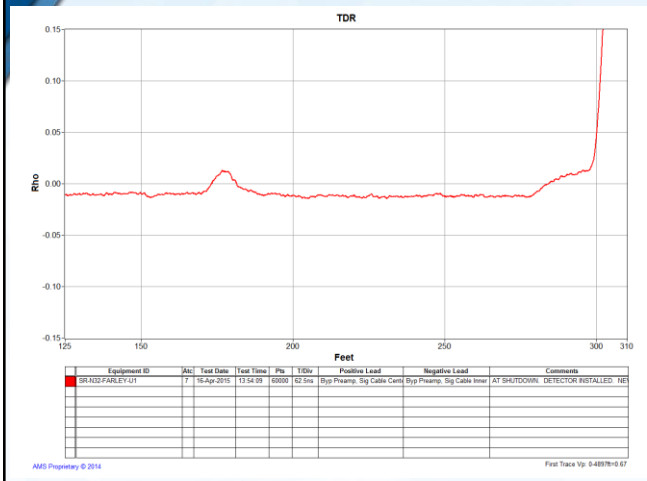
SAME TDR PLOT, BUT ZOOMED IN



Identify:

1. Preamp (Bypassed)
2. Outboard Penetration
3. Inboard Penetration
4. Mineral Insulated Cable
5. Detector

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ANALYZING CHAR FDR DATA

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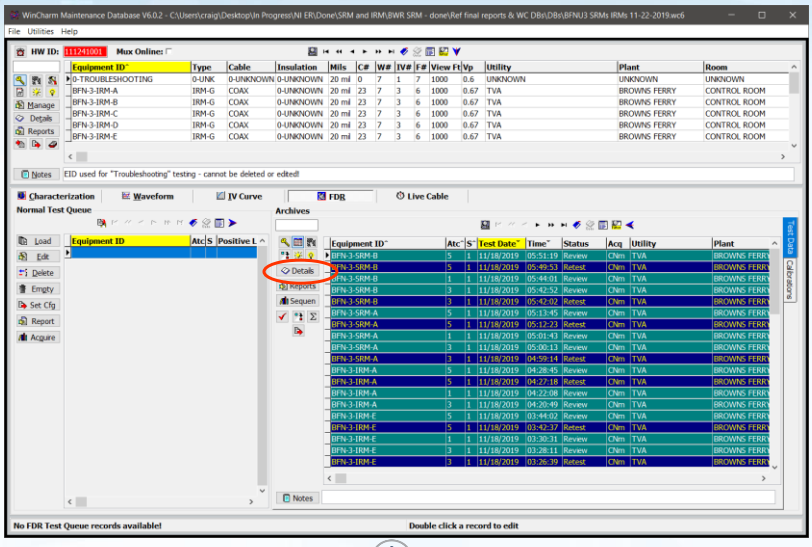
TO DISPLAY THE FDR PLOT, IN ARCHIVES, SELECT "DETAILS" TO SHOW PLOT



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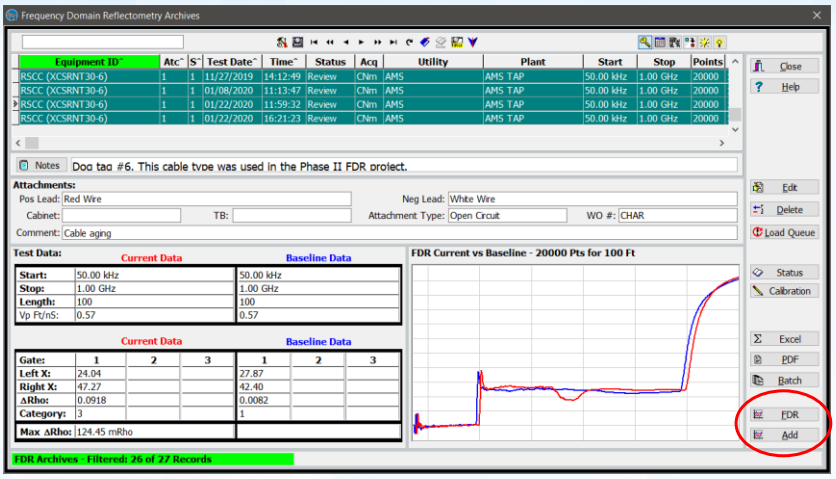
NOW SELECT "FDR" TO DISPLAY FDR PLOT



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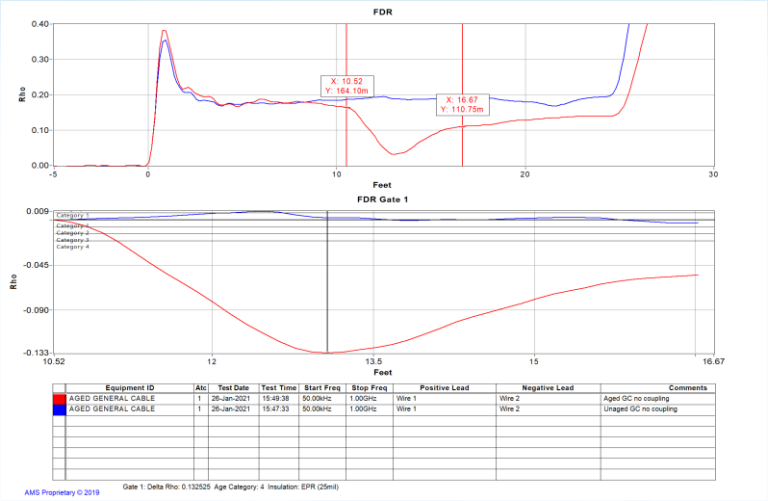
FDR PLOT GATING FEATURE



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REVIEW AND QUESTIONS??

- What are limitations of the reflectometry test?
- What can the TDR tell you?
- What can the FDR tell you that TDR cannot?
- Where can you find the cable information?
- Is it necessary to perform all the hard calculations?
- Can you determine the approximate resistances or characteristics?

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LAB EXERCISE

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LAB EXERCISE

Configure CHAR System for TDR

- Objectives:
  - Calculate cable impedance
  - adjust velocity of propagation to match cable length
  - understand time base adjustments on TDR plot
- Each group will perform the exercises in Lab Procedure

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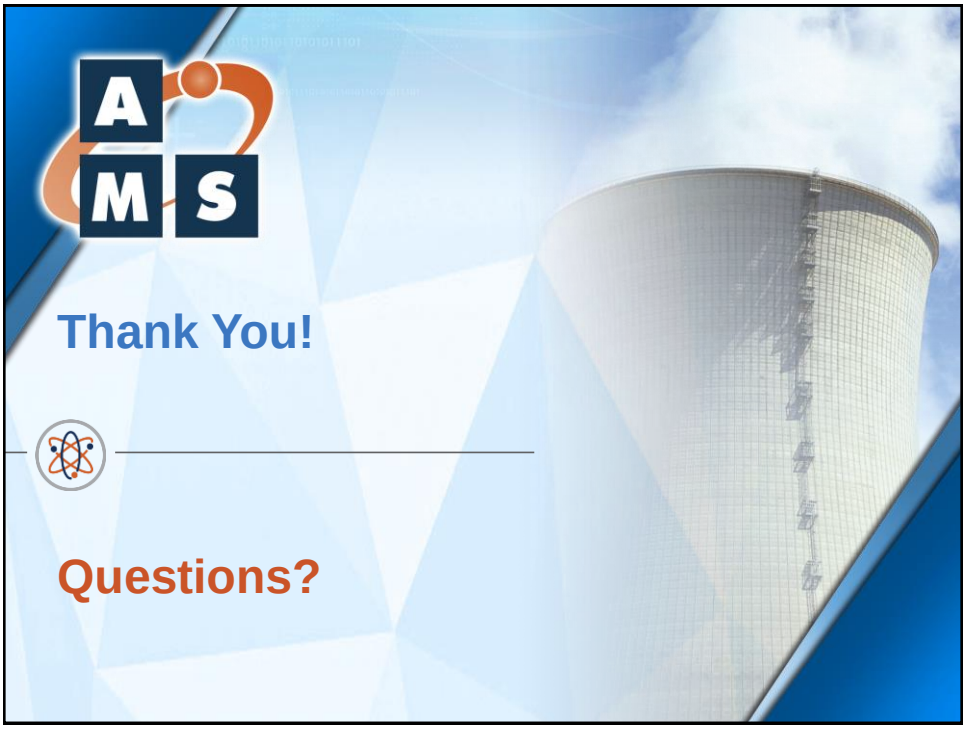
Thank You!
Questions?