ECAD Testing

Case Histories

Circuit Degradation

- Prolonged exposure to heat, moisture, and chemicals can degrade insulation quality.
- Breakdown may occur within the circuit's cables, connections, or end device.
- Degradation – heat stress, moisture intrusion, corrosion, loose connections, and failed splices.

Heat Stress

May change the physical properties of the insulating material.

- Embrittled Insulation
- Dielectric Constant Changes
- Impedance Changes
- Low IR, low DAR

Moisture Intrusion

- Dielectric Constant Changes
- Impedance Changes
- Low IR, low DAR

Capacitance ($C=K\varepsilon o(A/d)$)

K= dielectric constant, εo = permittivity, A = plate area, d = distance between plates.

K values: Air = 1, Polyethylene = 2.3, Rubber = 3, Water = 81

Corrosion / Failed Splices / Loose Connections

- Increased Loop Resistance
- High Impedance
- Low IR, low DAR (some cases)

Key Electrical Measurements

- Impedance (Z)
- Time Domain Reflectometry (TDR)
- DC resistance (loop checks)
- Insulation Resistance (IR)
- Dielectric Absorption Ratio (DAR)
- Polarization Index (PI)

Impedance Measurements

- Phase Angle (θ)
- Impedance (Z)
- AC Resistance (R)
- Reactance (X)
- Capacitance (C)
- Dissipation Factor (DF)
- Inductance (L)
- Quality Factor (QF)
- Frequency measurements = 100 Hz to 40 kHz
- Referred to as "Lumped" impedance data

Formulas

We acquire impedance and phase angle.

Resistance $R = Z(\cos\theta)$

Reactance $X = Z(\sin\theta)$

Impedance $Z = \sqrt{R^2 + X^2}$

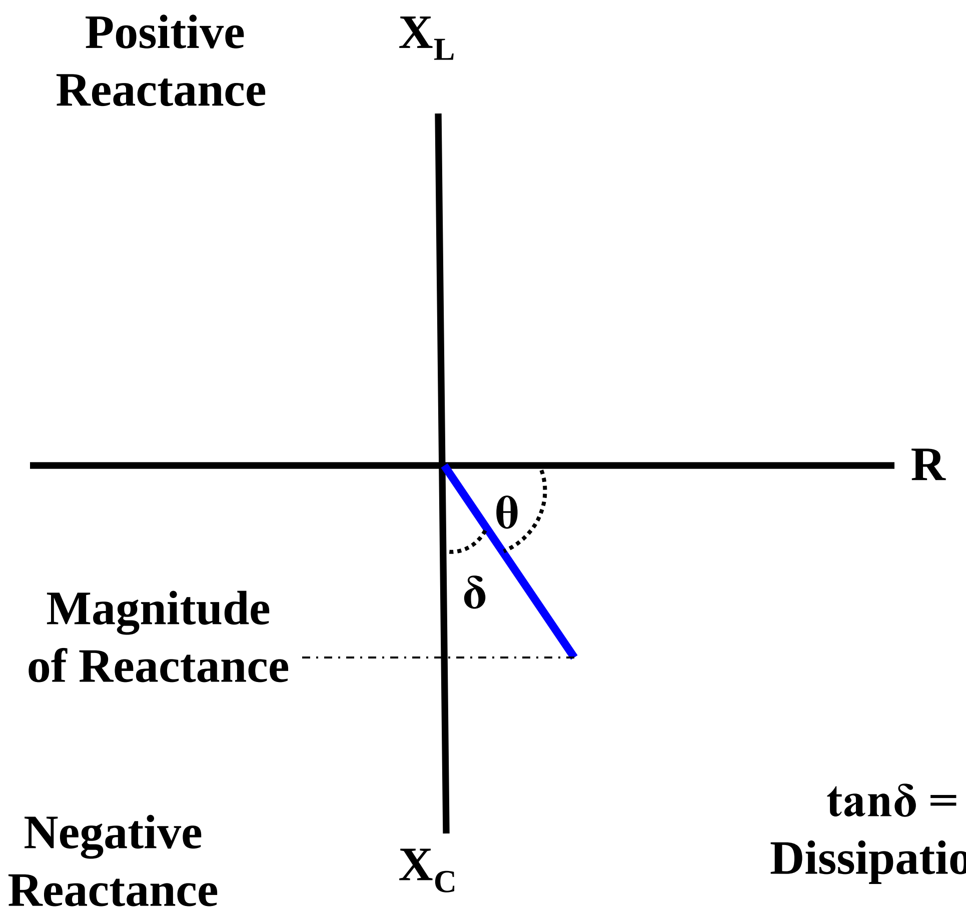
Capacitance $C = -1/X(2\pi F)$

Inductance $L = X/2\pi F$

Dissipation Factor $DF = R/X$

Quality Factor $QF = X/R$

Impedance Vector



tanδ = R/X = Dissipation Factor

DF = R/X

- **Resistive Connections.**

  Circuit reactance (Xc) approaches R with increasing frequency.   With small changes in R (connection anomaly), the DF rate of change is greater at higher frequencies.

- **Moisture Intrusion.**

  Reactive (Xc) component is typically very large at lower frequencies. Circuit reactance (Xc) approaches R with increasing frequency. The addition of a small amount tends to reduce the reactive component, whereas the DF rate of change is greater at the lower frequencies.

TDR

- Cable Radar
- Fast risetime pulse propagated down the line (cable)
- Impedance variations greater or less than the source impedance reflects part or all of the TDR energy back to the source
- Characteristic impedance ($Zc = \sqrt{L/C}$), the measure of resistance to the electrical current, is simply the impedance the TDR pulse sees at every point down the line.
- Measured in ohms, based on reflection coefficient (rho)
- TDR is the “distributed” impedance data
- Graphically displays “lumped impedance” distributed over the length of the circuit
- Locations noted in time and vary by specific cable velocity factors

Insulation Resistance (IR)

- Total leakage current
- Combination of charging, absorption, and leakage currents
- IR values typically start out low (high current) and increase (low current) with test duration
- Typical to establish minimum acceptable IR
- Subsequent IR testing may produce acceptable (above minimum) values, but much lower than initial values.

IR Practice (Rule of Thumb)

- Correction at high temperature – typically IR values are reduced by a factor of 2 for each 10°C (increase).
- Dual voltage IR- performing 2 separate IR tests at 2 different voltages - typically IR values should show <25% difference.

Polarization Ratios

- Polarizing molecules (dipoles)
- Dielectric absorption ratio, DAR = 60 sec. value / 30 sec. value
- Polarization index, PI = 10 min. value / 1 min. value
- Acceptable DAR (and PI) values typically >1.00
- End component may affect DAR/PI.

Case Histories

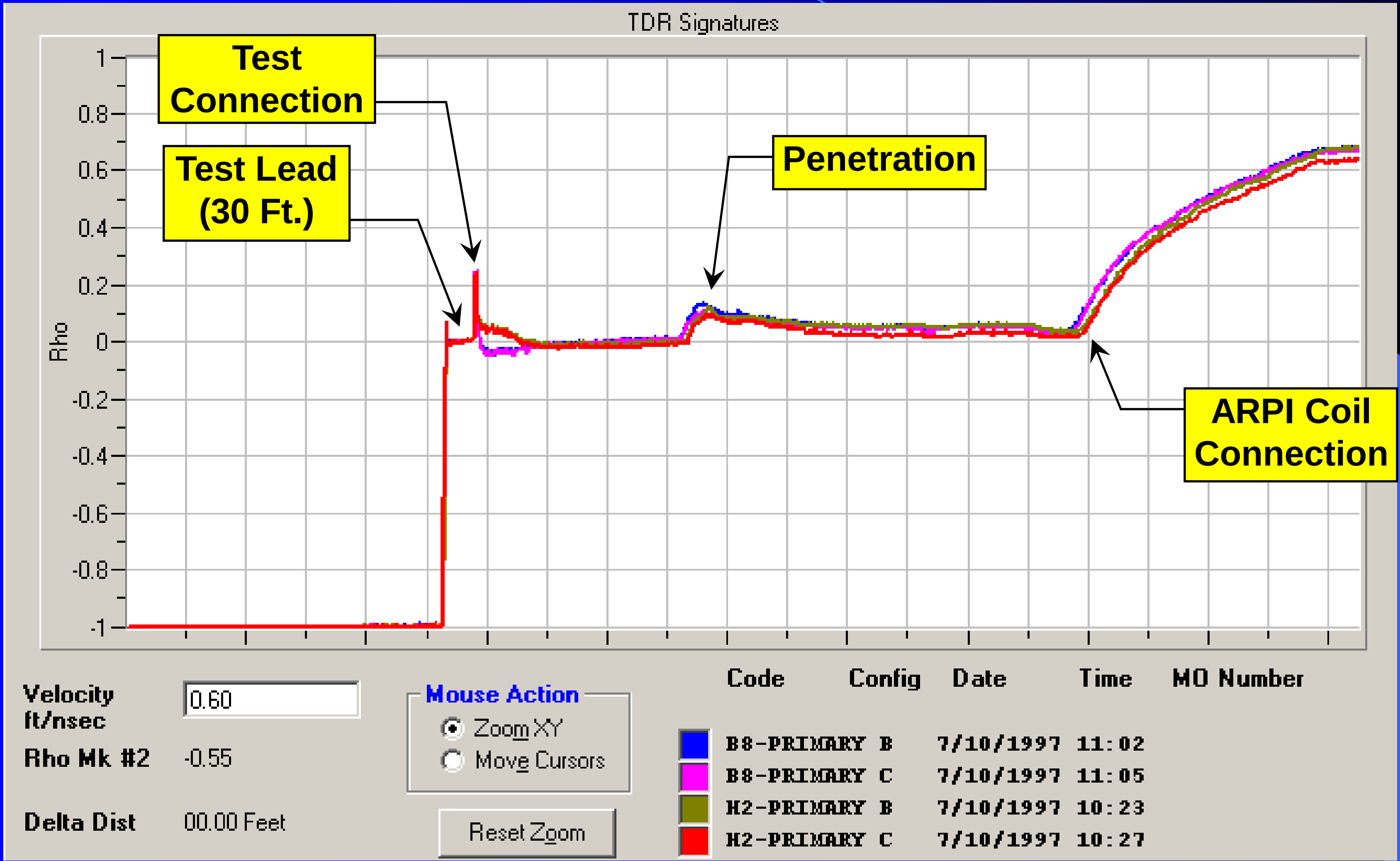
Case History #1

ARPI Circuit
(Coil Anomaly)

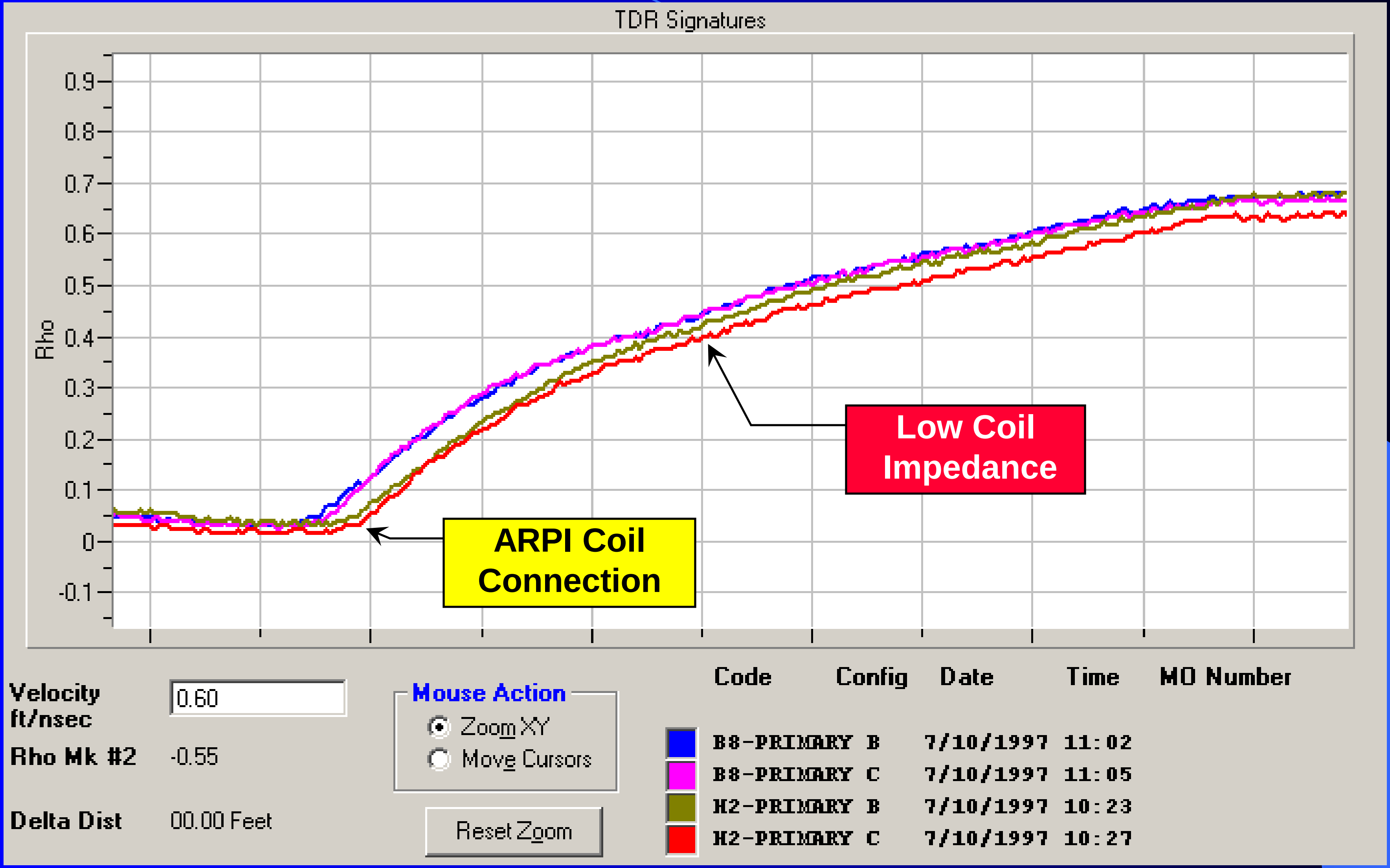
ARPI - Coil Lead 2 to Shield

CODE	Capacitance	Dissipation Factor
B8-PRIMARY	0.15 uF	1.36 D
F10-PRIMARY	0.11 uF	1.01 D
F6-PRIMARY	0.12 uF	1.12 D
F8-PRIMARY	0.11 uF	936.34 mD
H2-PRIMARY	**0.20 uF**	**1.96 D**
H6-PRIMARY	0.10 uF	851.31 mD
K10-PRIMARY	0.11 uF	916.75 mD
K6-PRIMARY	0.11 uF	919.10 mD
K8-PRIMARY	0.11 uF	906.14 mD

ARPI – Coil Lead to Shield TDR Signatures



ARPI – Enhanced View of The Coils



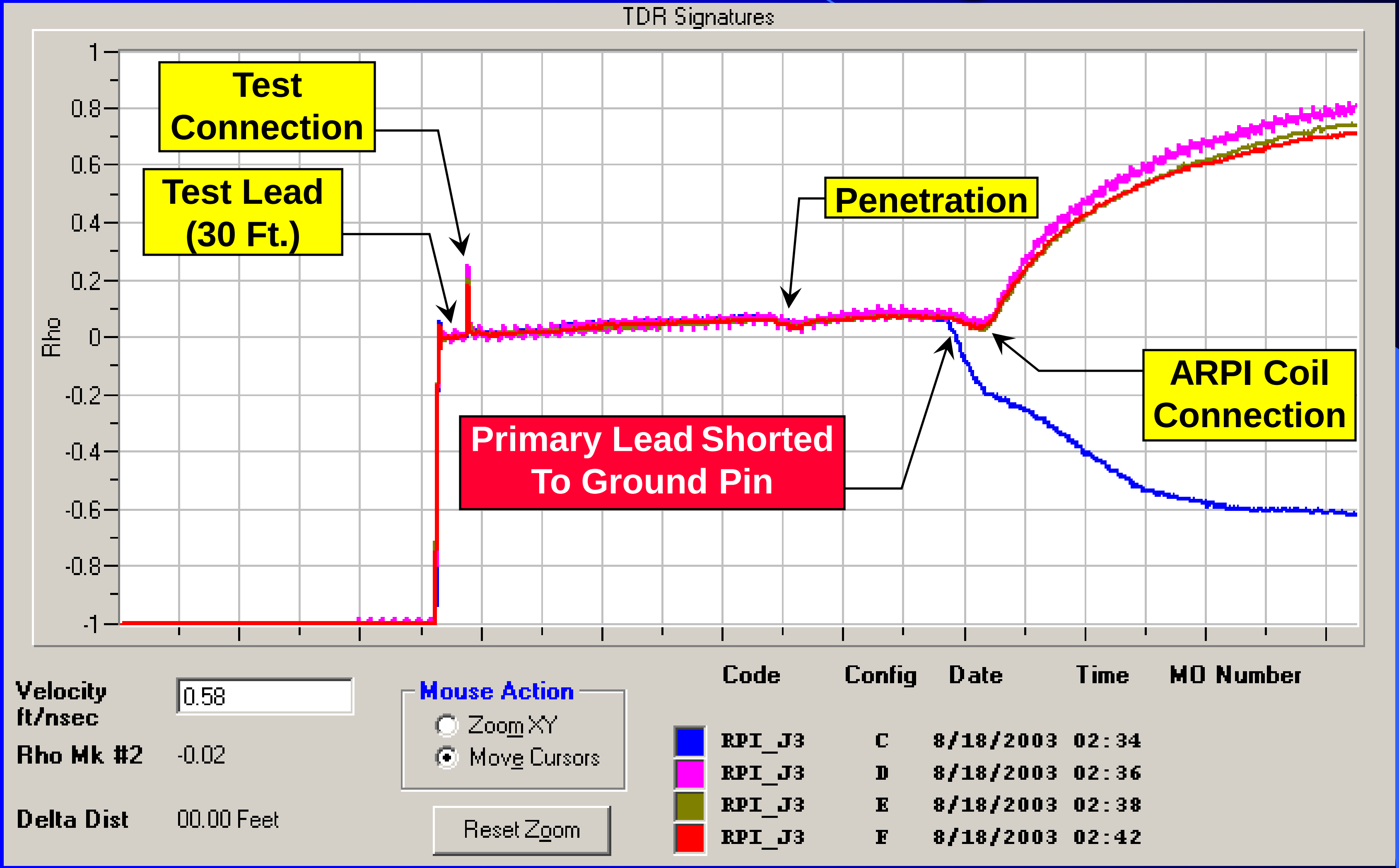
Case History #2

ARPI Circuit
(Failed Splice)

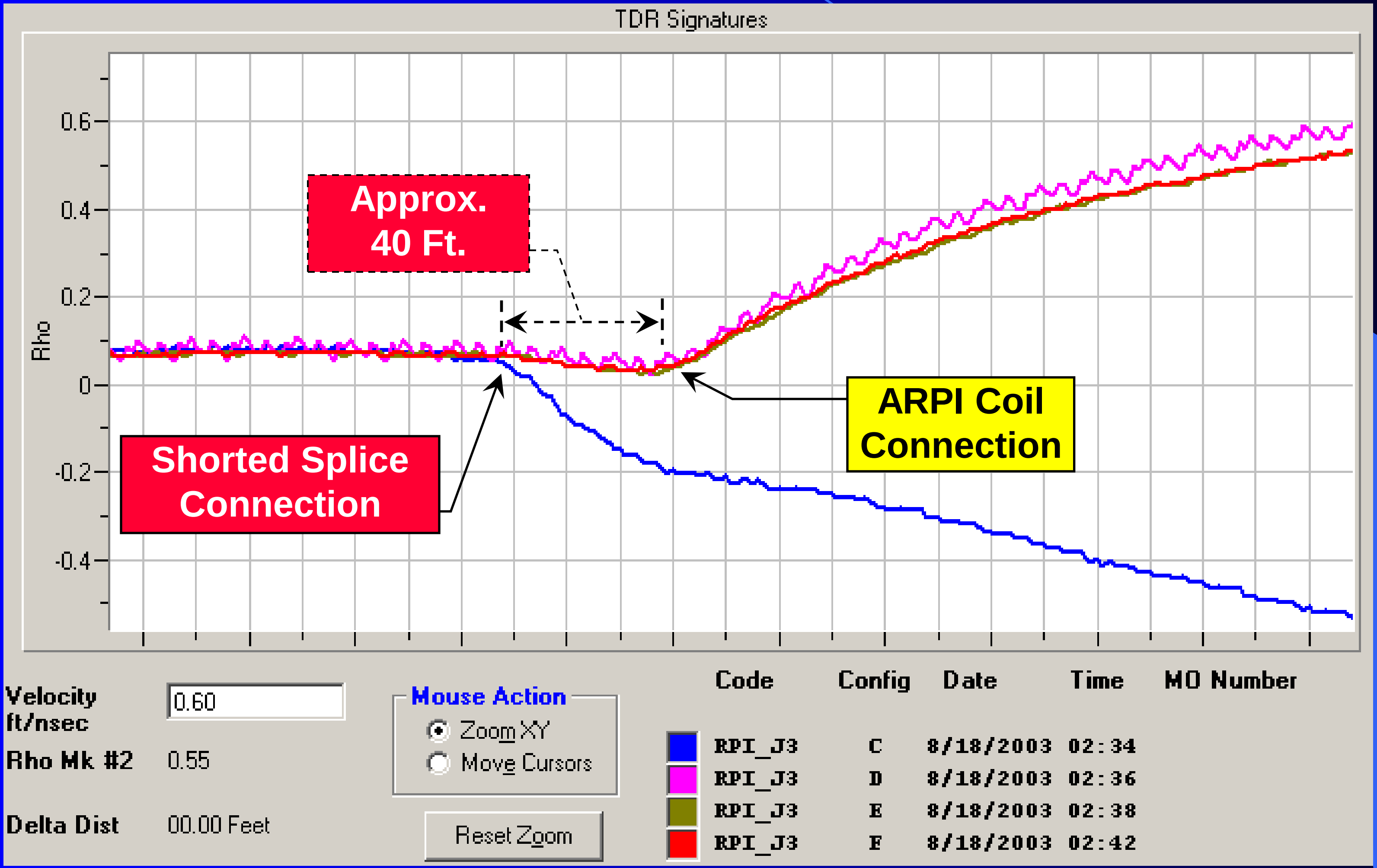
ARPI - Coil Leads to Ground Pin

CODE	CFG	DC Res./ IR	Inductance/ Capacitance	Quality Factor/ Dissipation Factor
RPI_J3	C	7.41	81.80 uH	69.42 mQ
RPI_J3	D	22.85	104.18 mH	2.47 Q
RPI_J3	E	330.80 M	48.30 nF	72.24 mD
RPI_J3	F	> 31.00 M	49.13 nF	86.47 mD
RPI_P10	C	271.01 M	45.79 nF	62.39 mD
RPI_P10	D	> 31.00 M	45.69 nF	62.41 mD
RPI_P10	E	401.82 M	47.03 nF	79.86 mD
RPI_P10	F	> 31.00 M	46.70 nF	72.94 mD

ARPI – Coil Lead to Ground Pin TDR Signatures



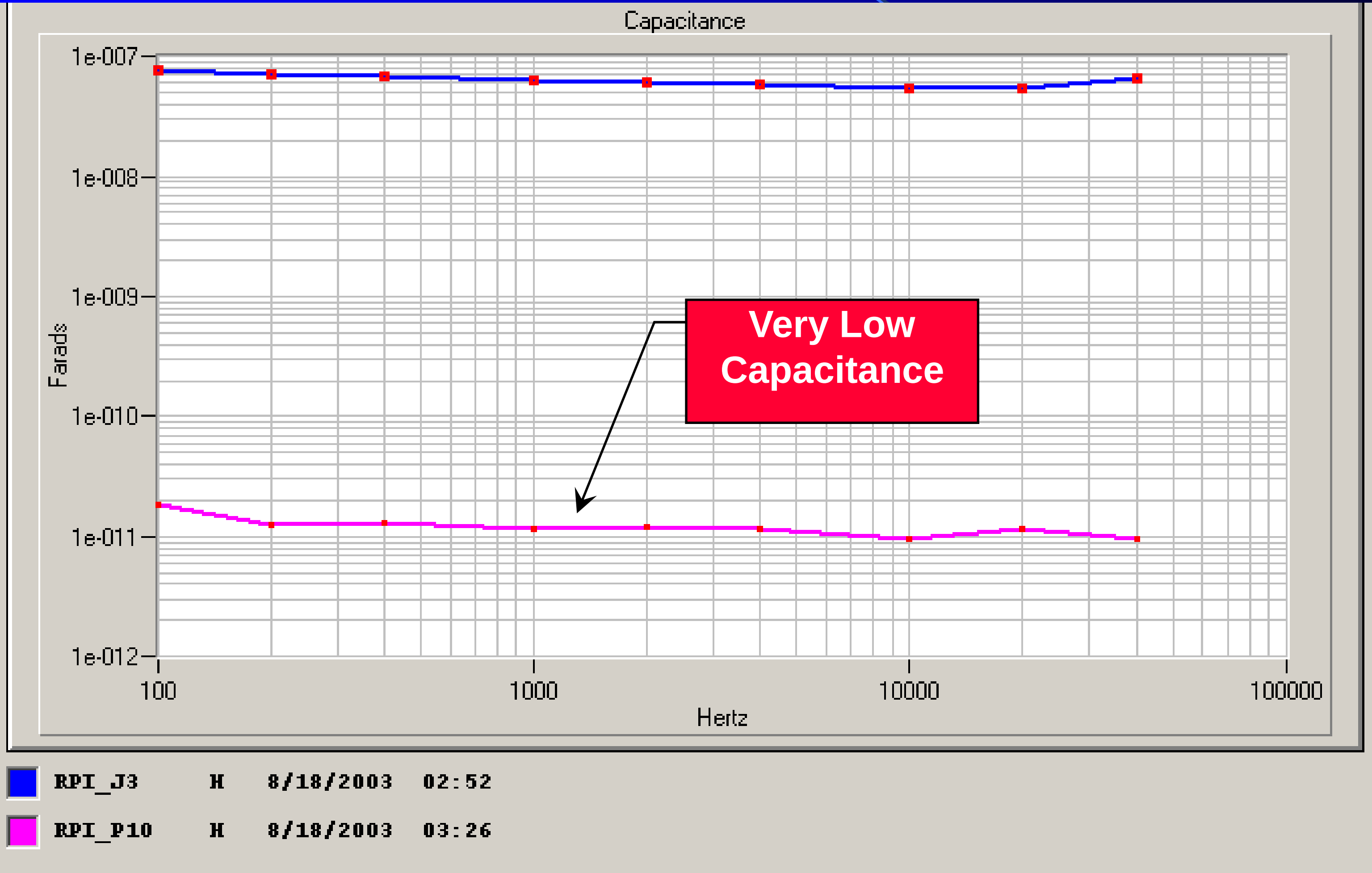
ARPI – Enhanced View of the Suspect Area (Splice)



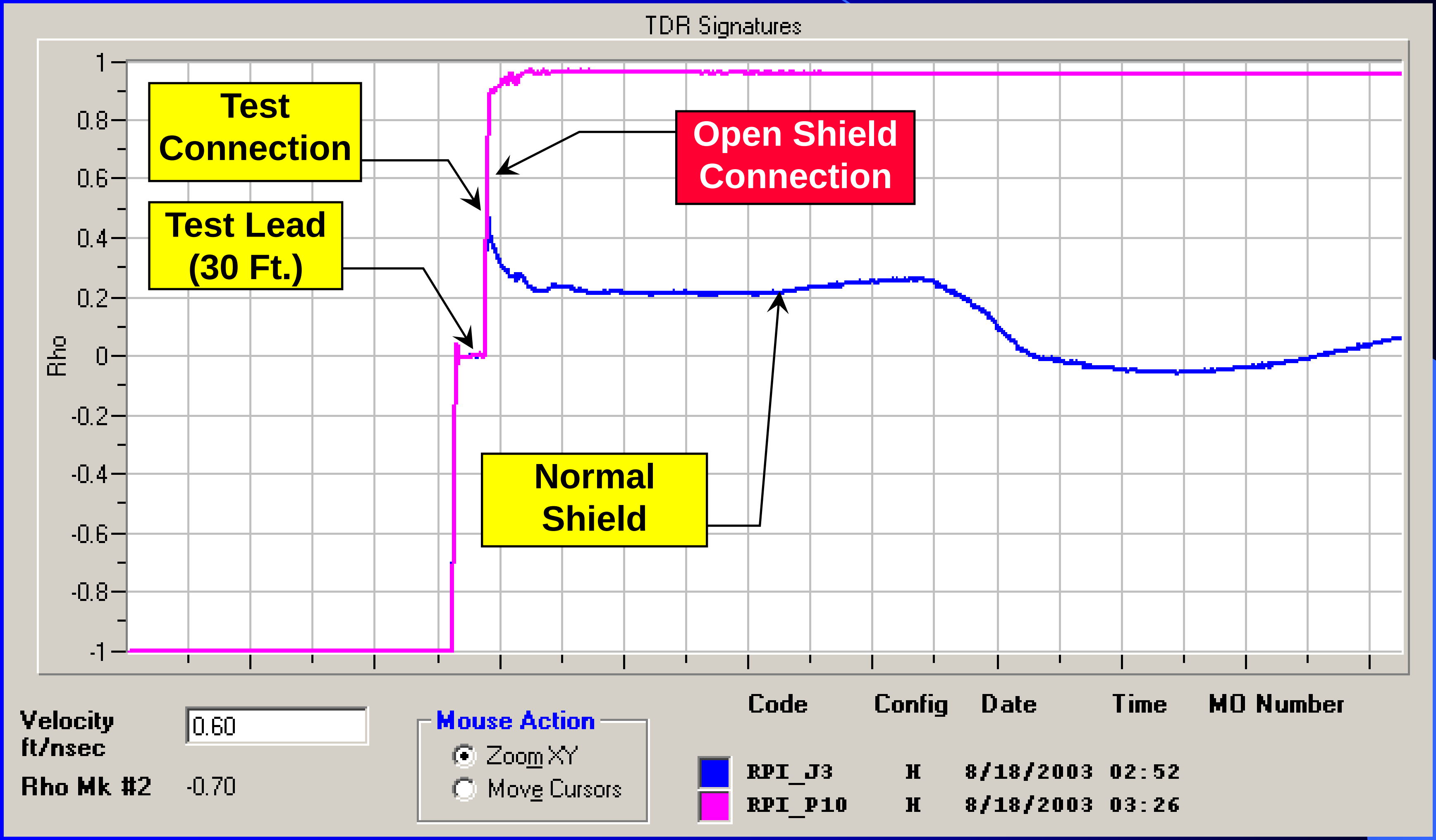
Case History #3

ARPI Circuit
(Open Shield Connection)

ARPI – Shield to Ground Capacitance Vs. Frequency



ARPI – Shield to Ground TDR Signatures



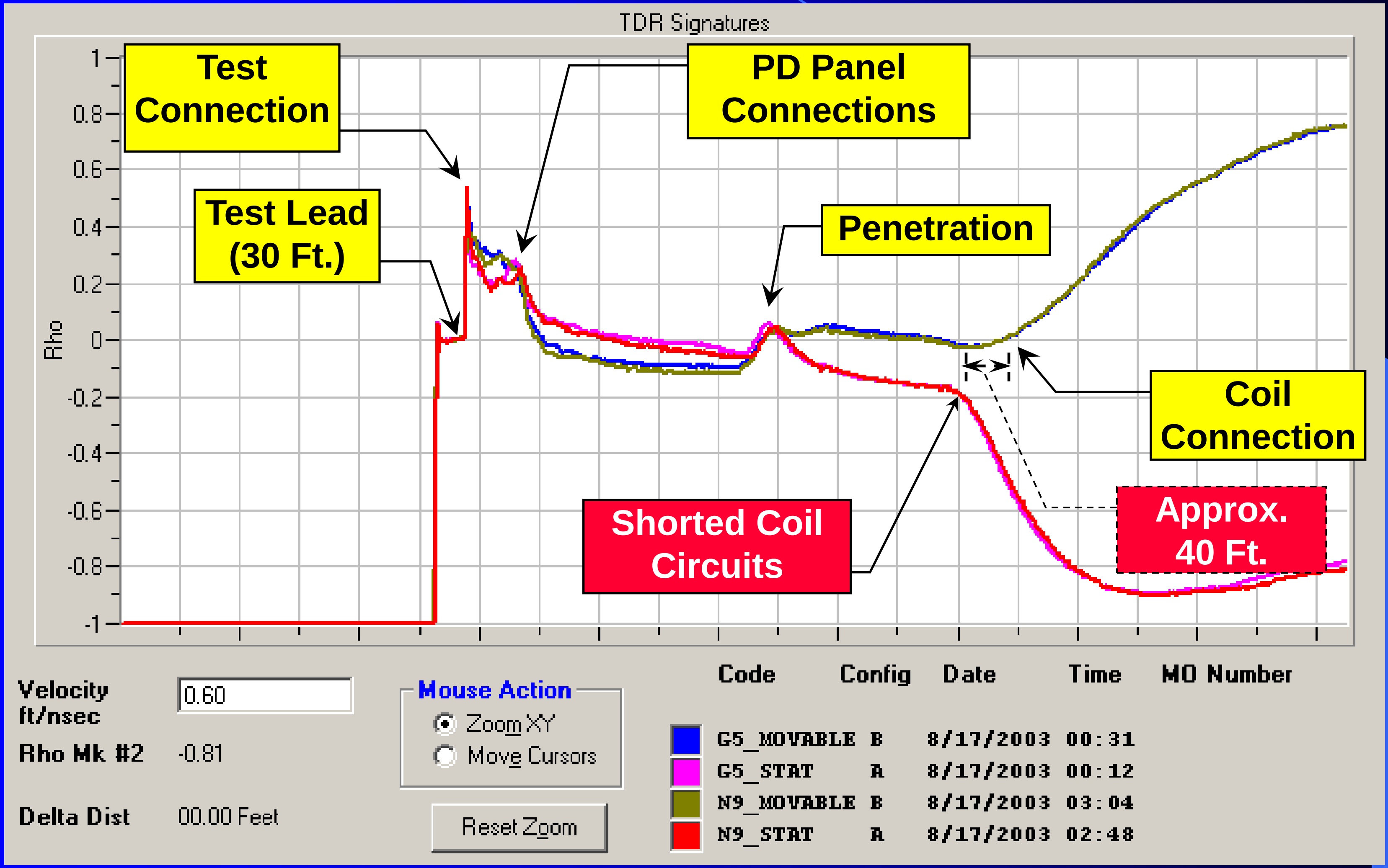
Case History #4

CRDM Circuits
(Failed Splices)

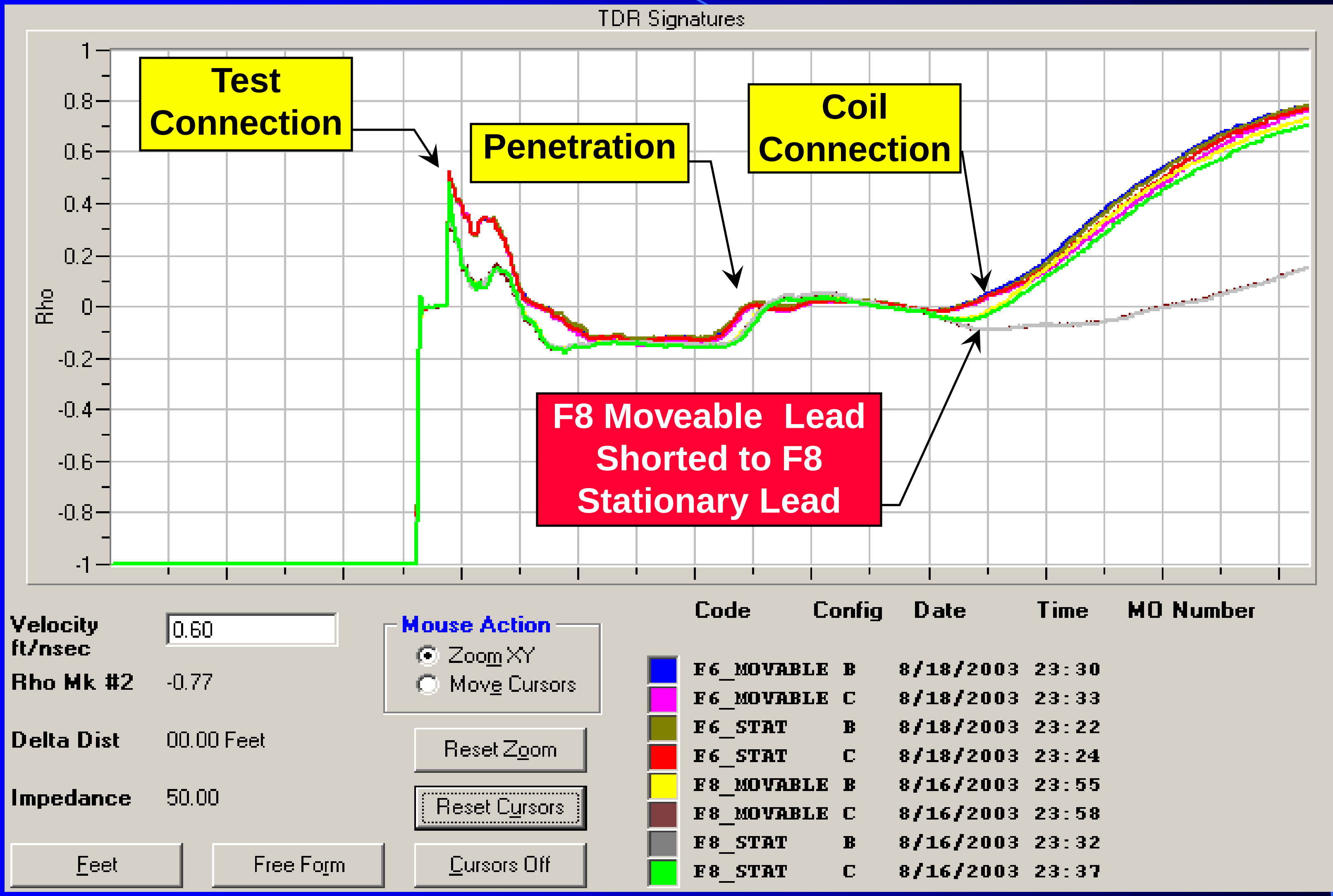
Data Across Coils

CODE	DC RES (Ω)	AC RES (Ω)	Inductance	Quality Factor
G3_STAT	11.36	123.48	248.46 mH	1.26 Q
G5_STAT	**387.29 m**	**384.89 m**	**89.75 uH**	**146.51 mQ**
N11_STAT	11.54	122.10	247.09 mH	1.27 Q
N13_STAT	11.45	125.03	252.63 mH	1.27 Q
N3_STAT	11.32	118.05	239.97 mH	1.28 Q
N5_STAT	11.13	120.82	247.68 mH	1.29 Q
N7_STAT	11.91	123.92	252.36 mH	1.28 Q
N9_STAT	**395.35 m**	**401.15 m**	**88.67 uH**	**138.89 mQ**
P10_STAT	11.63	129.77	260.71 mH	1.26 Q
P6_STAT	11.48	121.74	246.67 mH	1.27 Q
P8_STAT	11.20	120.10	245.75 mH	1.29 Q

CRDM - TDR Signatures
Locating Shorted Cables



CRDM - TDR Signatures
Locating Shorted Cables



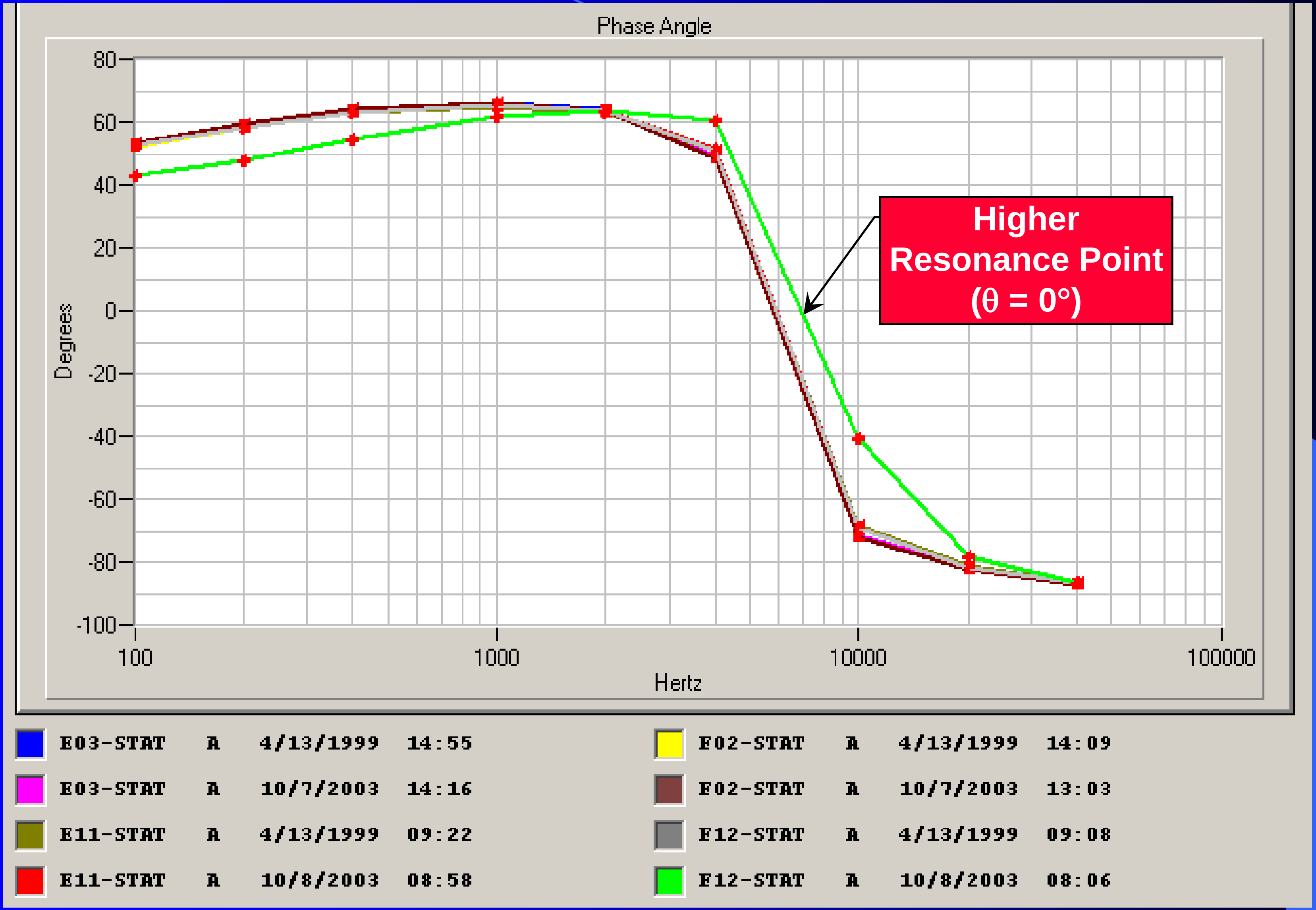
Case History #5

CRDM Circuit
Coil Anomaly
(Turn to Turn Short)

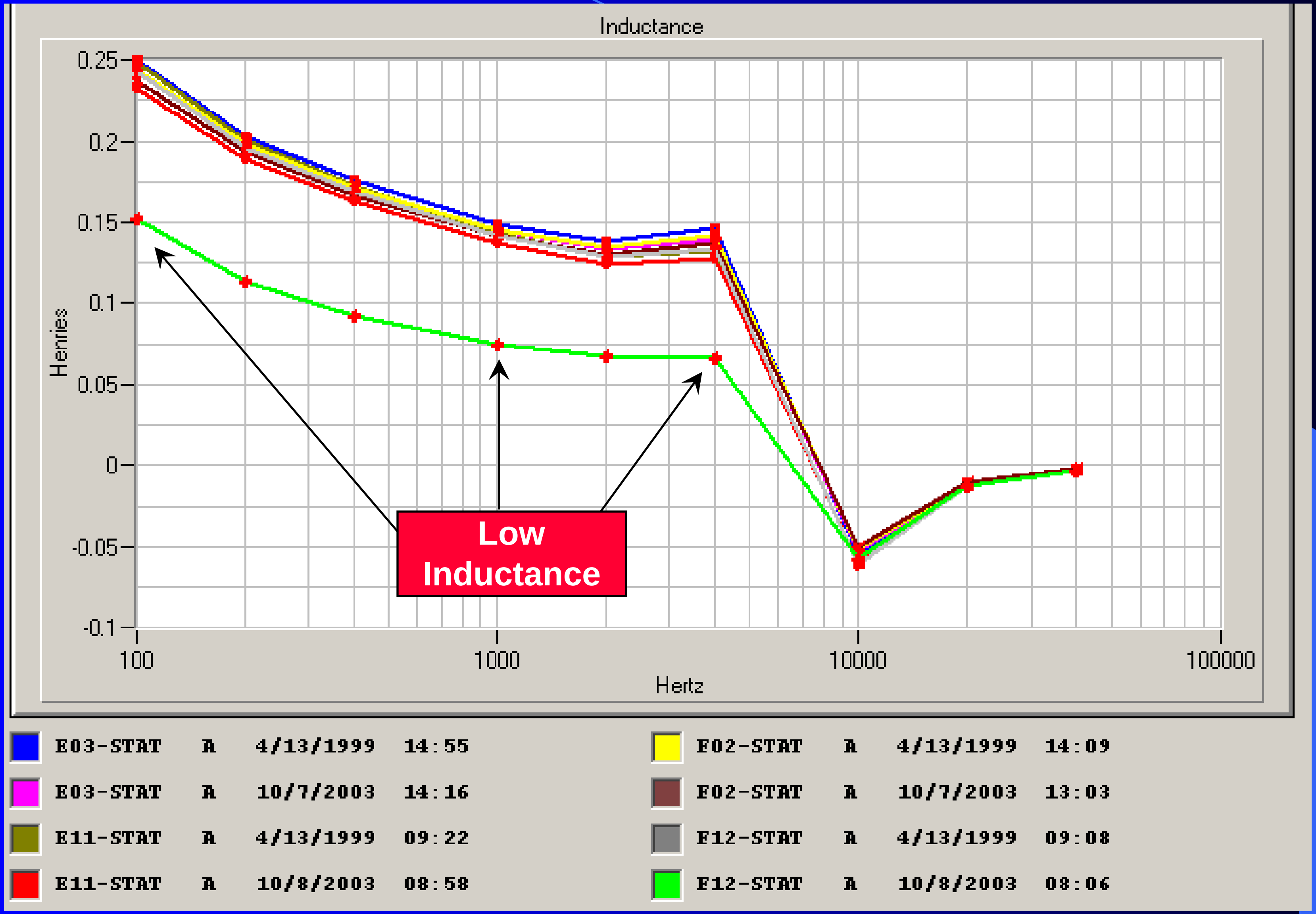
Coil Data

CODE	DATE	DC RES (Ω)	AC RES (Ω)	Inductance	Quality Factor
B06-STAT	4/13/1999	10.89	218.42	173.65 mH	2.00 Q
B06-STAT	10/8/2003	10.01	208.52	169.28 mH	2.04 Q
B08-STAT	4/13/1999	10.43	220.17	178.86 mH	2.04 Q
B08-STAT	10/7/2003	9.67	206.72	171.69 mH	2.09 Q
D04-STAT	4/13/1999	9.21	210.60	172.42 mH	2.06 Q
D04-STAT	10/7/2003	9.37	205.03	168.62 mH	2.07 Q
D10-STAT	4/13/1999	10.48	217.82	178.40 mH	2.06 Q
D10-STAT	10/8/2003	9.71	208.93	173.04 mH	2.08 Q
E11-STAT	4/13/1999	9.76	222.13	171.97 mH	1.95 Q
E11-STAT	10/8/2003	9.75	203.00	163.06 mH	2.02 Q
F02-STAT	4/13/1999	10.03	213.58	171.45 mH	2.02 Q
F02-STAT	10/7/2003	9.85	204.73	167.02 mH	2.05 Q
F12-STAT	4/13/1999	9.93	214.85	168.70 mH	1.97 Q
F12-STAT	10/8/2003	9.80	**164.58**	**91.68 mH**	**1.40 Q**
G03-STAT	4/13/1999	10.80	210.41	167.06 mH	2.00 Q
G03-STAT	10/7/2003	10.40	203.05	163.53 mH	2.02 Q
G05-STAT	4/13/1999	9.47	217.14	176.35 mH	2.04 Q
G05-STAT	10/7/2003	9.59	209.99	172.65 mH	2.07 Q

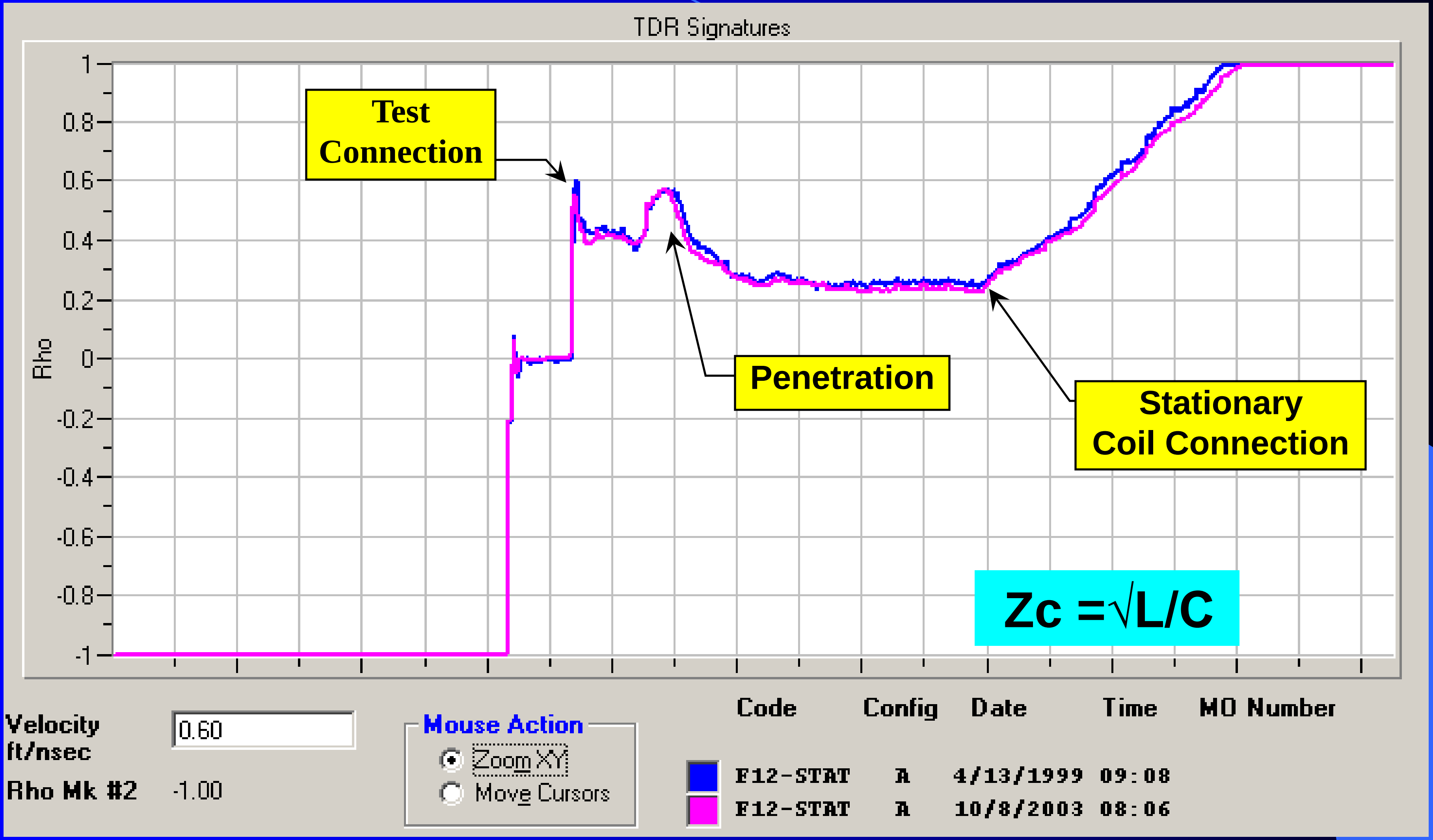
Coil Resonance



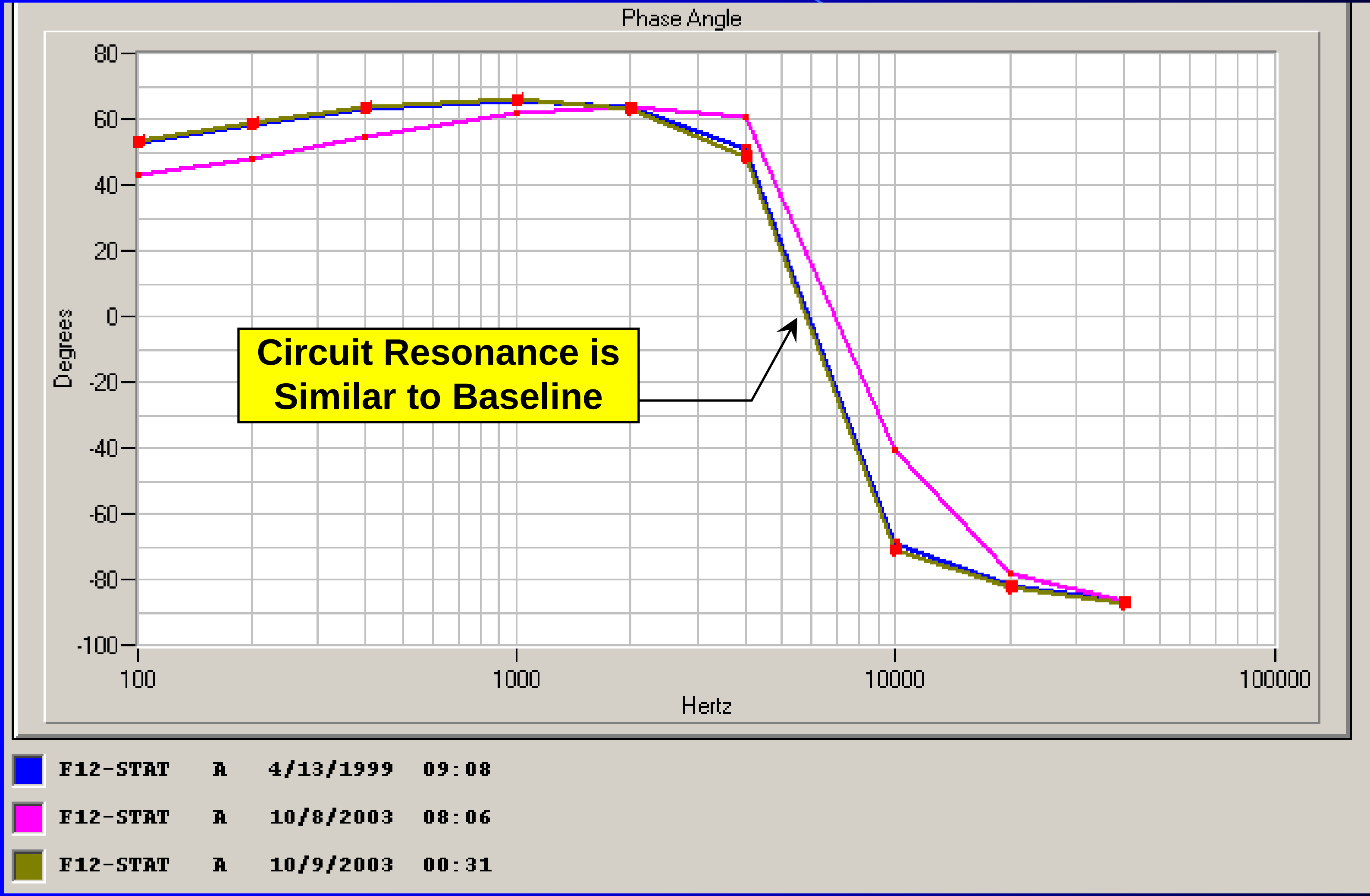
Coil Inductance



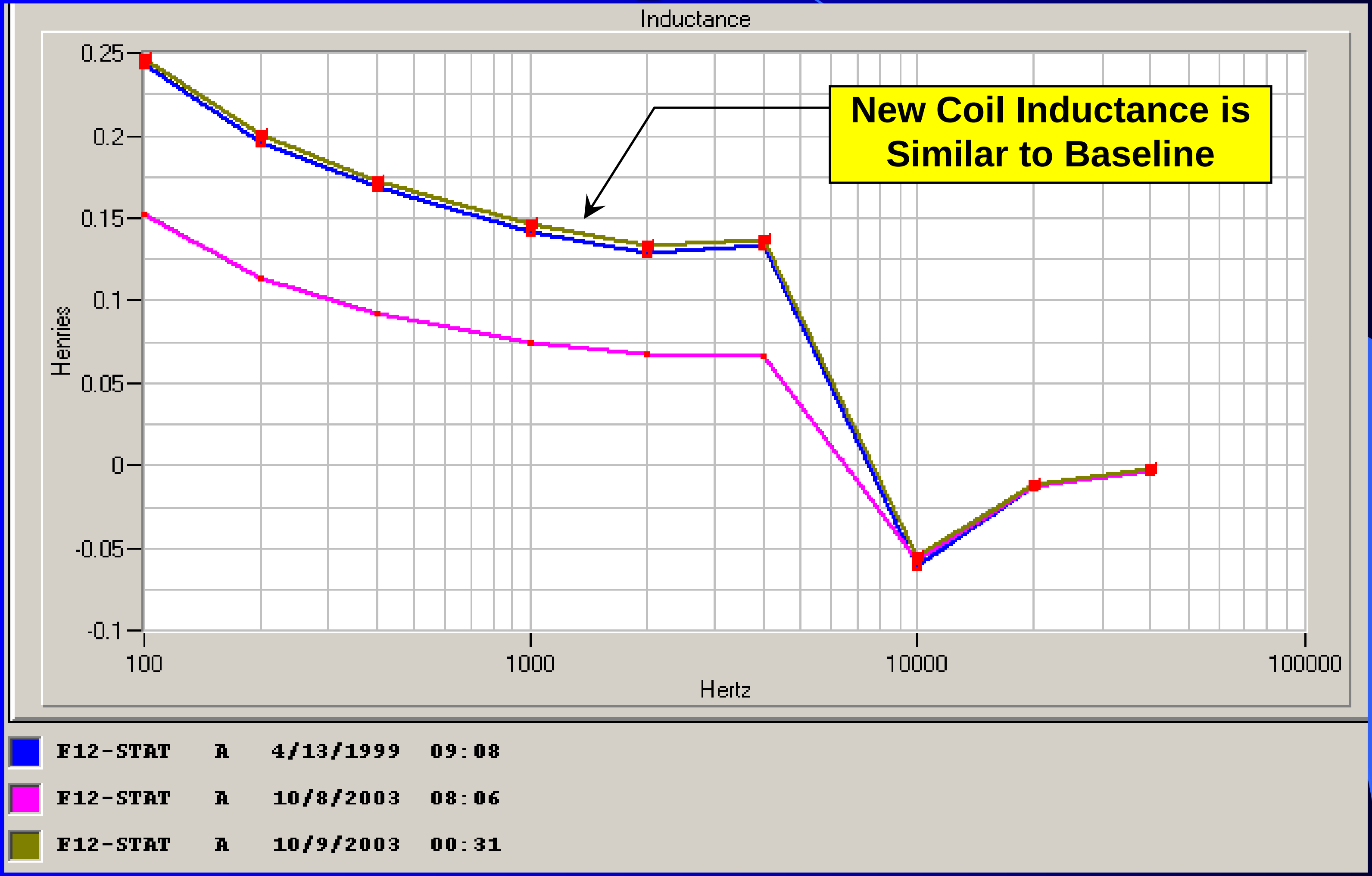
CRDM Coil – TDR Signatures



Circuit Resonance After Coil Replacement



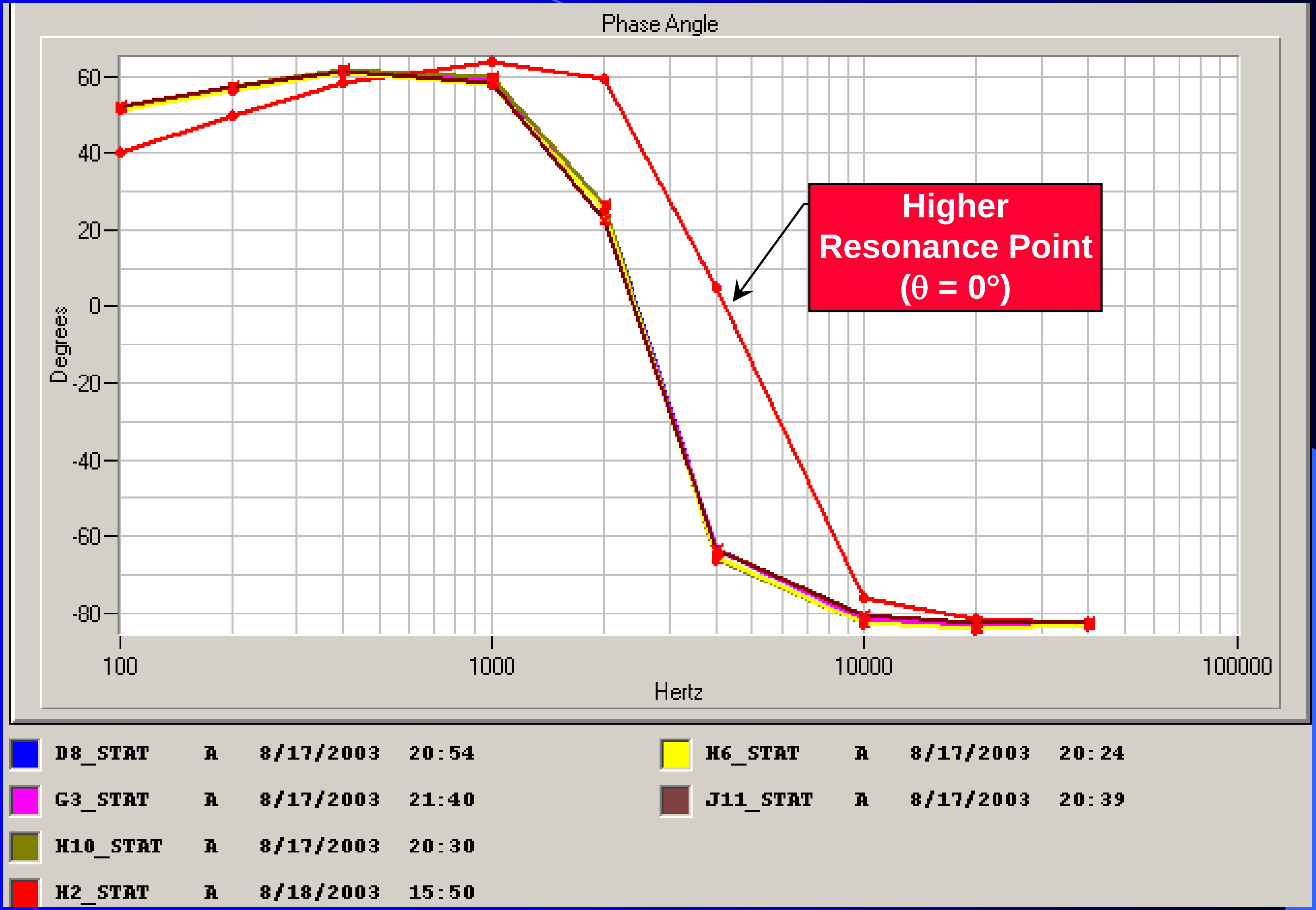
Coil Inductance After Replacement



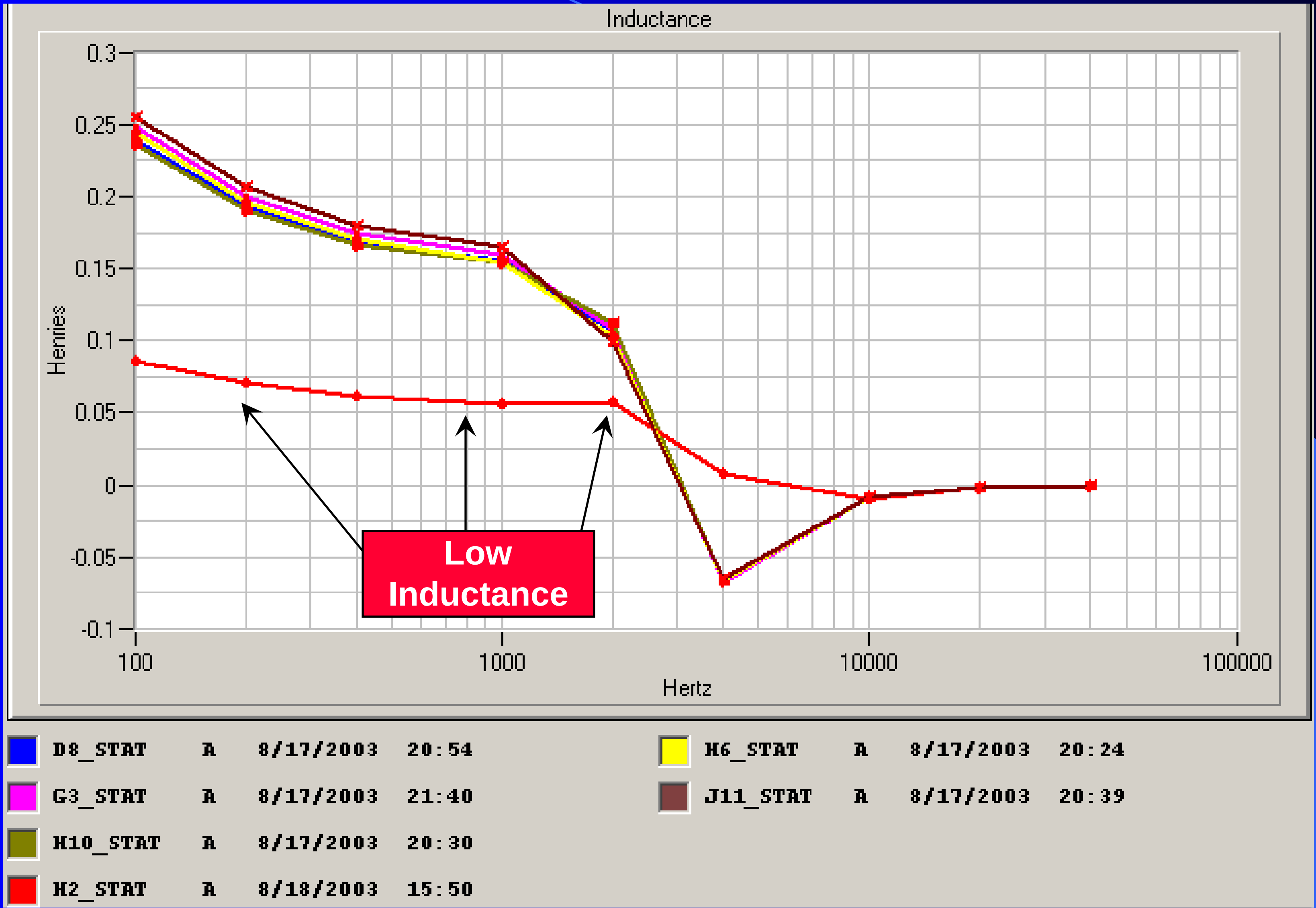
Case History #6

CRDM Circuit
Coil Anomaly
(Suspected Turn to
Turn Short)

Coil Resonance



Coil Inductance



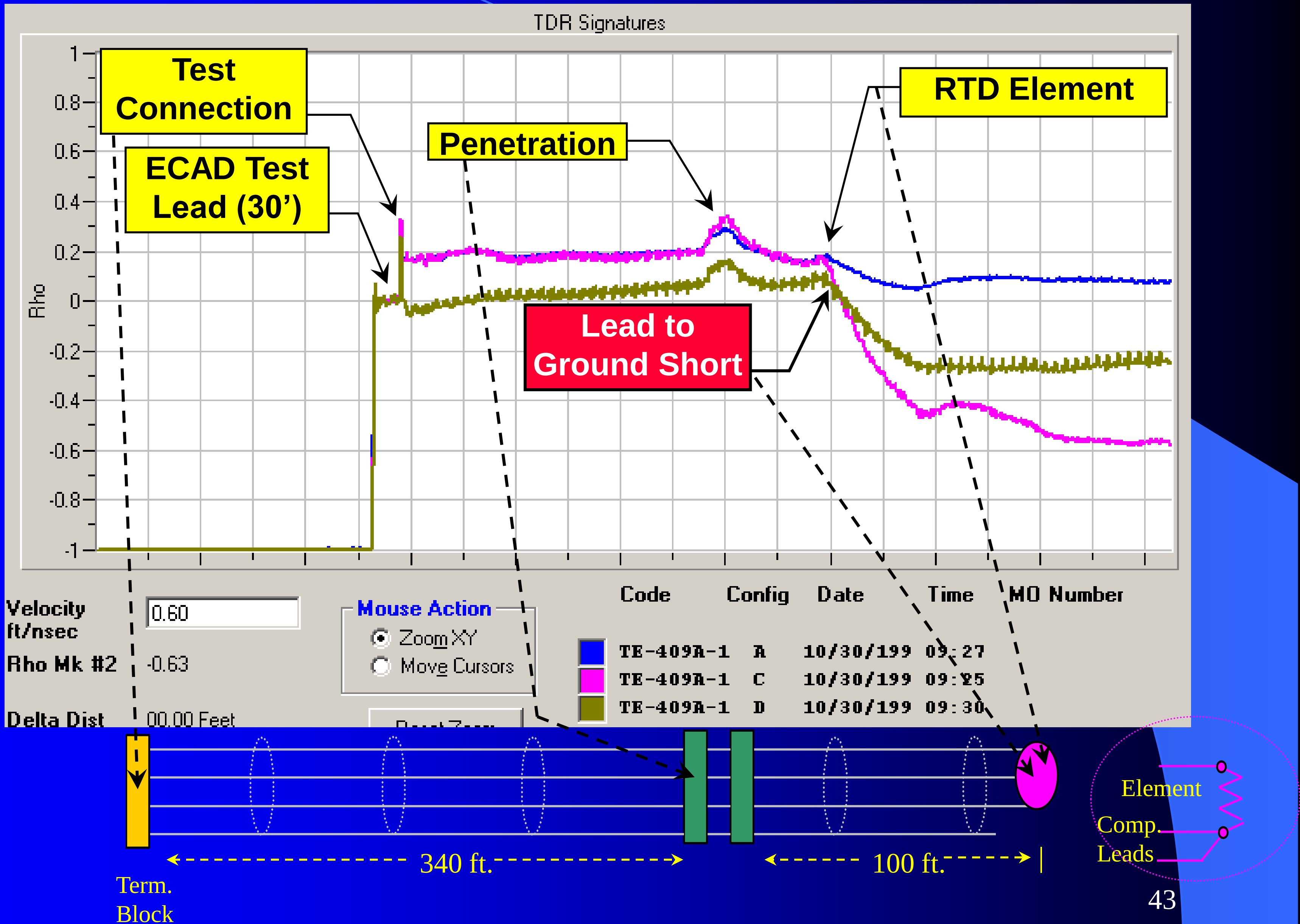
Case History #7

RTD Circuit
(Lead to Ground Short)

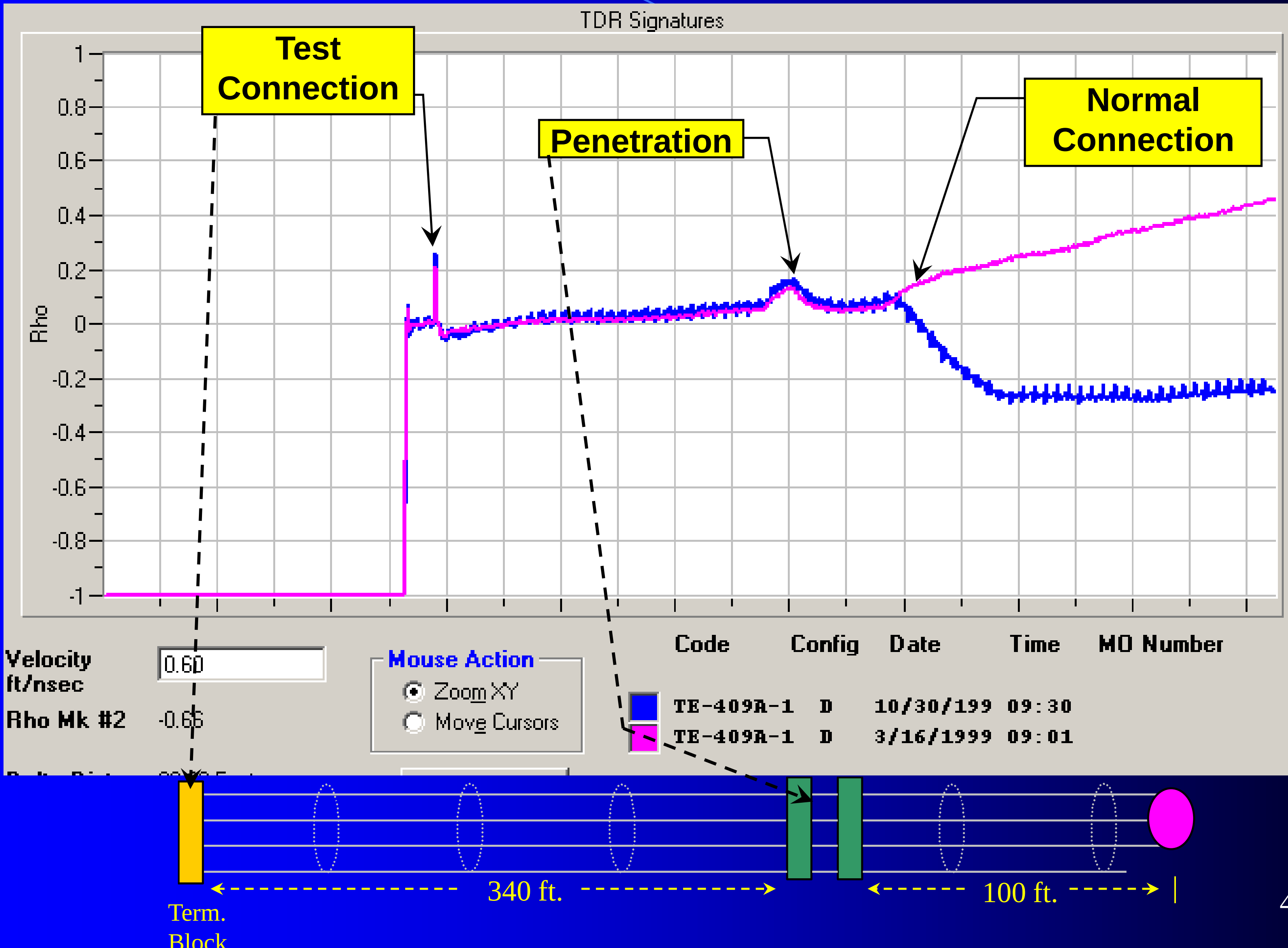
3 Wire RTD Circuit - Lead to Shield Data

Device	Cfg.	Date	IR/DC Res.	DAR	Cap./ Ind.	Diss. / Qual.
TE-409A-1	D	10/30/97	0.00	N/A	0.22 mH	515.12 mQ
TE-409A-1	E	10/30/97	107.96	N/A	87.03 uF	66.08 D
TE-409A-1	F	10/30/97	107.93	N/A	81.28 uF	61.74 D
TE-409A-1	D	3/16/99	6.09 G	1.29	52.32 nF	29.40 mD
TE-409A-1	E	3/16/99	31.00 M	N/A	52.33 nF	17.40 mD
TE-409A-1	F	3/16/99	31.00 M	N/A	52.35 nF	17.40 mD

3 Wire RTD Circuit - Lead to Ground Short



3 Wire RTD Circuit - After Repair



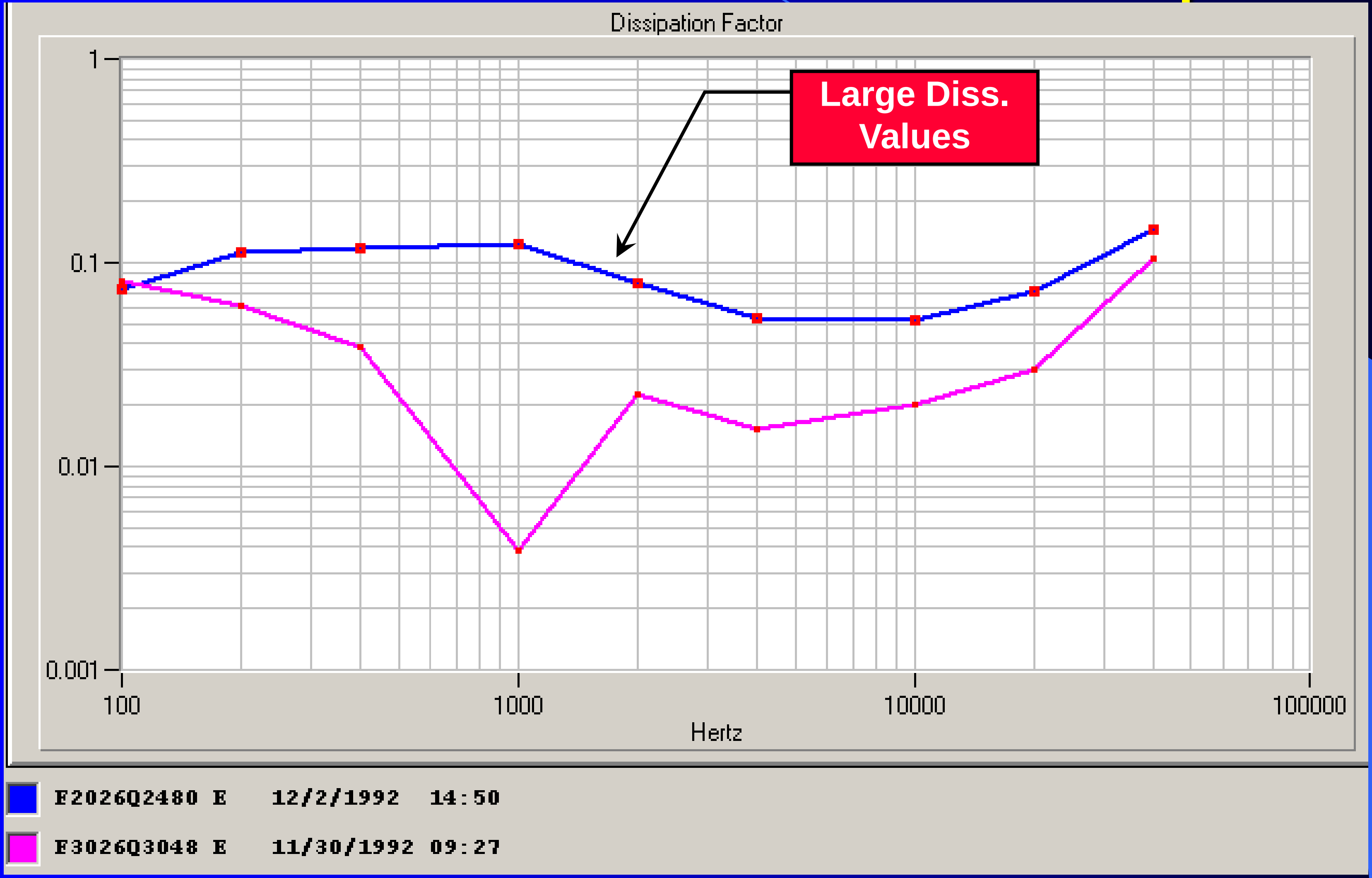
Case History #8

TC Cables
(Heat Stressed Cable)

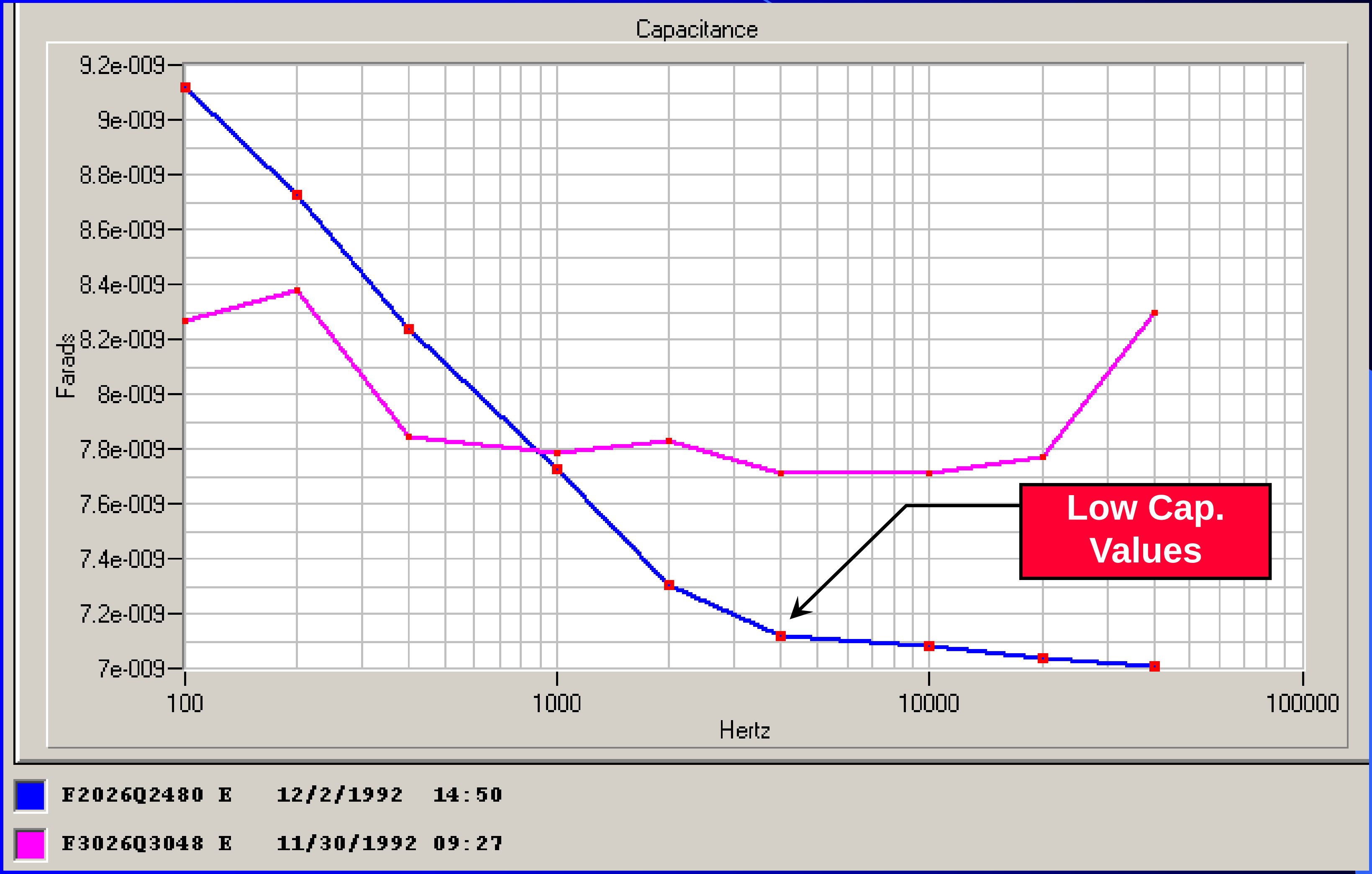
TC Data – Heat Stressed Insulation (Lead to Ground)

Device	IR	DAR	Cap.	Diss.
F2026Q2480	4.07 M	0.99	7.72 nF	122.15 mD
F3026Q30480	30.83 M	1.31	7.79 nF	3.88 mD

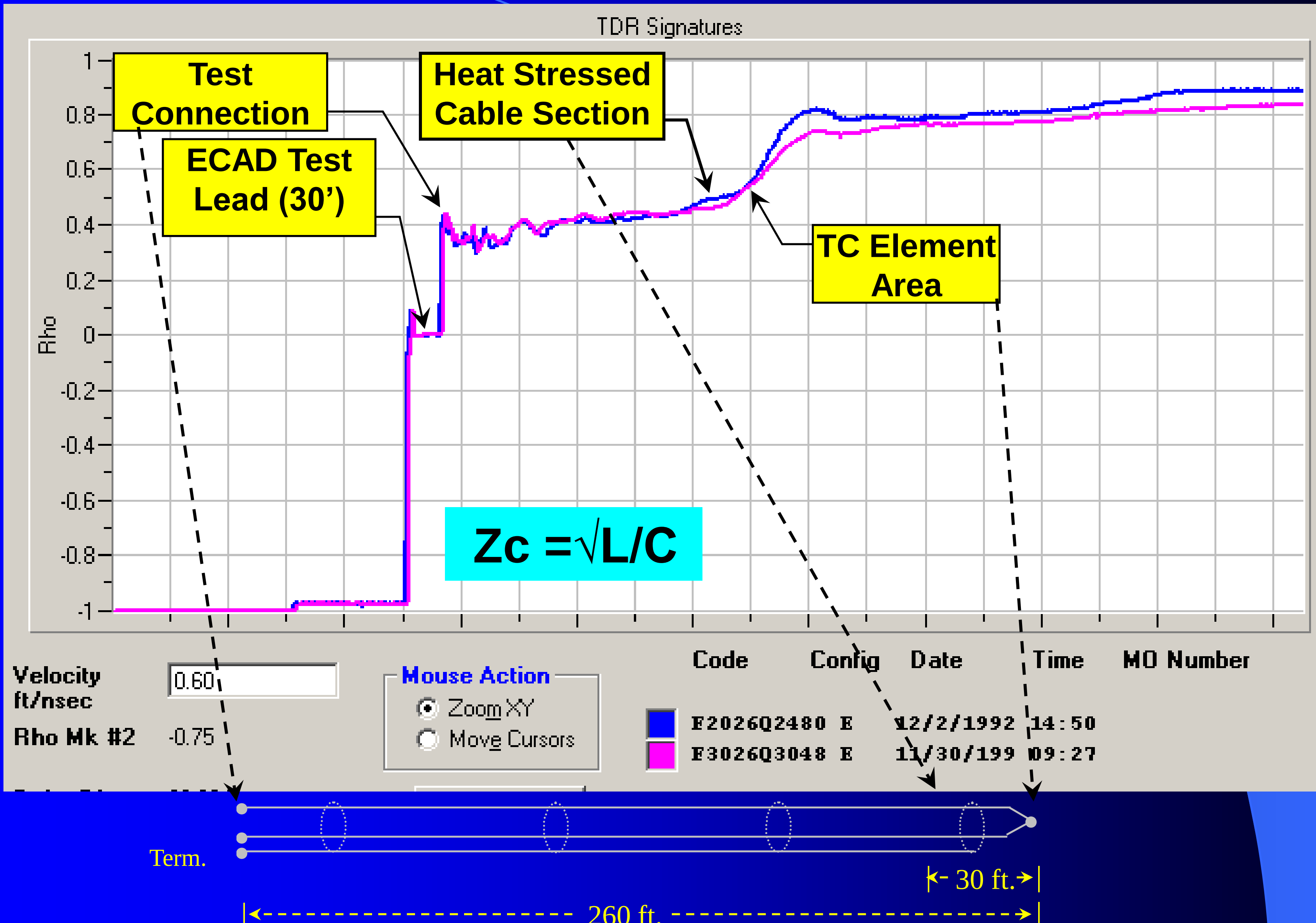
TC Data – Heat Stressed Insulation – Diss. Vs. Freq.



TC Data – Heat Stressed Insulation – Cap. Vs. Freq.



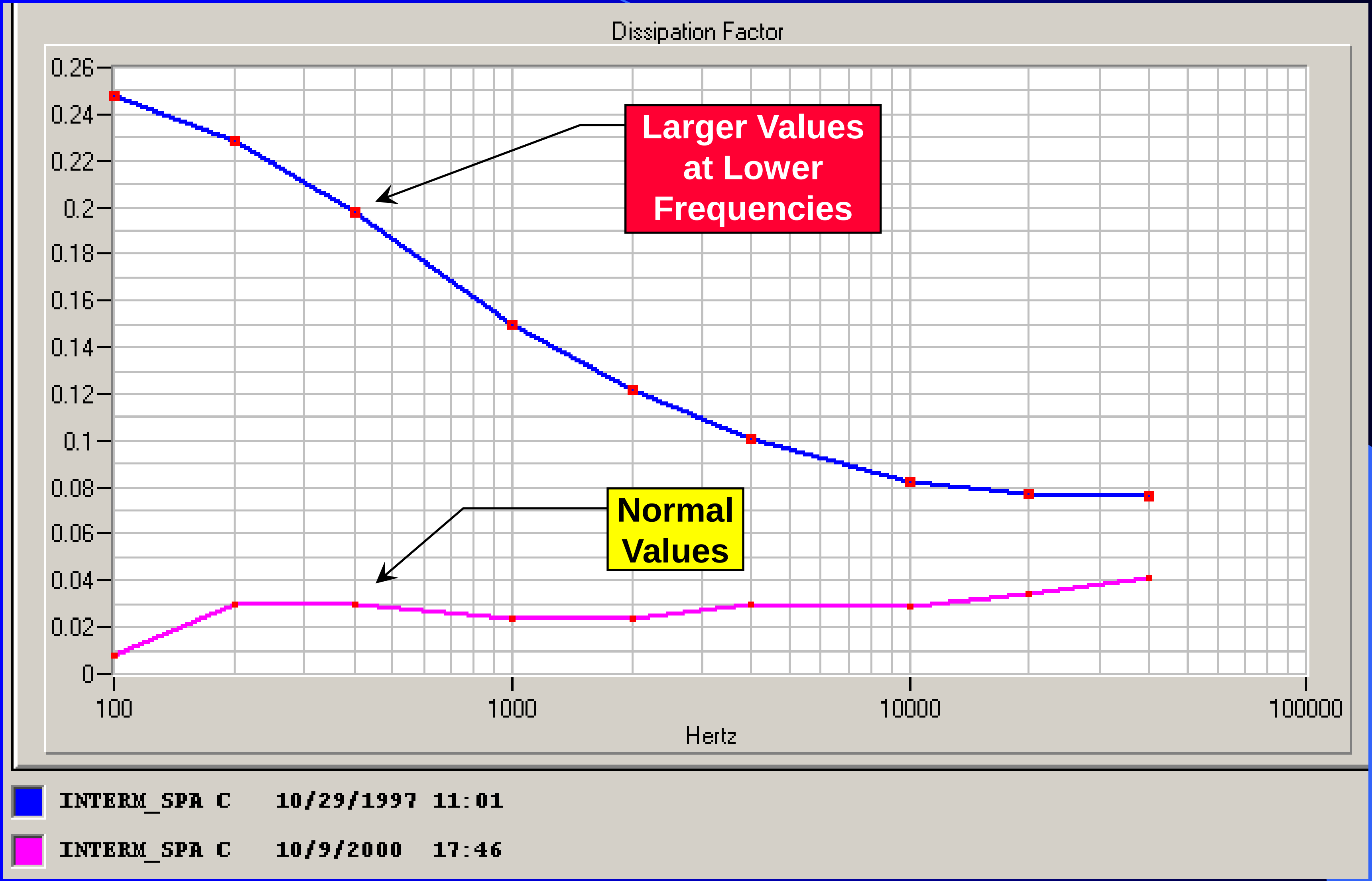
TC – TDR Signatures



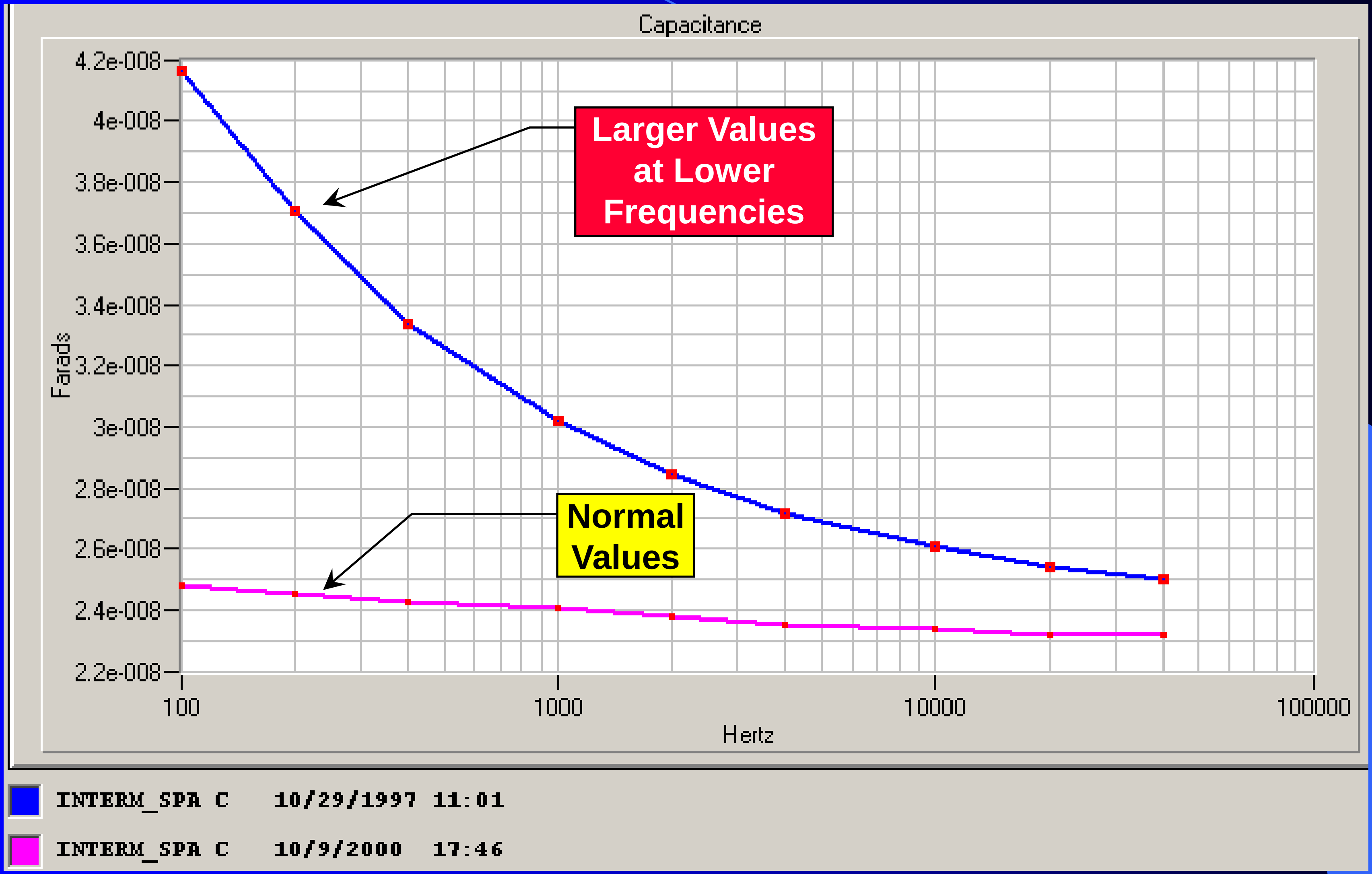
Case History #9

Wet Triaxial Cable

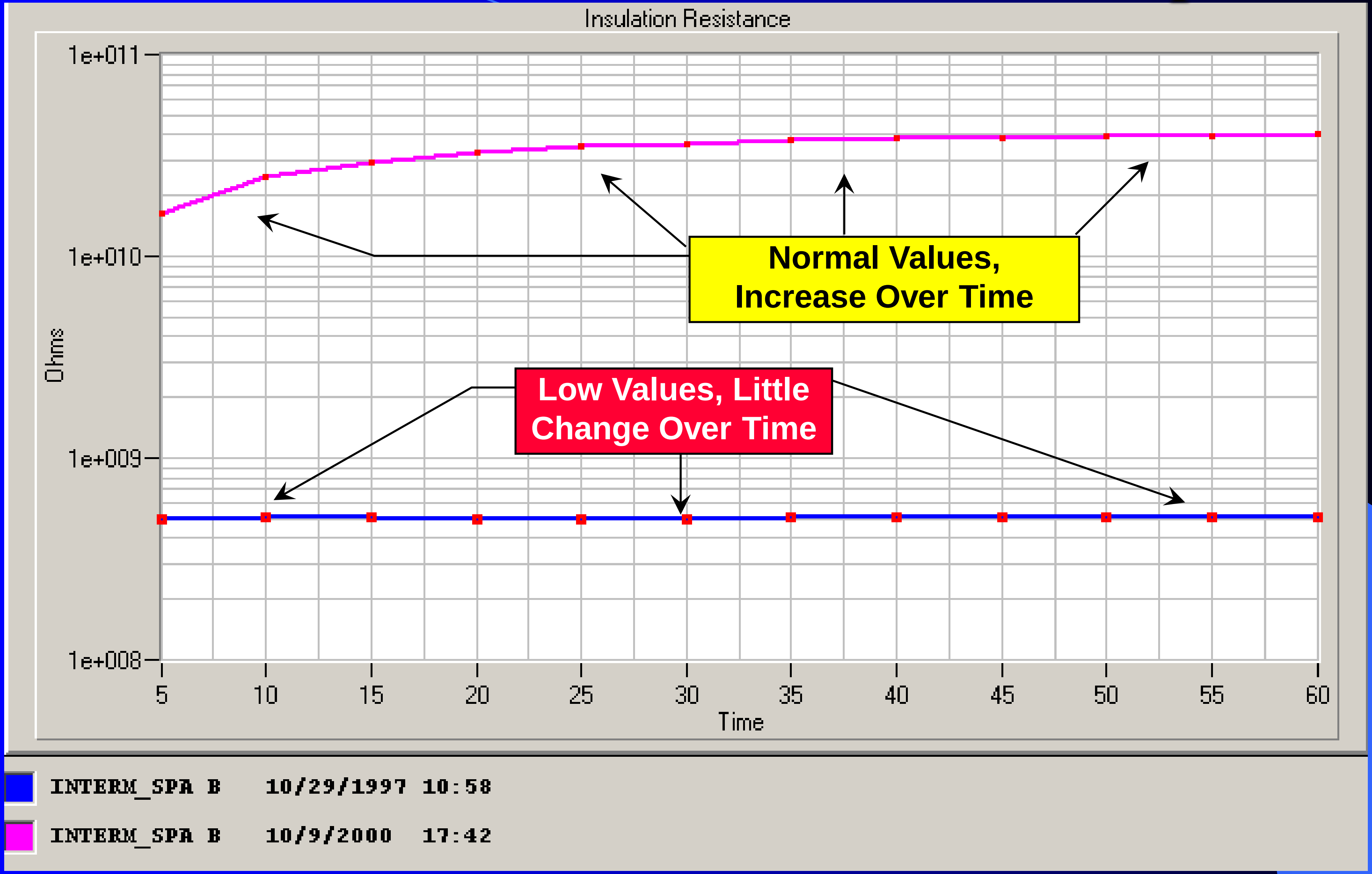
Dissipation Vs. Frequency Graph



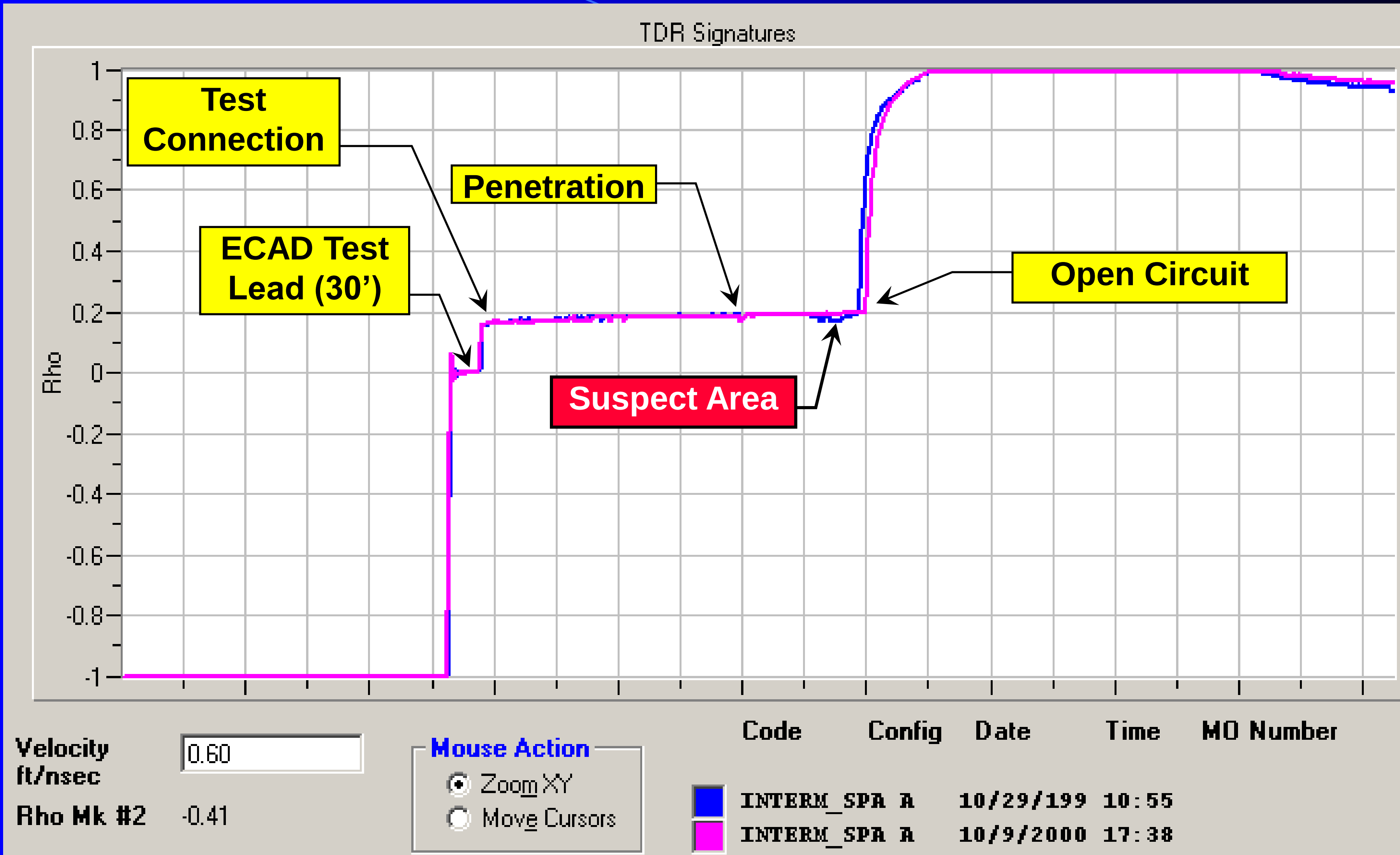
Capacitance Vs. Frequency Graph



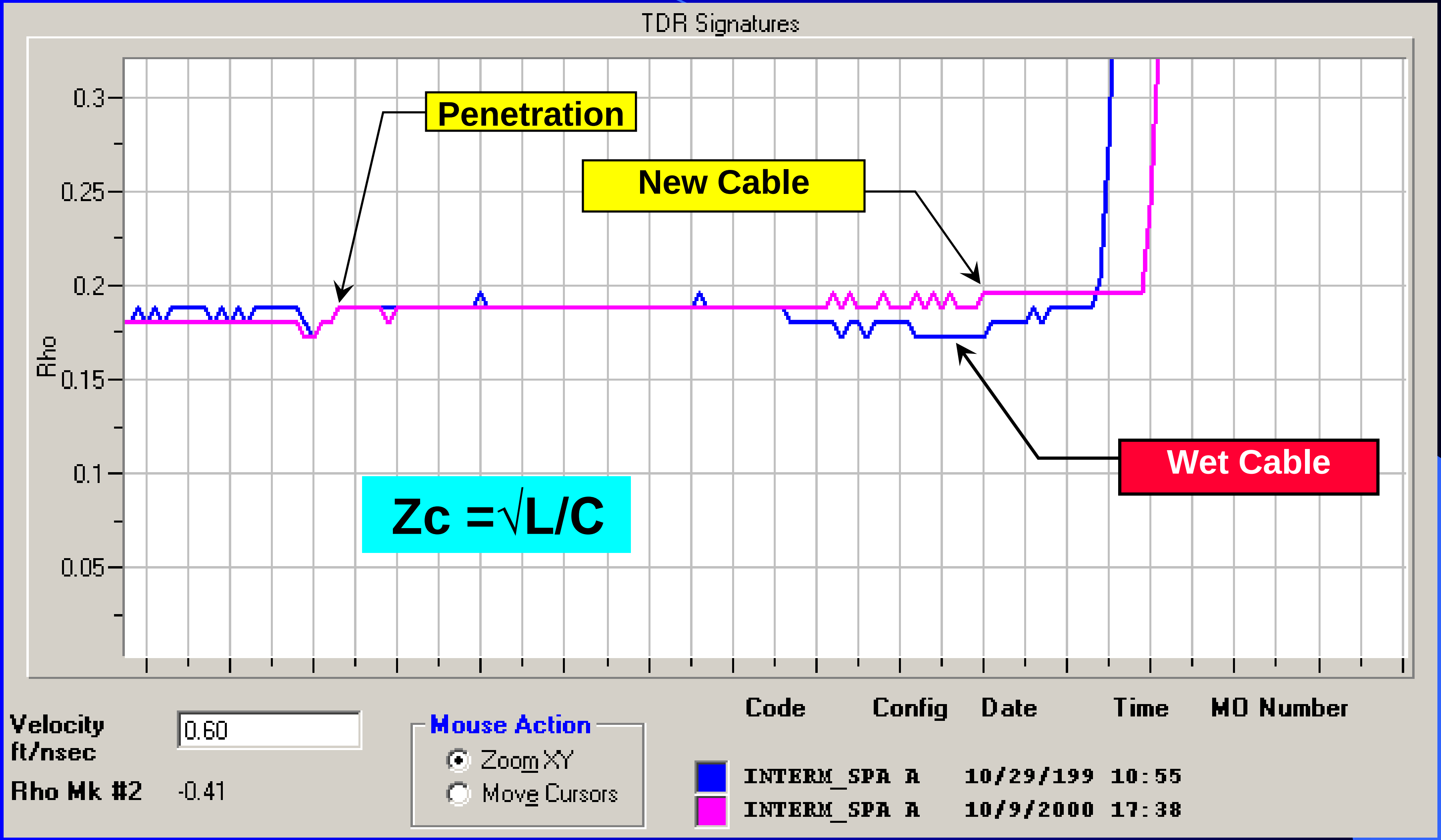
Insulation Resistance Vs. Time Graph



Wet Triaxial Cable – TDR Signatures



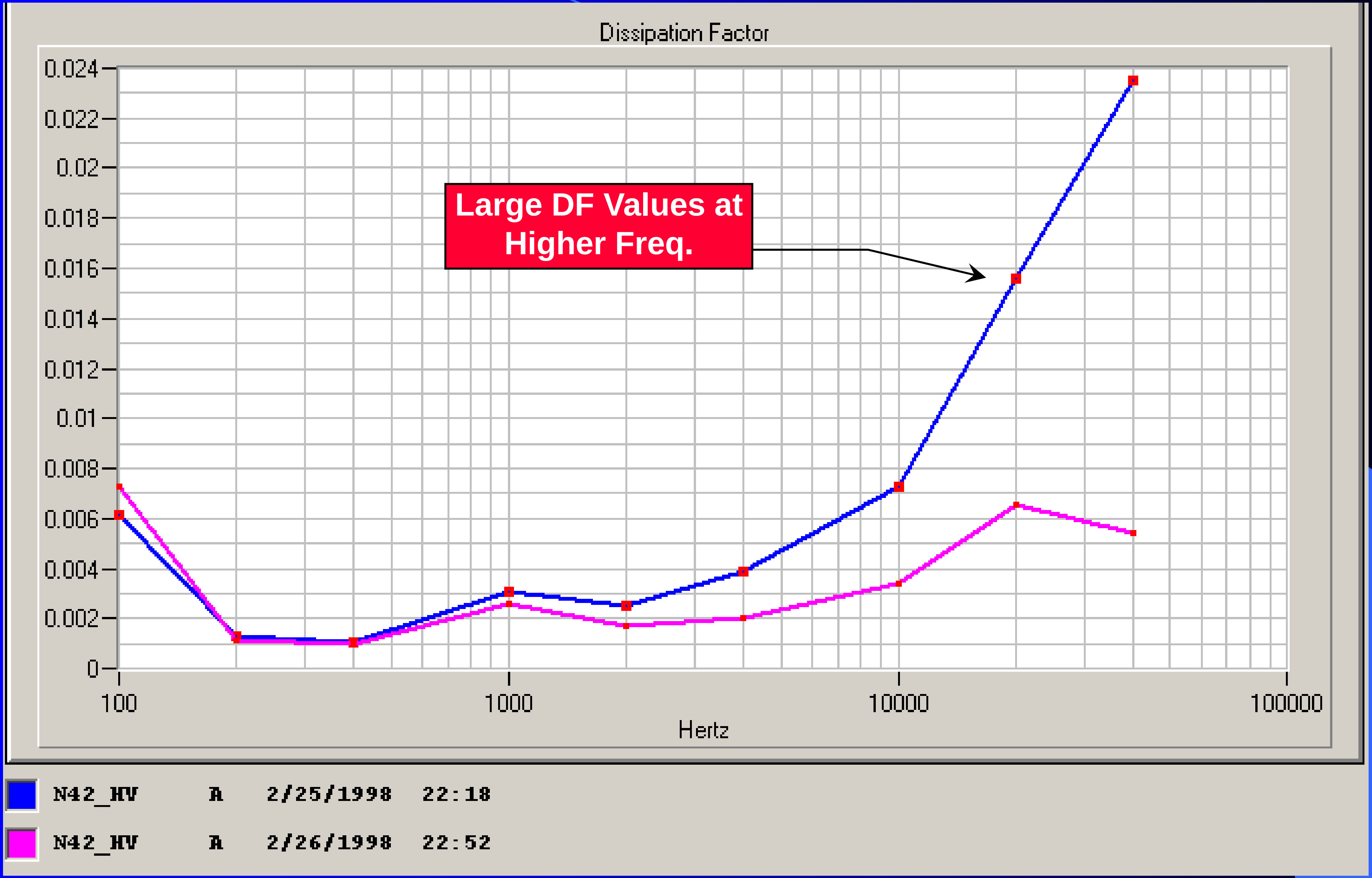
Enhanced View of Suspect Area



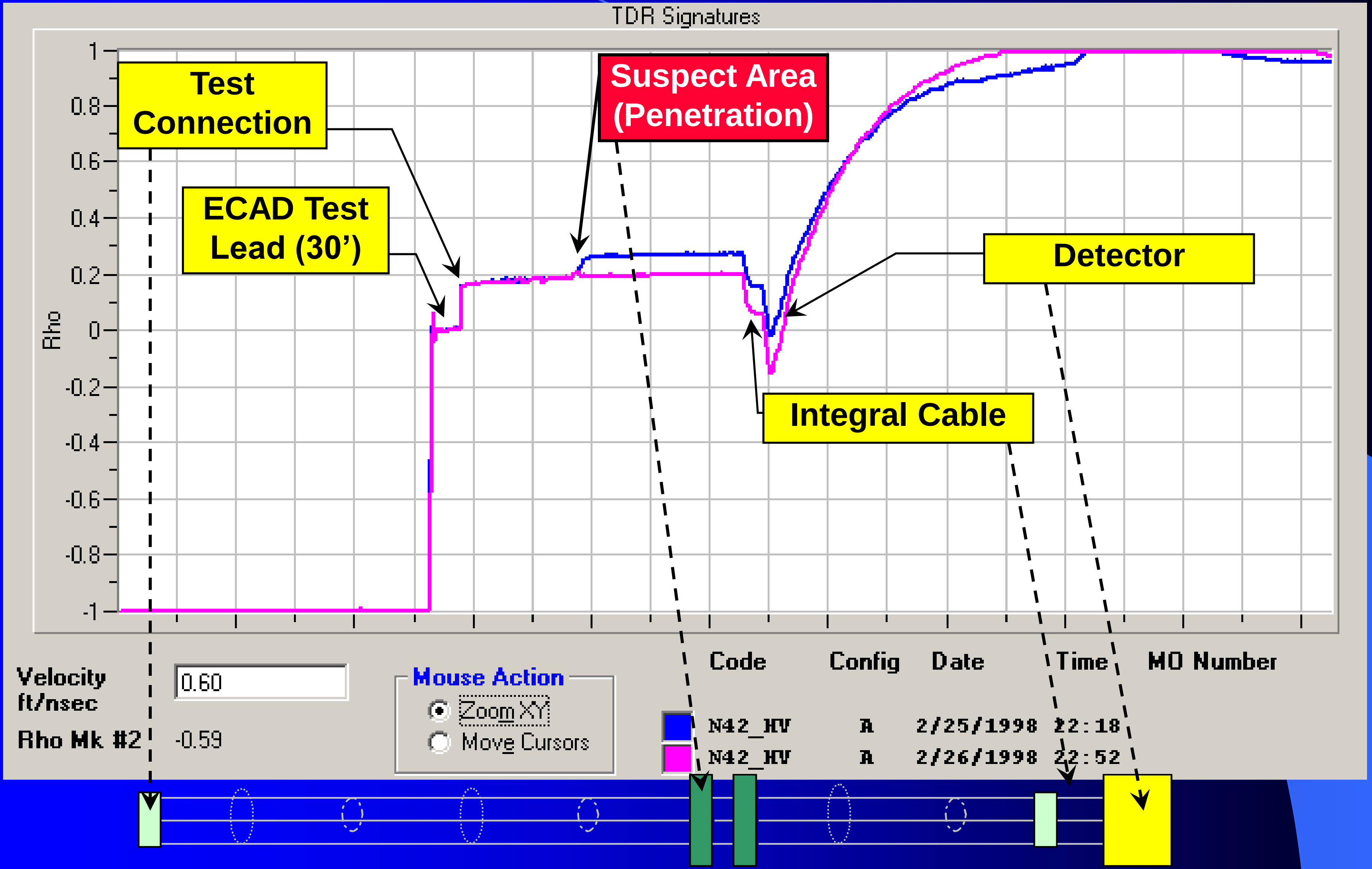
Case History #10

Resistive Connection

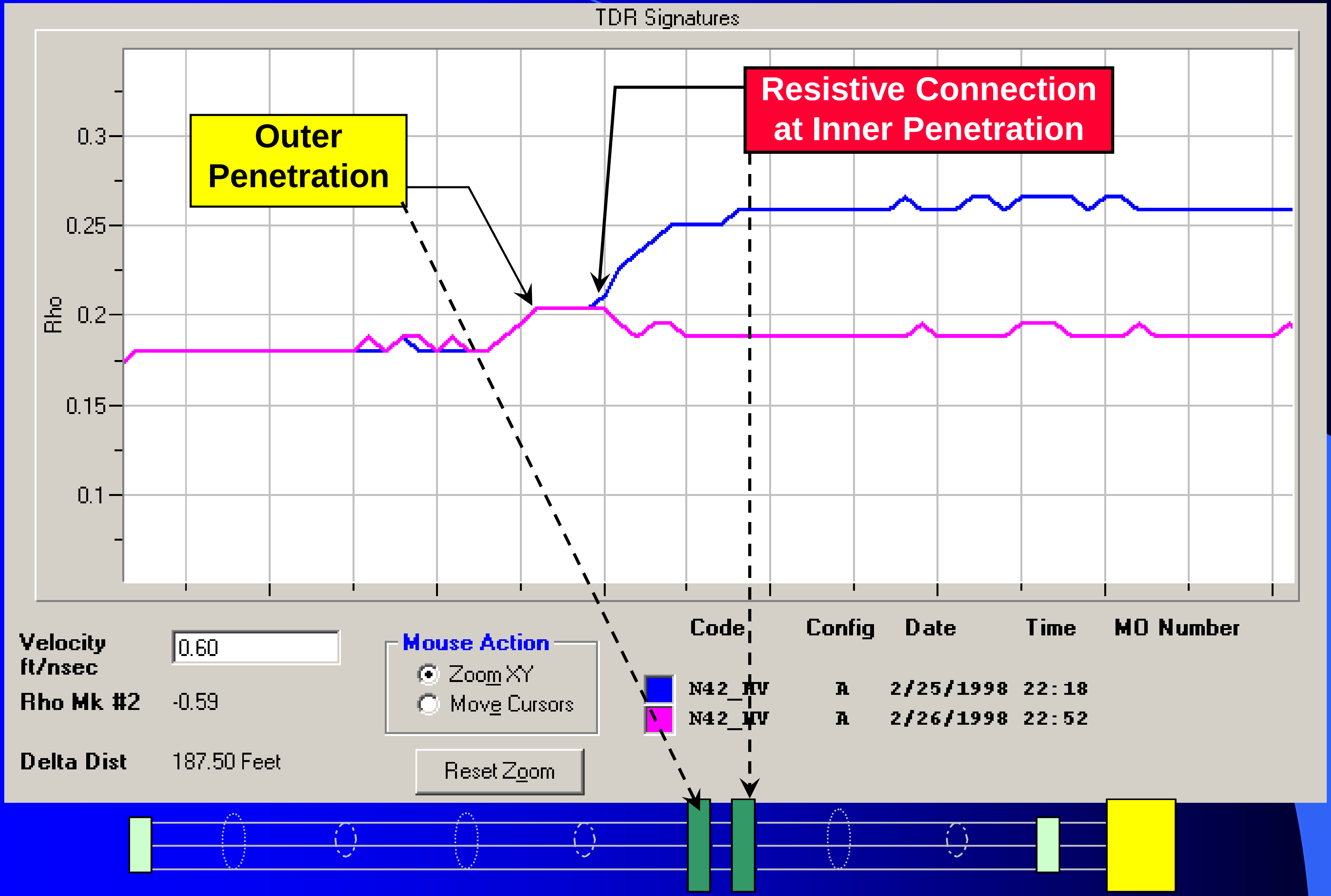
Dissipation Vs. Frequency Graph



Resistive Connection - TDR



Enhanced View of Suspect Area



Case History #11

4.16 kV Underground Feeder Cables (Moisture Intrusion)

4.16 kV Feeder Cable Data

Test Description

Cfg.	Description
A	Phase A to Phase B
B	Phase A to Phase C
C	Phase B to Phase C
D	Phase A to Shield (Drain)
E	Phase B to Shield (Drain)
F	Phase C to Shield (Drain)

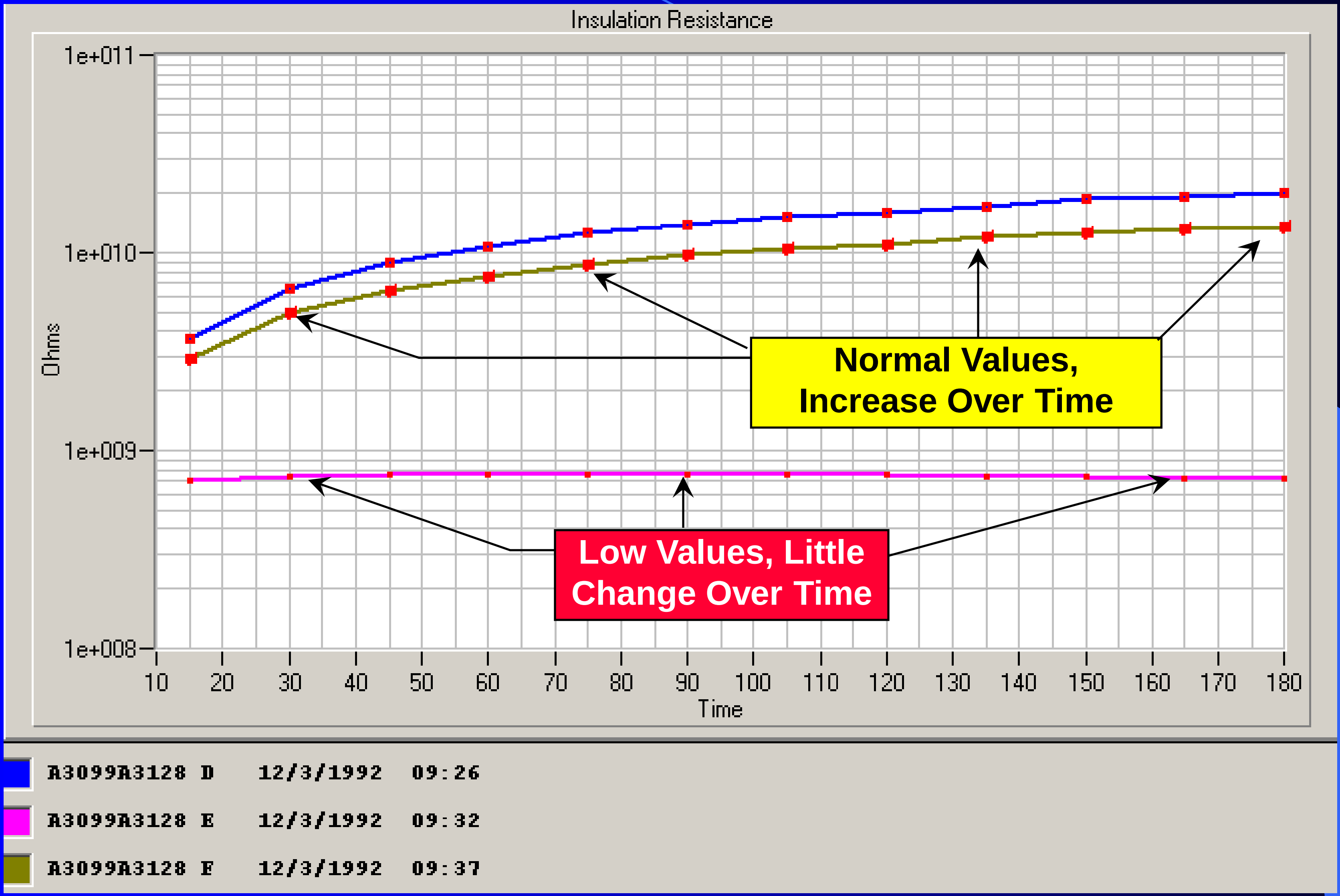
Phase to Phase Data

Device	Cfg.	IR	PR	Cap.	Diss.
A3099A3128	A	19.84 G	5.1	2.69 uF	4.71 D
A3099A3128	B	21.80 G	5.46	3.07 uF	5.43 D
A3099A3128	C	856.28 M	0.85	4.20 uF	7.07 D

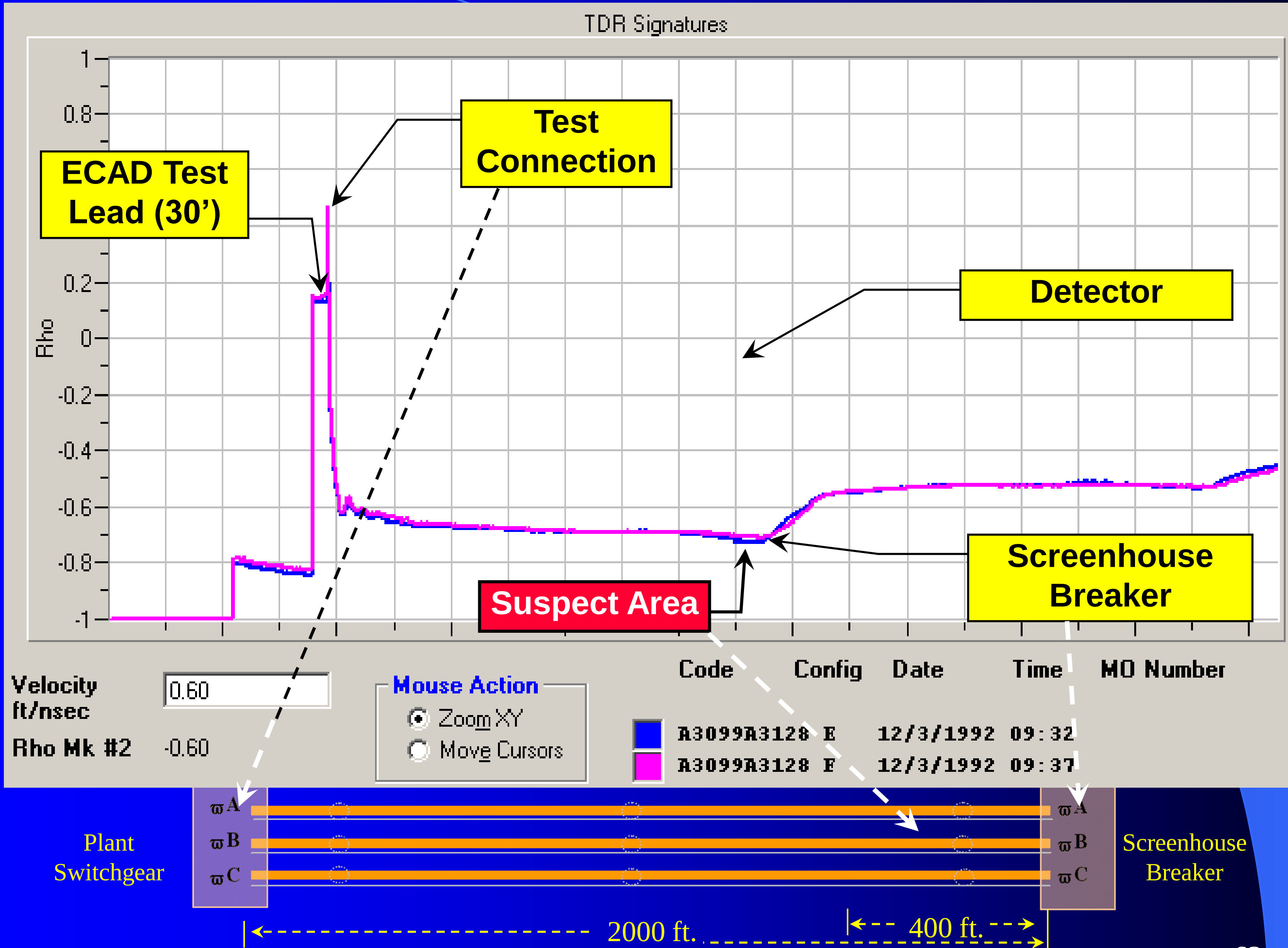
Phase to Shield (Drain) Data

Device	Cfg.	IR	PR
A3099A3128	D	20.02 G	5.49
A3099A3128	E	717.67 M	1.03
A3099A3128	F	13.60 G	4.7

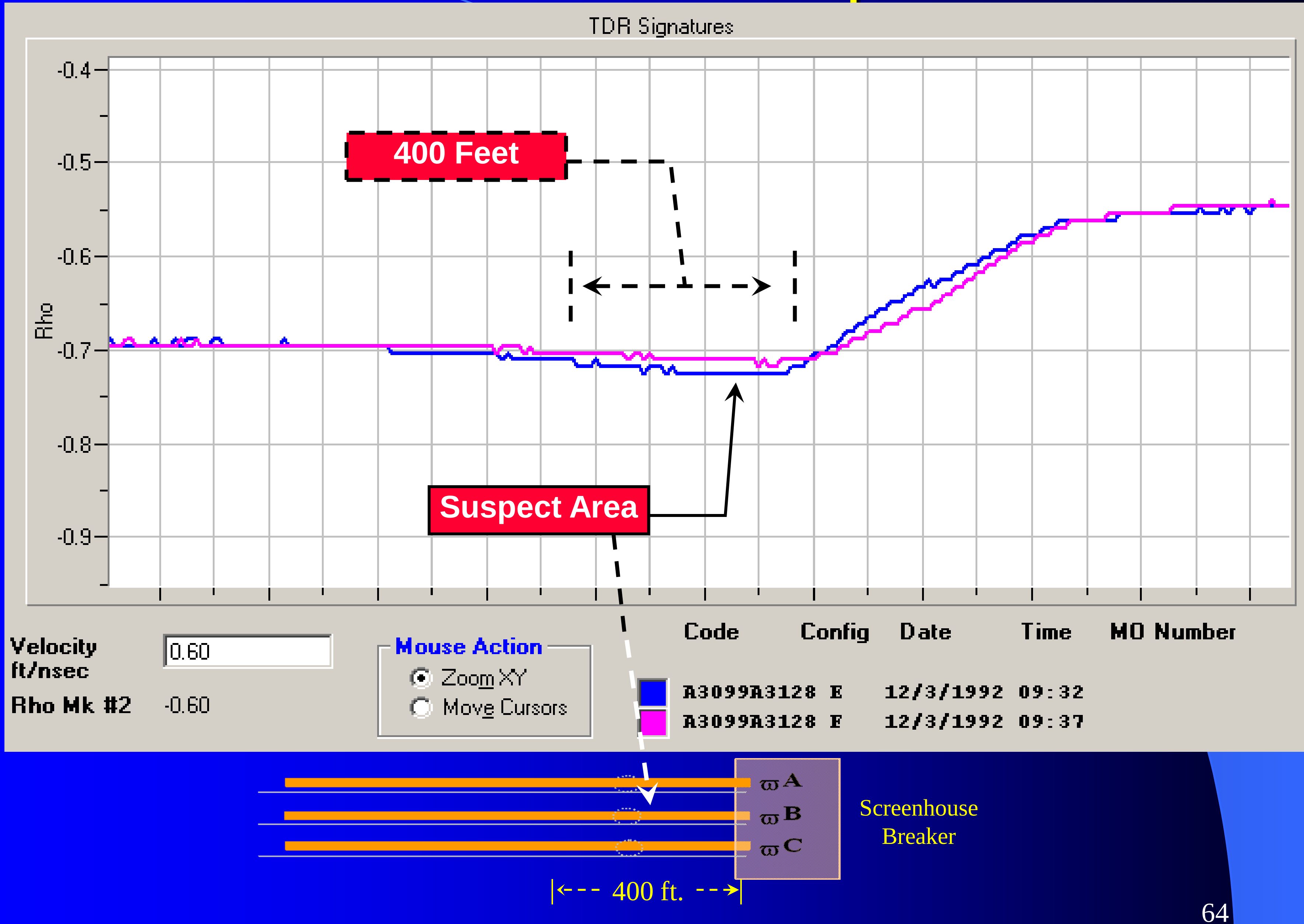
4.16 kV Feeder Cable – IR Vs. Time



4.16 kV Feeder Cable - TDRs



Enhanced View of Suspect Area



Case History #12

Conductor Geometry

Multiple Conductors Spiraled Around Single Conductor