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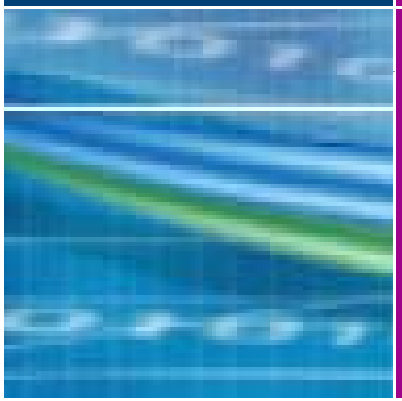

Bend Radius

Steve Lampen
Multimedia Technology Manager
Belden

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What We Believed

- Bending a cable affects the performance.
  - –Affects dimensions = impedance
  - –Impedance = reflection = Return Loss
- "Don't bend tighter than 10x diameter"
- Damage cannot be undone
  - –Unbending cable only hides damage
- Stranded cables are better at bending.
- Flexible cables are better at bending.
- Smaller cables are better at bending

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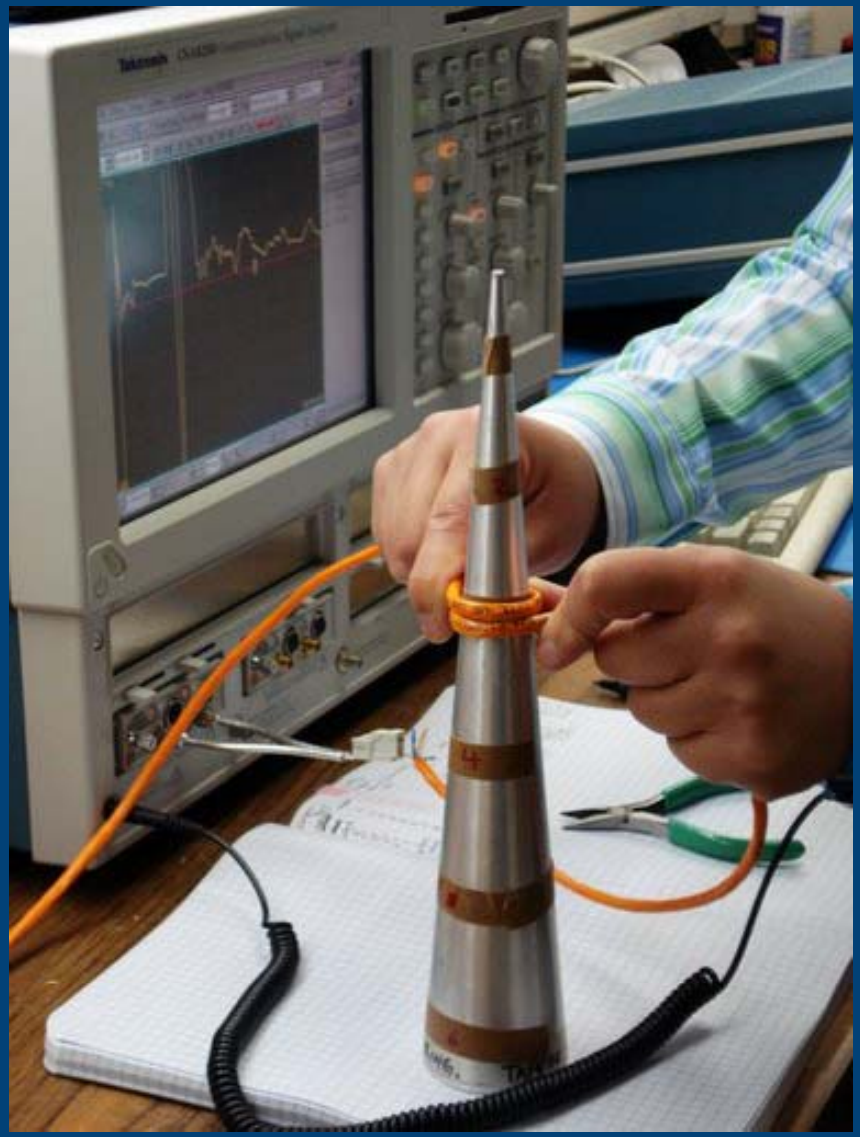
What We Did



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What We Did

- Cone mandrel
- 6” circumference maximum
- 1” circumference minimum

Cone Circumference	Equivalent Diameter	Radius
6 inches	1.908 inches	.954 inches
5 inches	1.592 inches	.796 inches
4 inches	1.272 inches	.636 inches
3 inches	.954 inches	.477 inches
2 inches	.636 inches	.318 inches
1 inches	.318 inches	.159 inches

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What We Did

- Tektronix 11801C
  - Digital Sampling Oscilloscope
- Special test jig for 75Ω coax
  - No connectors!
  - We weren't very careful
    - Not looking at connector
- First test – unbent
- 6", 5", 4", 3", 2", 1"
- Folded cable with pliers
- Unfolded cable by hand

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Cables We Tested

- All Belden cables
  - No competitors
- Belden 1694A HD coax RG-6
- Belden 1505A HD coax RG-59
- Belden 1694F HD coax flexible RG-6
- Belden 1505F HD coax flexible RG-59
- Belden 1800B AES 1-pair foil shield
- Belden 1800F flexible AES 1-pair braid shield

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Coax Requirements

- Bending changes dimensions
- Dimensions = Impedance
- Variations in Impedance = Return Loss
- Return loss = signal reflection
- Belden return loss on coax
  - Typical -30 dB (99.9% match, 0.1% reflection)

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Coax Requirements

- 4.5 GHz Guarantee:
  - -23 dB 5 MHz -1.6 GHz
  - -21 dB 1.6 GHz - 4.5 GHz
- 3 GHz Guarantee
  - -23 dB 5 MHz - 850 MHz
  - -23 dB 850 MHz - 3 GHz
- 1694F Flexible cable (much less precise)
  - -20 dB 5 MHz - 850 MHz
  - -15 dB 850 MHz - 4.5 GHz
- 1505F Flexible cable
  - -15 dB 5MHz -3GHz
- SMPTE limit (all passive parts in the line)
  - -15 dB 5 MHz - 1.5 GHz
  - -10 dB 1.5 GHz - 3 GHz

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Critical Distance

- Quarter-wavelength
  - 4.5 GHz = 0.656 inches
  - 3 GHz = 0.984 inches
  - 1.5 GHz = 1.968 inches
  - 405 MHz = 7.289 inches

DIGITAL AUDIO

  - 75 MHz = 3.28 FEET
  - 24.576 MHz (192 kHz sampling) = 10.01 feet
  - 12.288 MHz (96 kHz sampling)= 20.02 feet
  - 6.144 MHz (48 kHz sampling) = 40.04 feet
  - 5.6448 MHz (44.1 kHz sampling) = 43.58 feet

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Belden 1694A HD Coax

Belden 1694A diameter (OD) = 0.275”

Circumference	Diameter	Radius	X 1694A Diameter
6 inches	1.908 inches	.954 inches	3.47
5 inches	1.592 inches	.796 inches	2.85
4 inches	1.272 inches	.636 inches	2.31
3 inches	.954 inches	.477 inches	1.73
2 inches	.636 inches	.318 inches	1.16
1 inches	.318 inches	.159 inches	0.58

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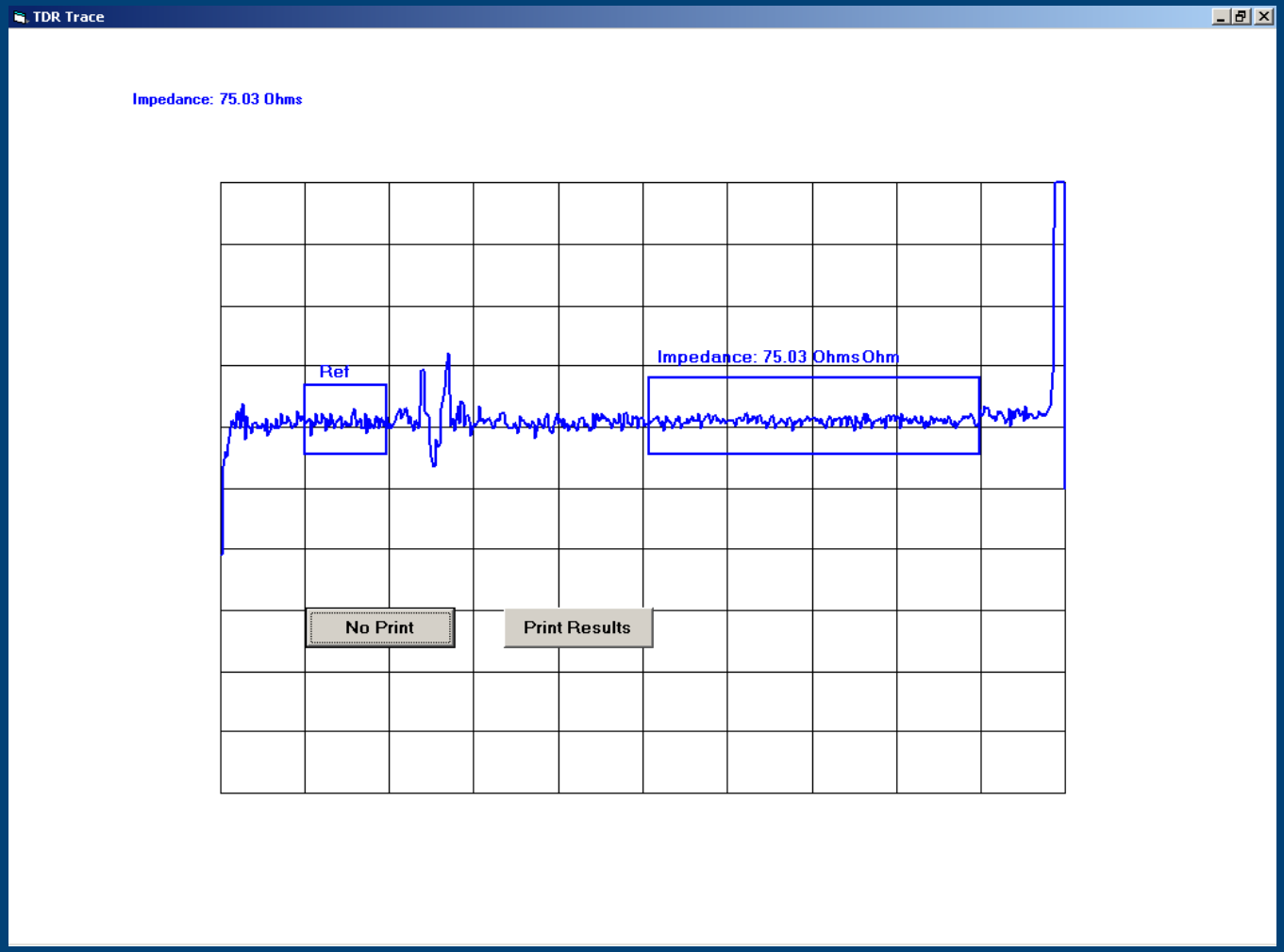
Belden 1694A Normal



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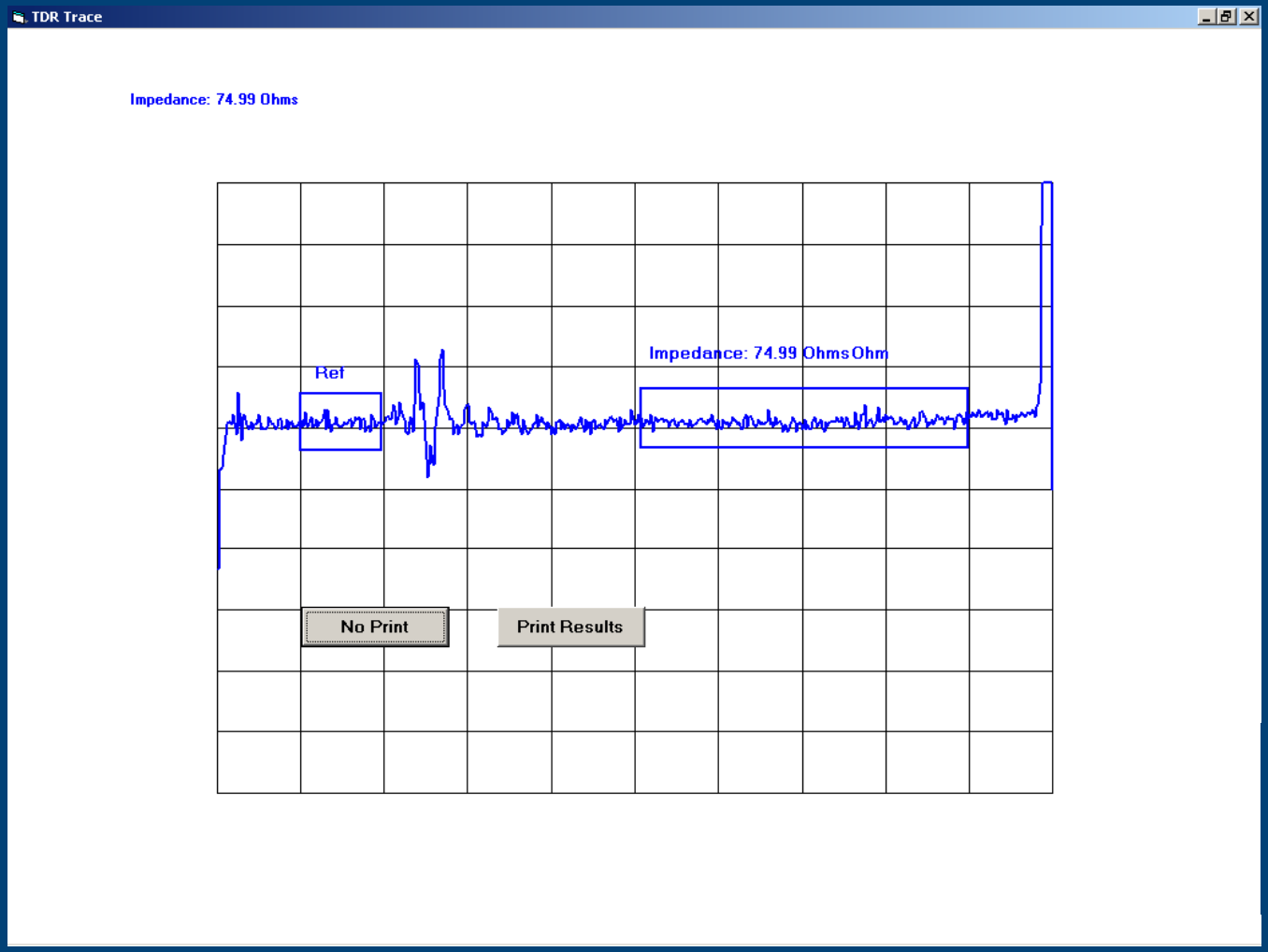
Belden 1694A at 3.47 x Diameter



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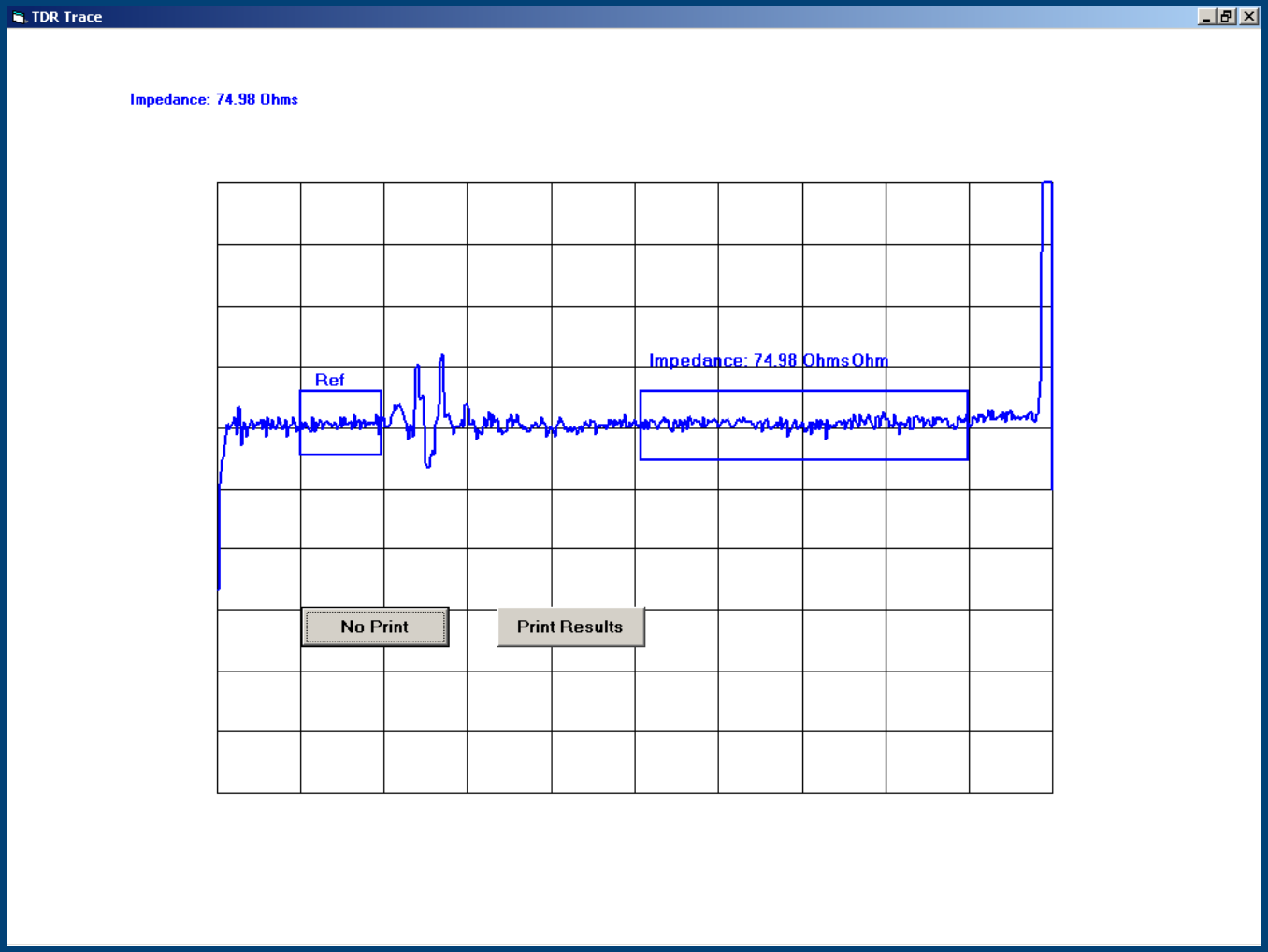
Belden 1694A at 2.85 x Diameter



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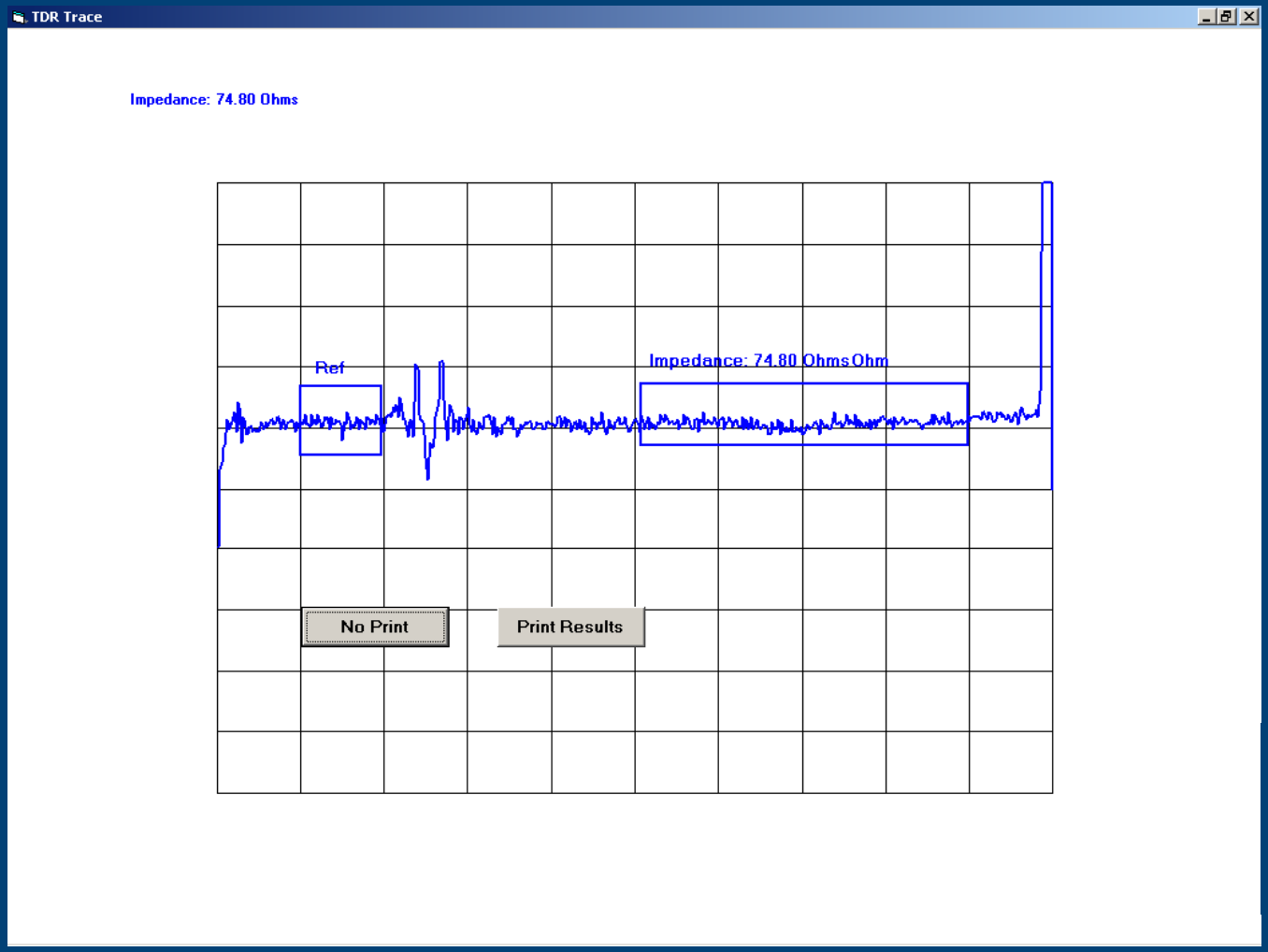
Belden 1694A at 2.31 x Diameter



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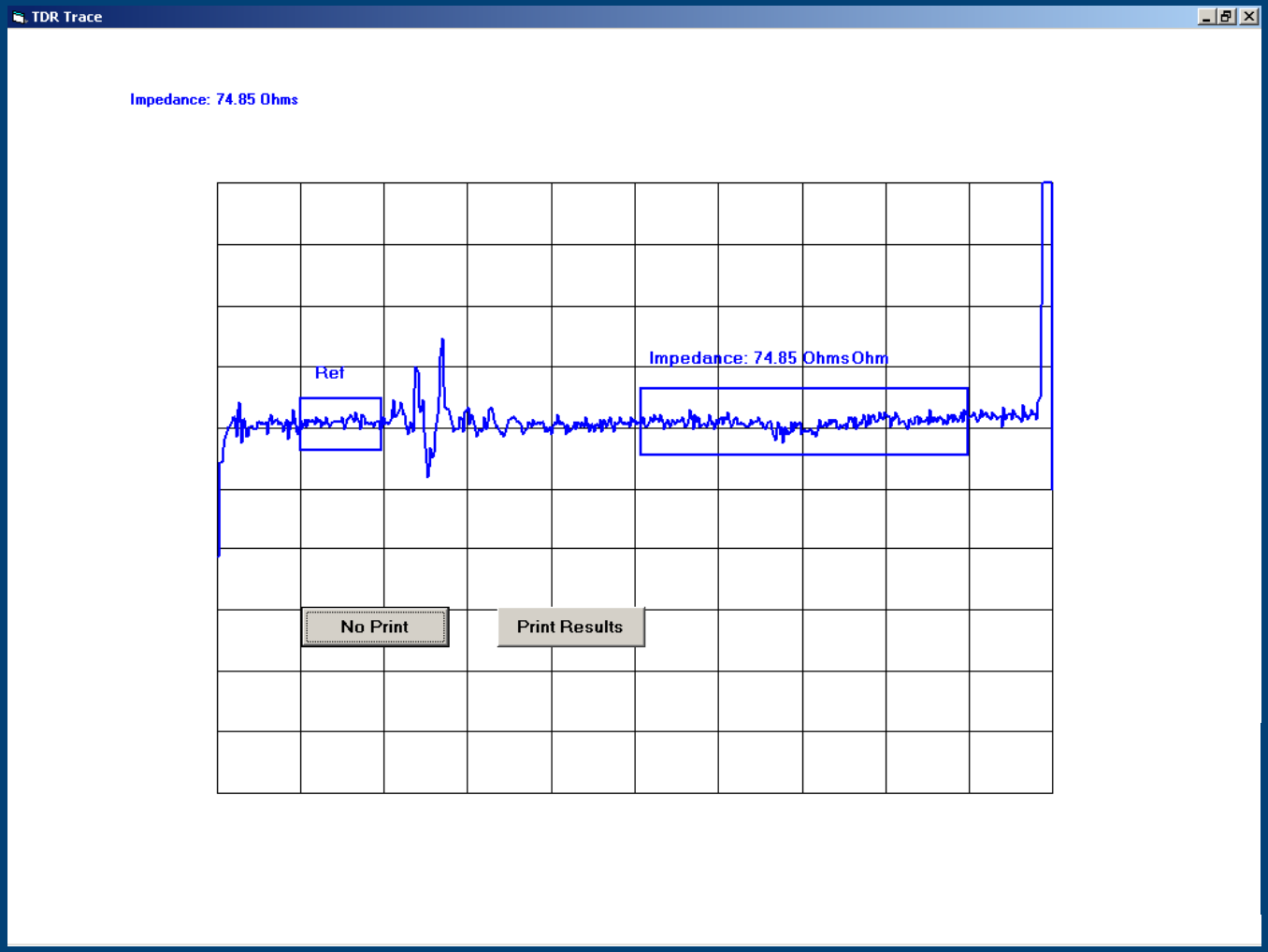
Belden 1694A at 1.73 x Diameter



Low point = 73.15Ω= -38.07 dB RL

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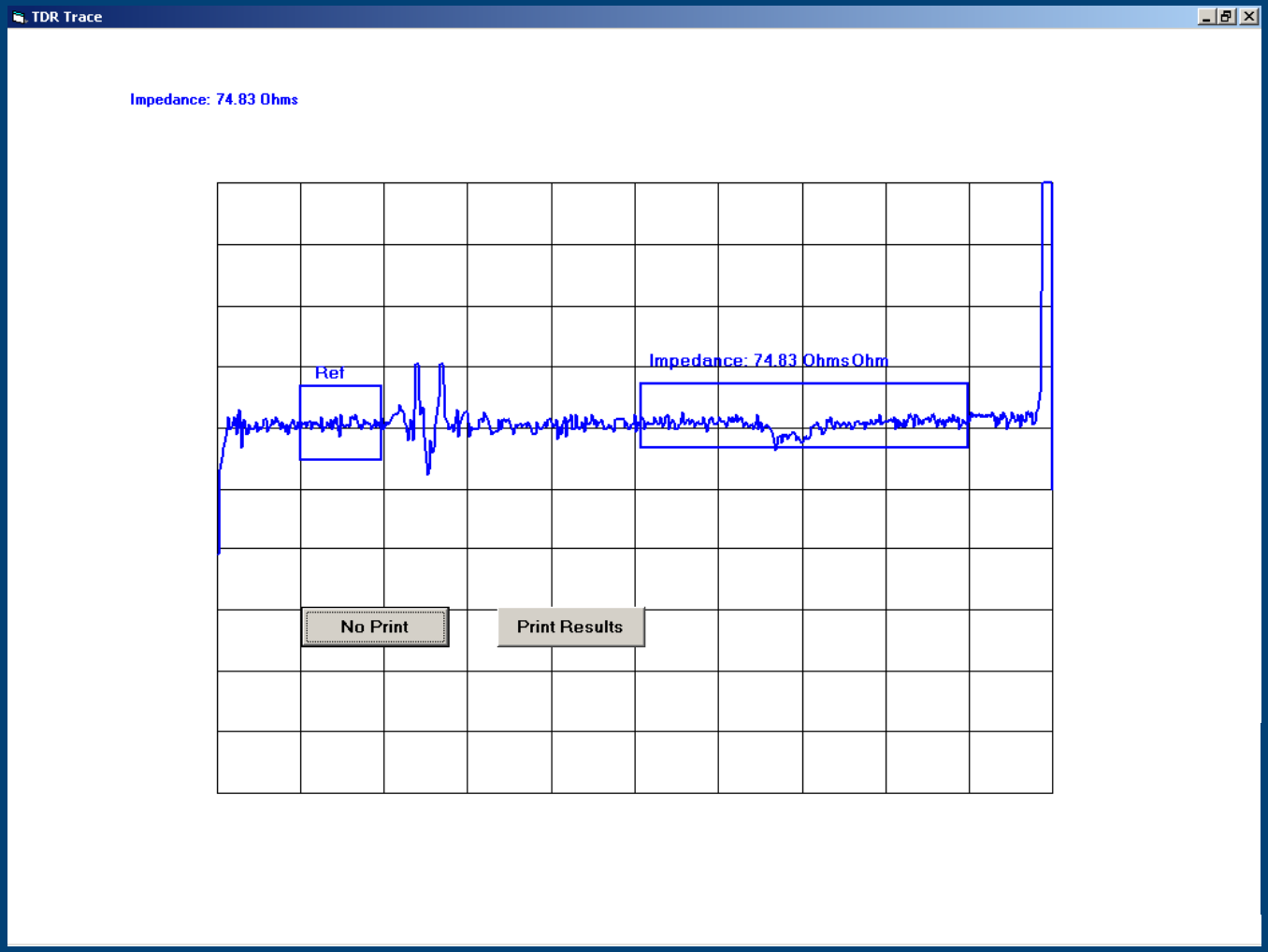
Belden 1694A at 1.16 x Diameter



Low point = 71.95Ω= -33.65 dB RL

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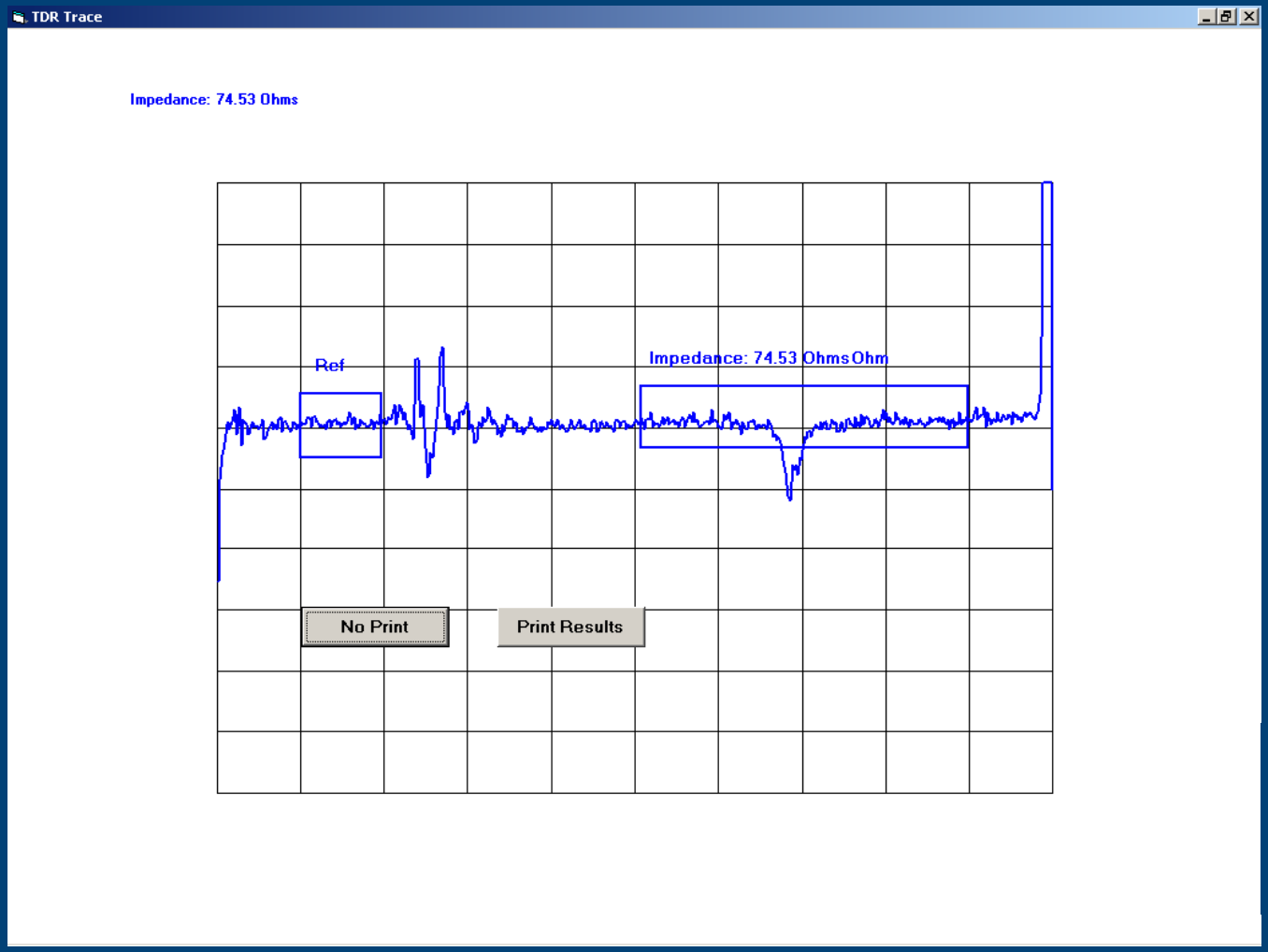
Belden 1694A at 0.58 x Diameter



Low point = 67.5Ω= -25.57 dB RL

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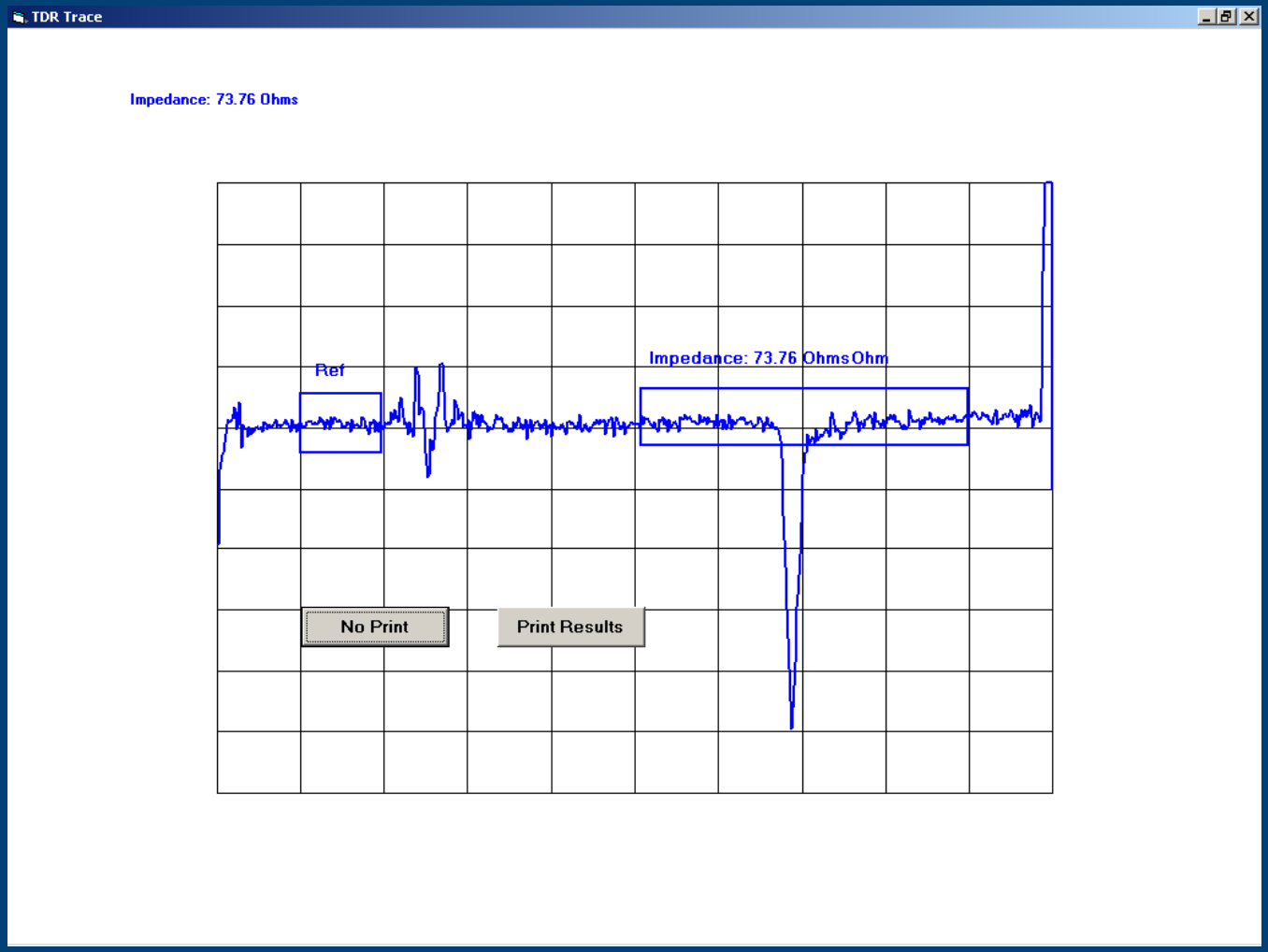
Belden 1694A Folded with Pliers



Low point = 49.7Ω= -13.85 dB RL

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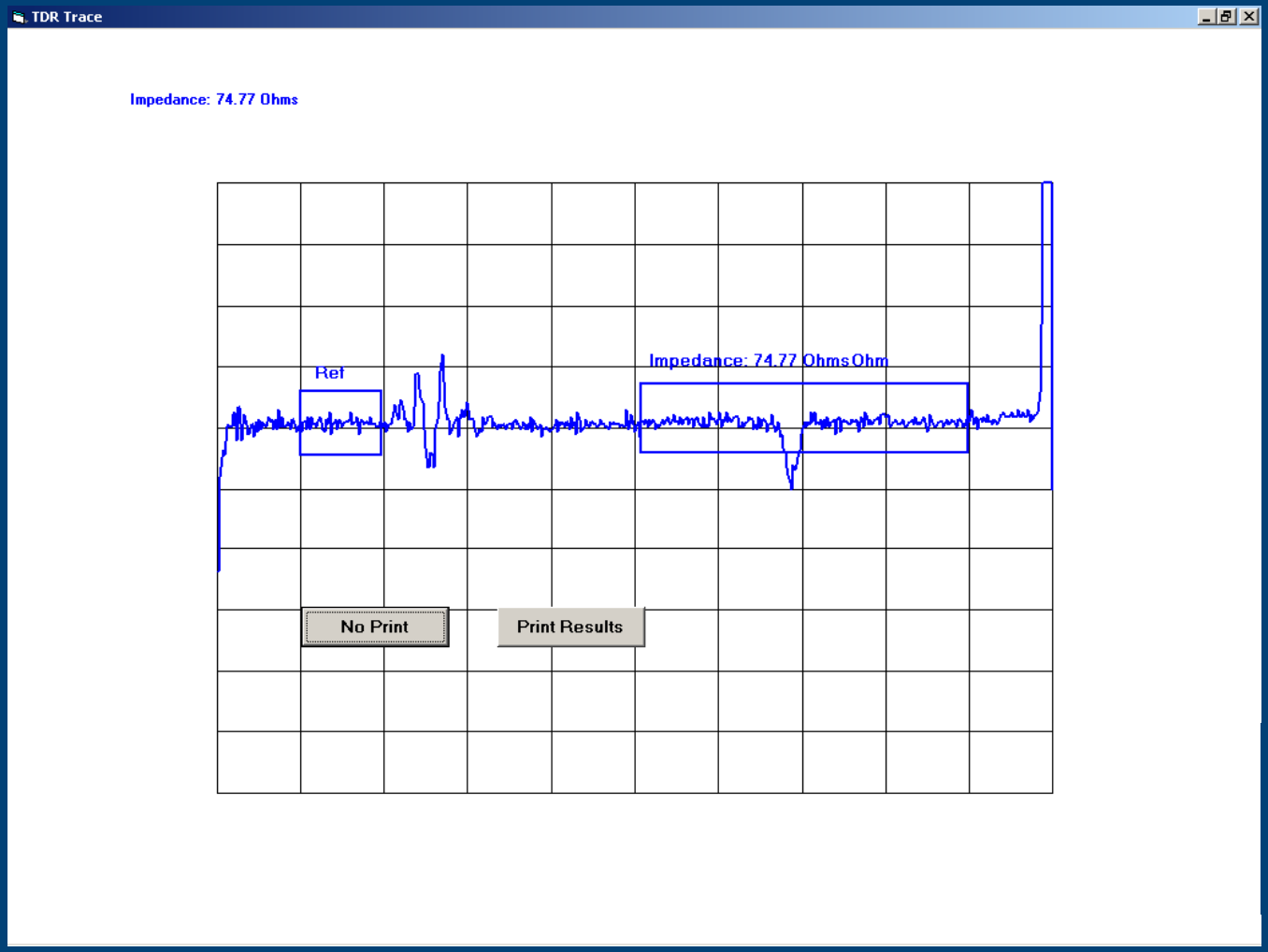
Belden 1694A “Unfolded”



Low point = 68.5Ω= -26.88 dB RL

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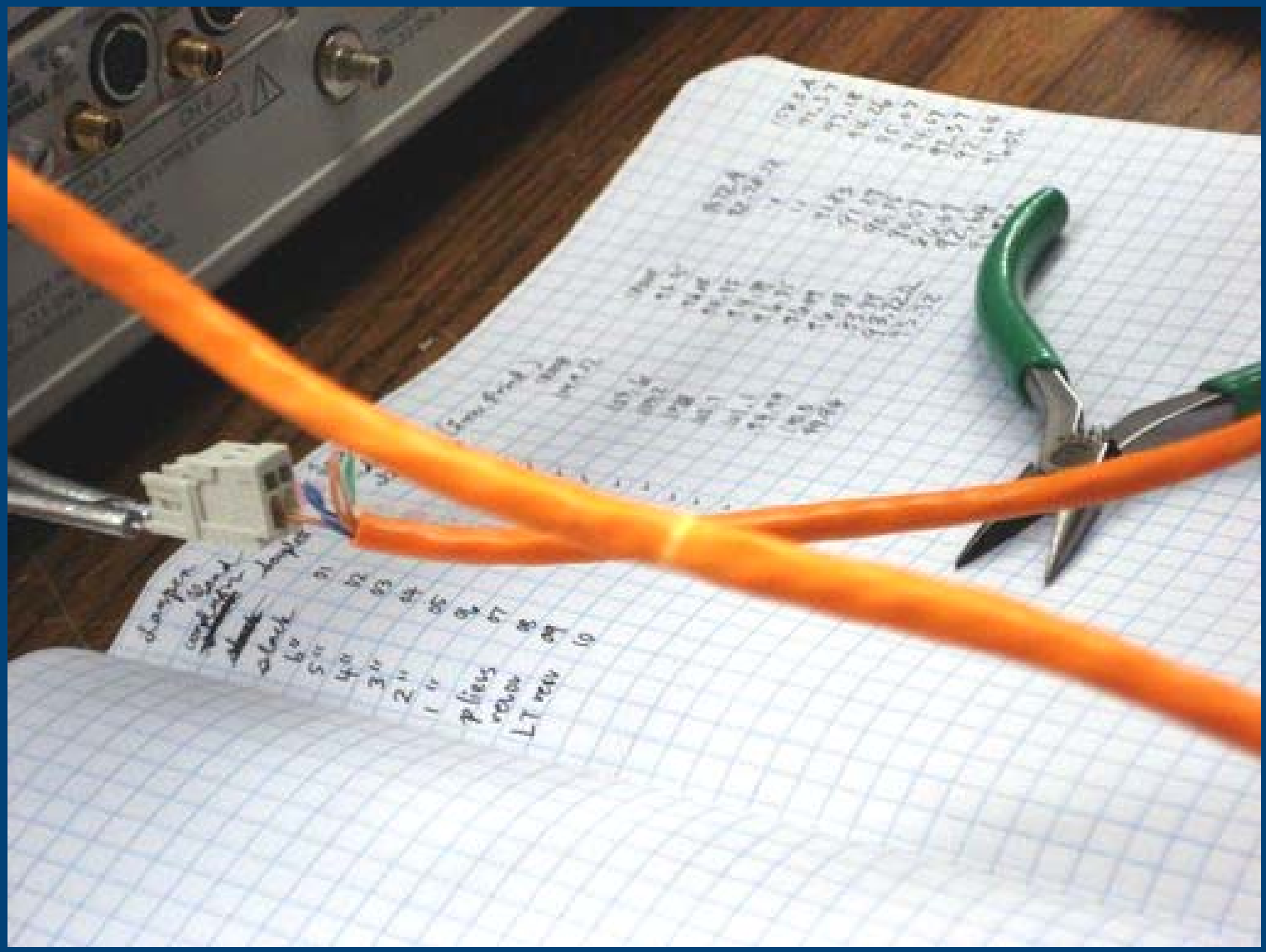
Stress Whitening



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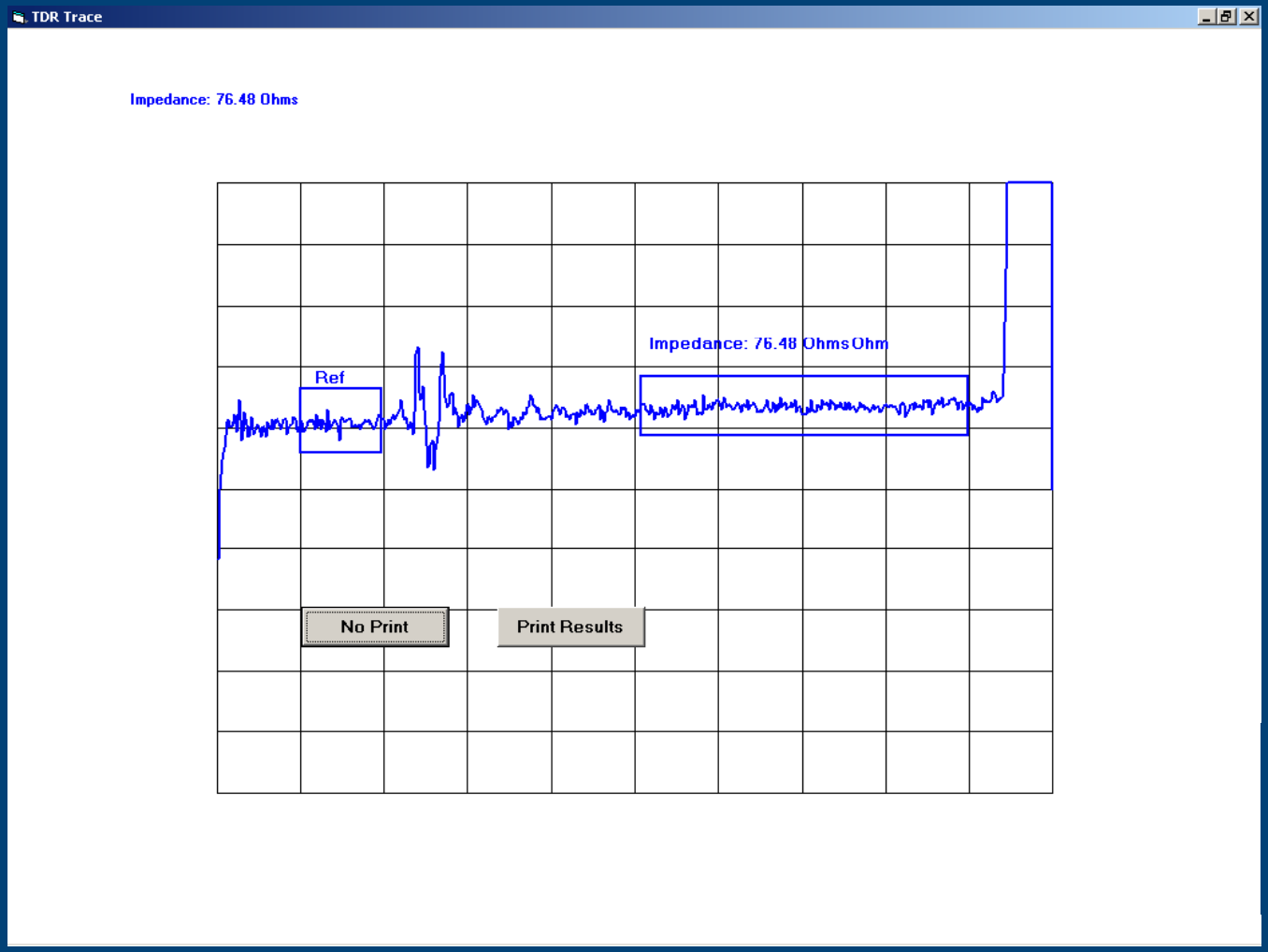
Belden 1505A

Circumference	Diameter	Radius	X 1505A Diameter
6 inches	1.908 inches	.954 inches	4.06
5 inches	1.592 inches	.796 inches	3.39
4 inches	1.272 inches	.636 inches	2.71
3 inches	.954 inches	.477 inches	2.03
2 inches	.636 inches	.318 inches	1.35
1 inches	.318 inches	.159 inches	1.18

©2008 Belden

Belden 1505A Normal



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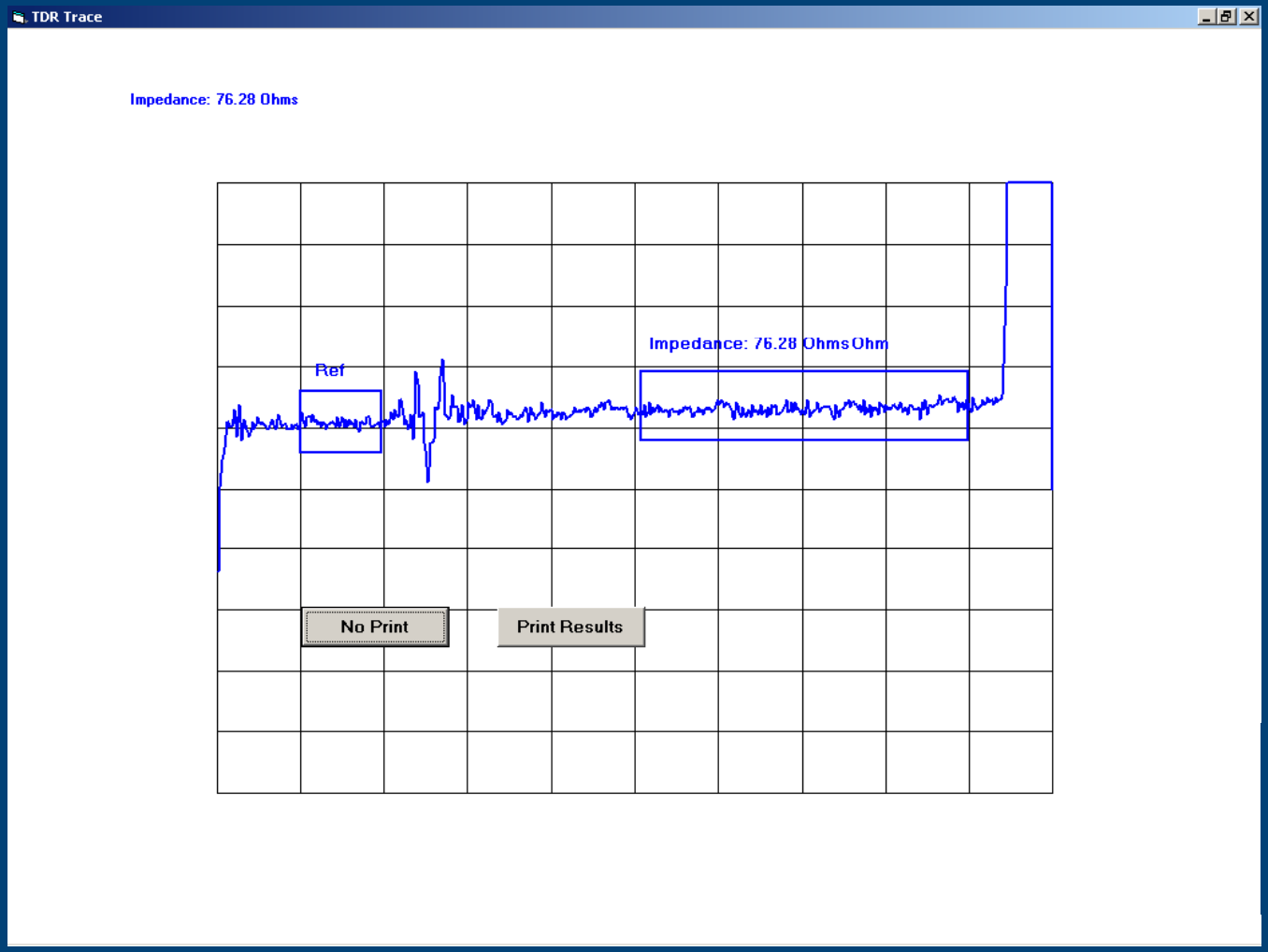
Belden 1505A at 4.06 x Diameter



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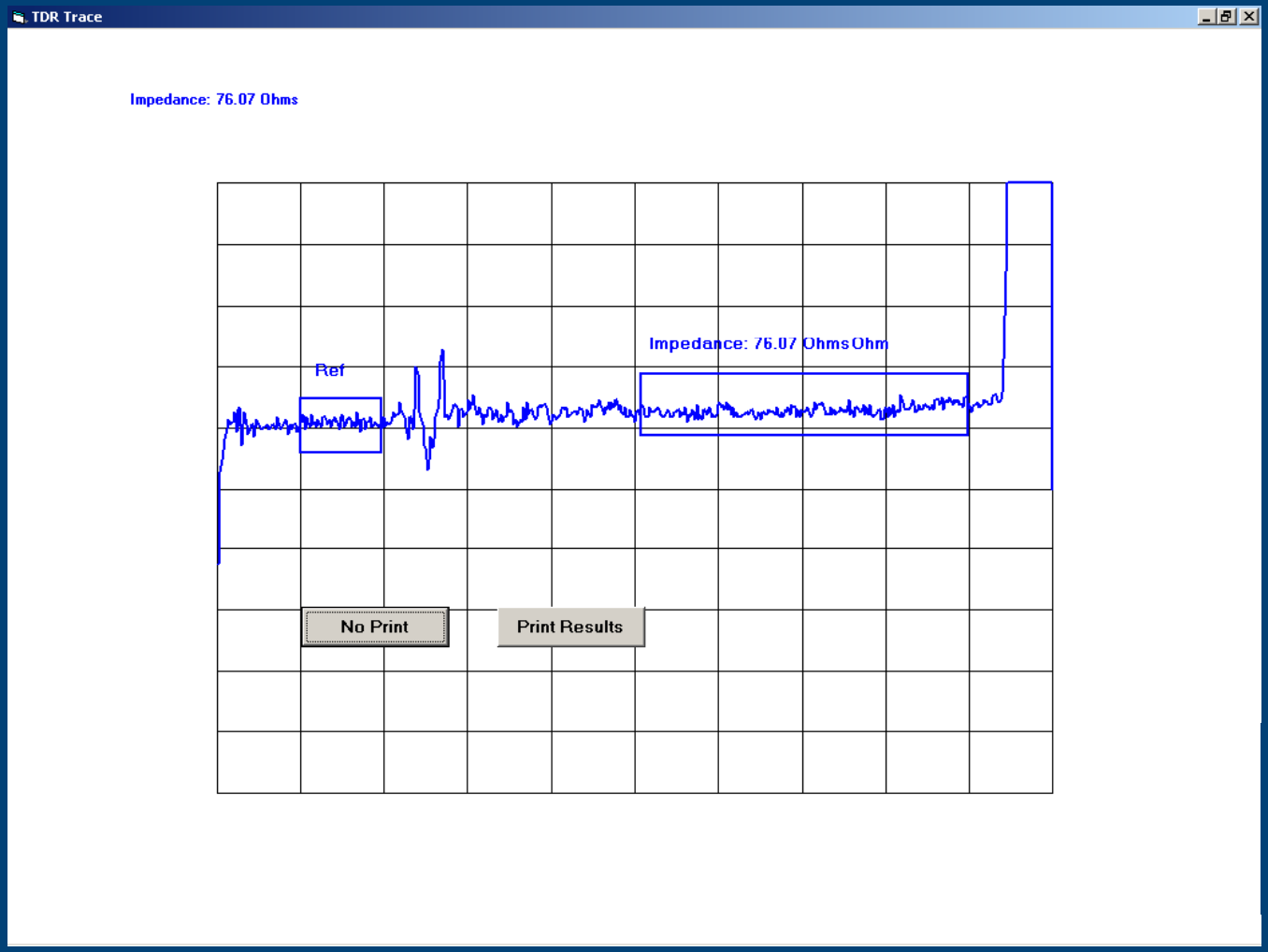
Belden 1505A at 3.39 x Diameter



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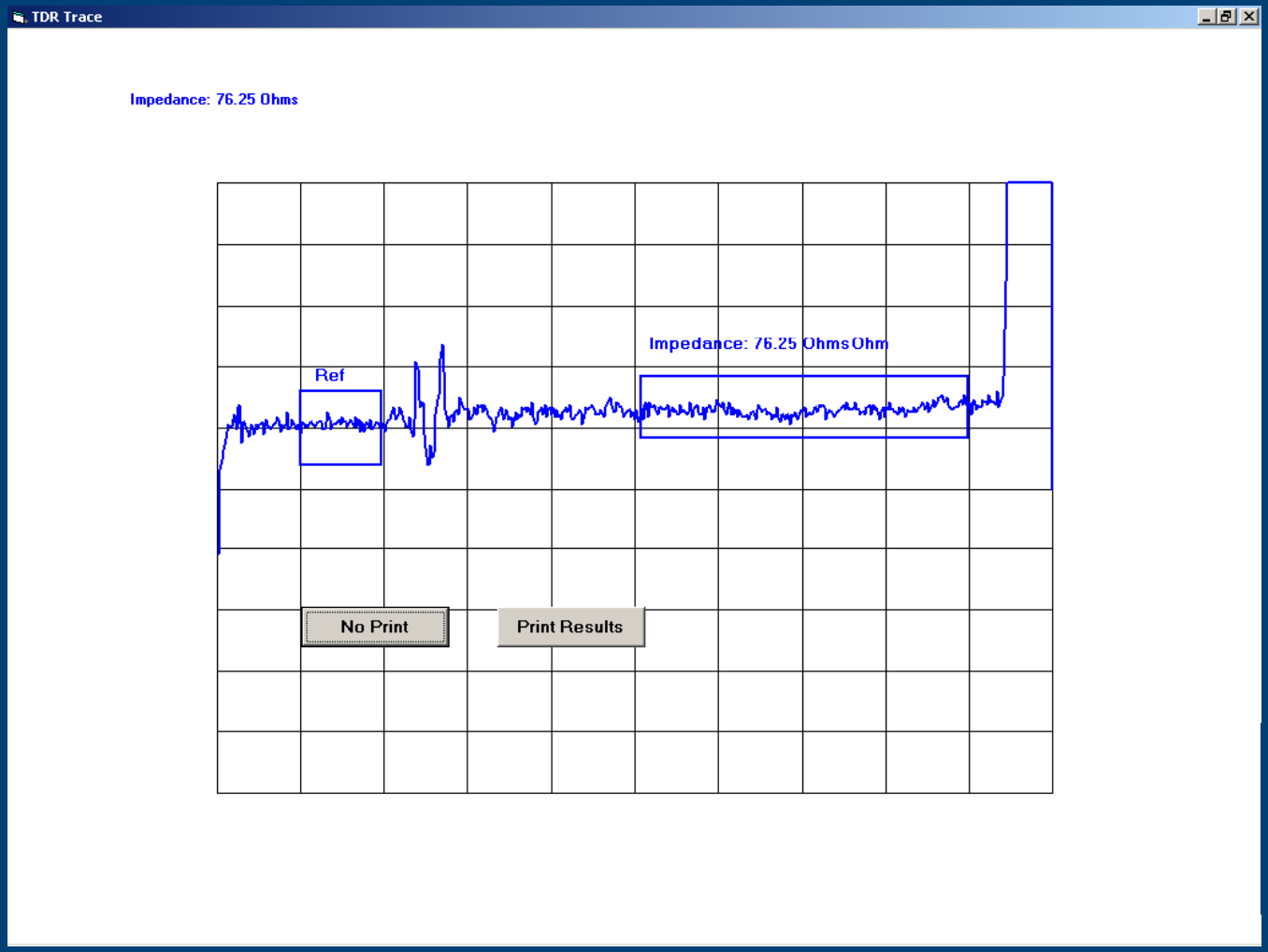
Belden 1505A at 2.71 x Diameter



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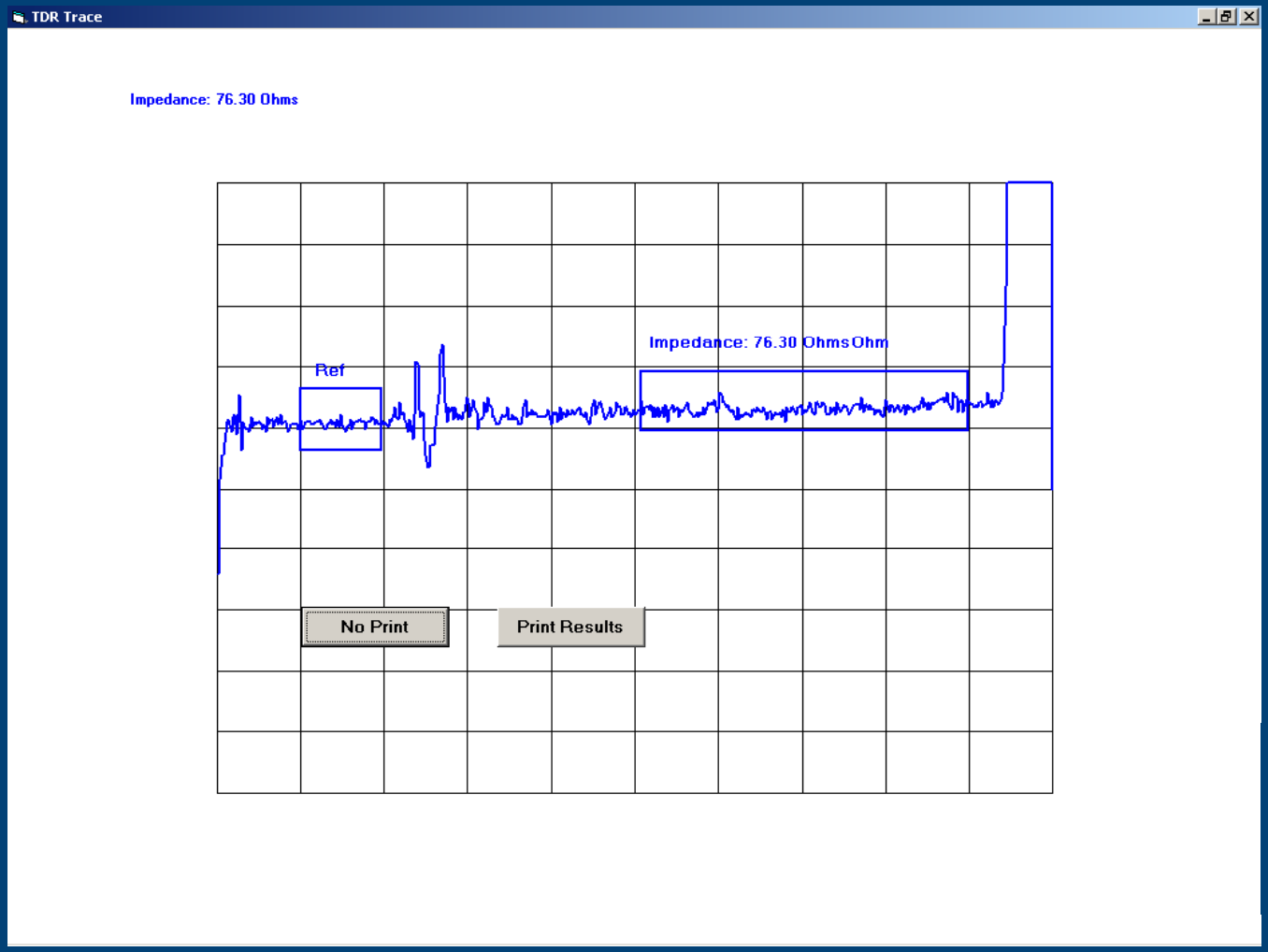
Belden 1505A at 2.03 x Diameter



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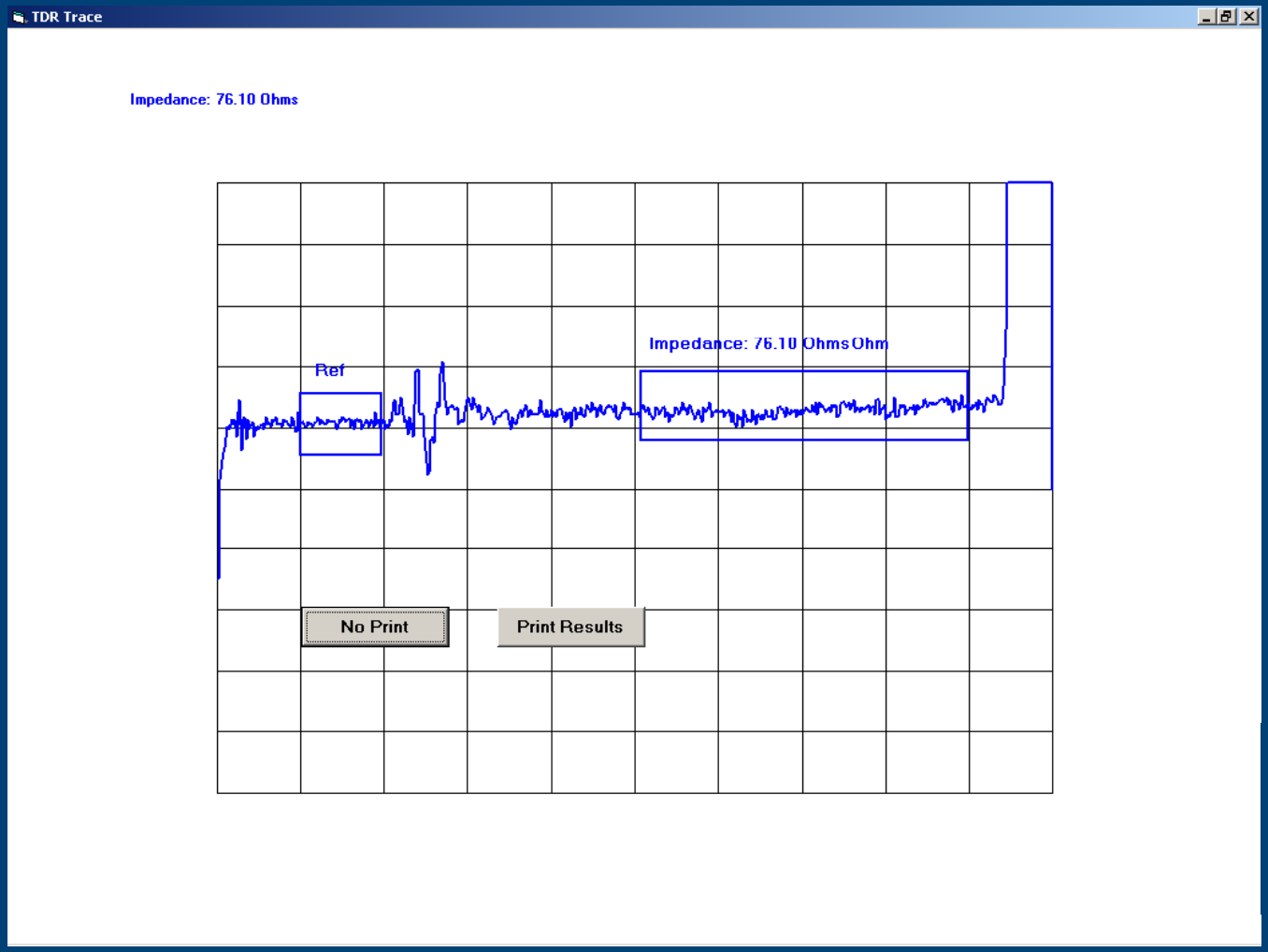
Belden 1505A at 1.35 x Diameter



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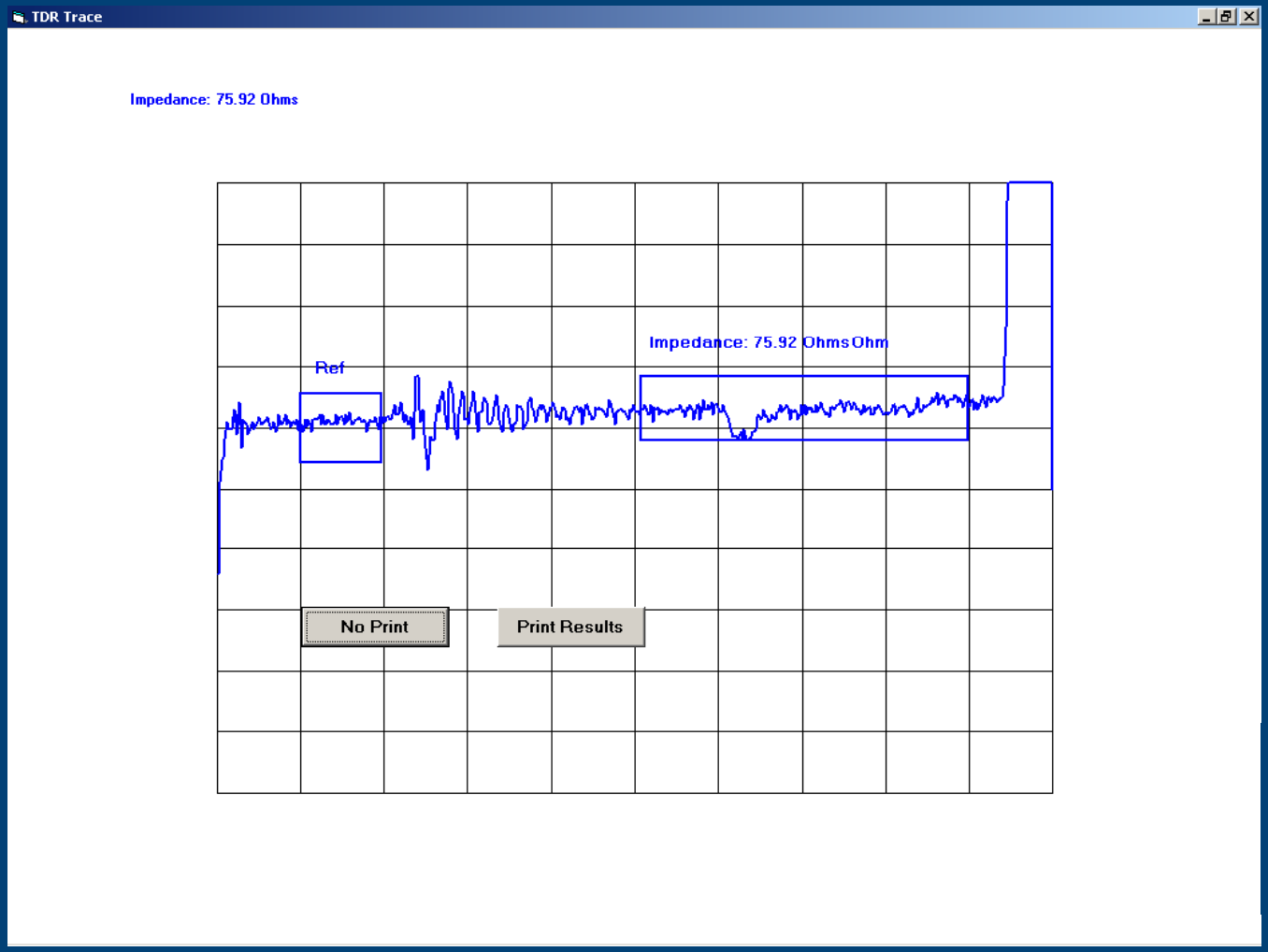
Belden 1505A at 1.18 x Diameter



Low point = 72.7Ω = -36.15 dB RL

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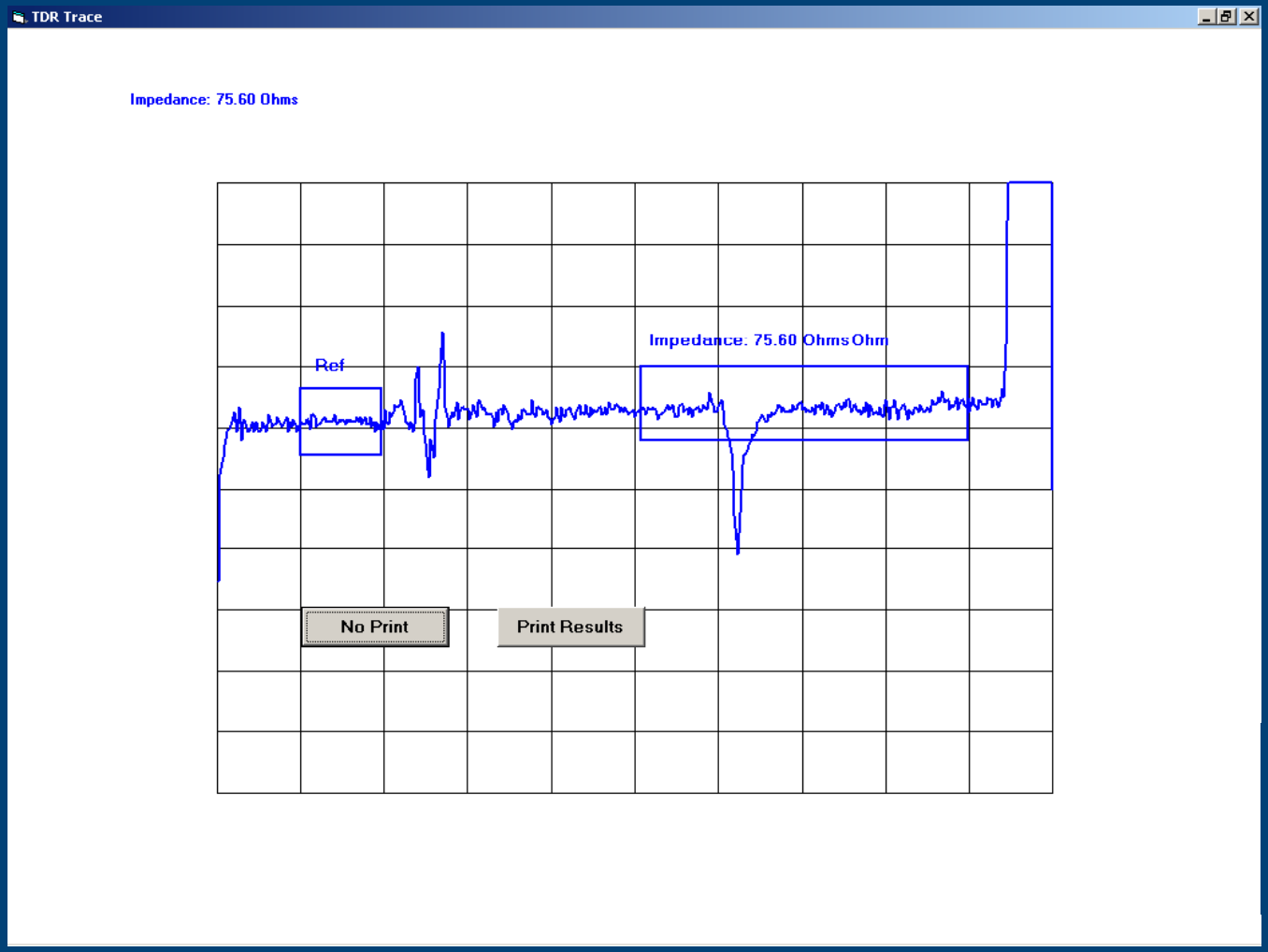
Belden 1505A Folded with Pliers



Low point = 62.49Ω = -20.82 dB RL

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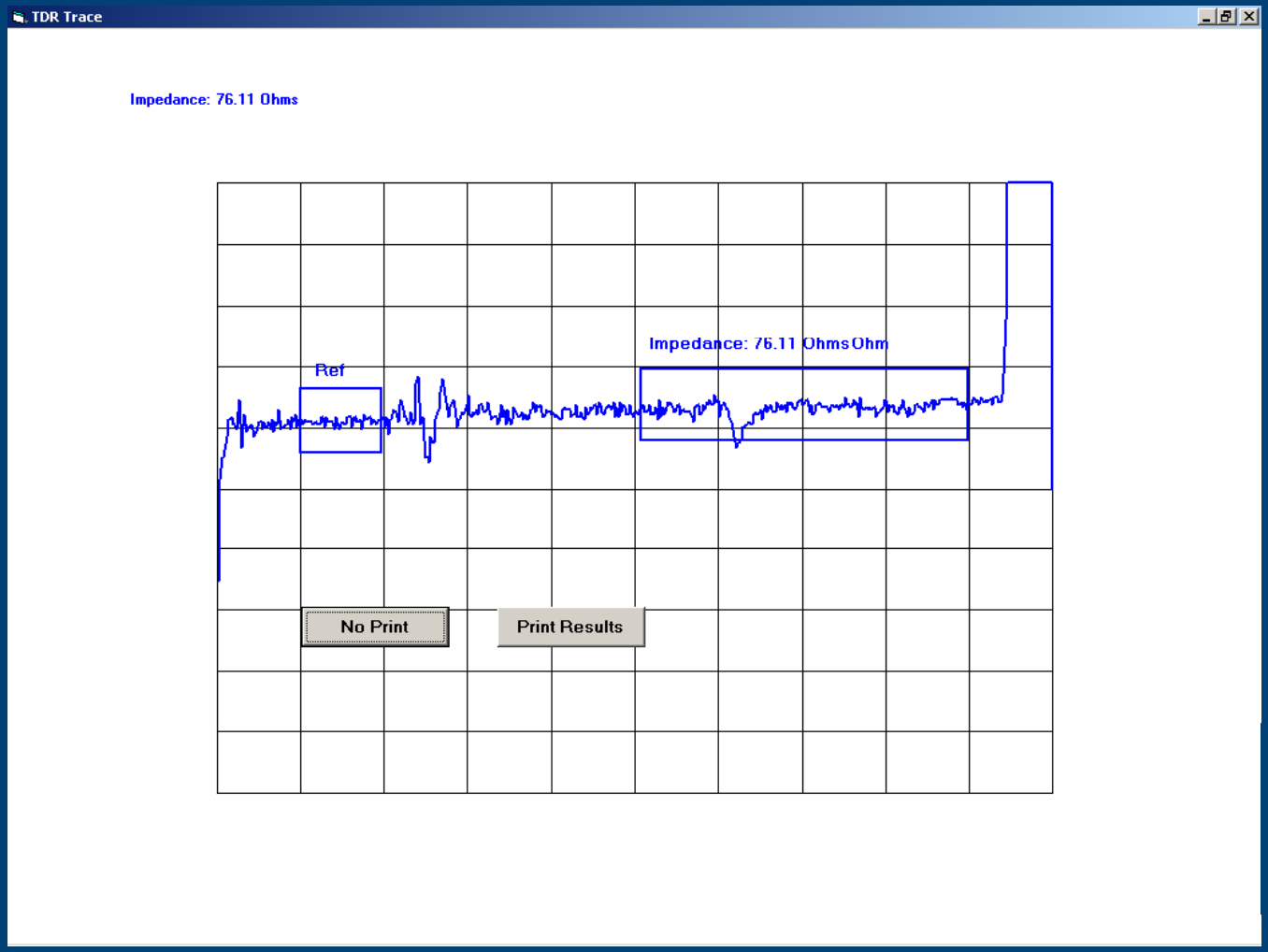
Belden 1505A Unfolded



Low point = 71.83Ω= -33.31 dB RL

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Belden 1694F

Circumference	Diameter	Radius	X 1694F Diameter
6 inches	1.908 inches	.954 inches	3.47
5 inches	1.592 inches	.796 inches	2.85
4 inches	1.272 inches	.636 inches	2.31
3 inches	.954 inches	.477 inches	1.73
2 inches	.636 inches	.318 inches	1.16
1 inches	.318 inches	.159 inches	0.58

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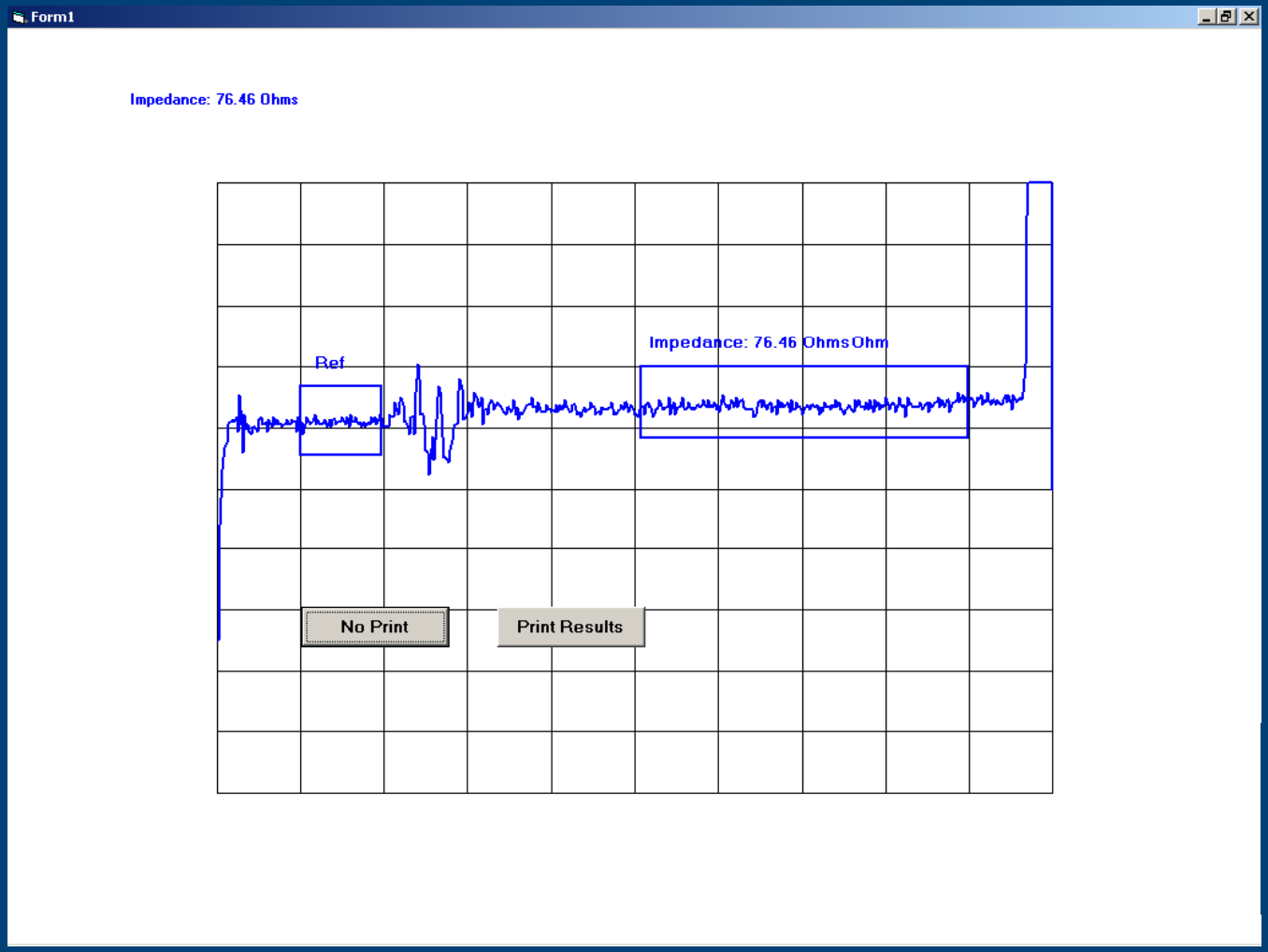
Belden 1694F Normal



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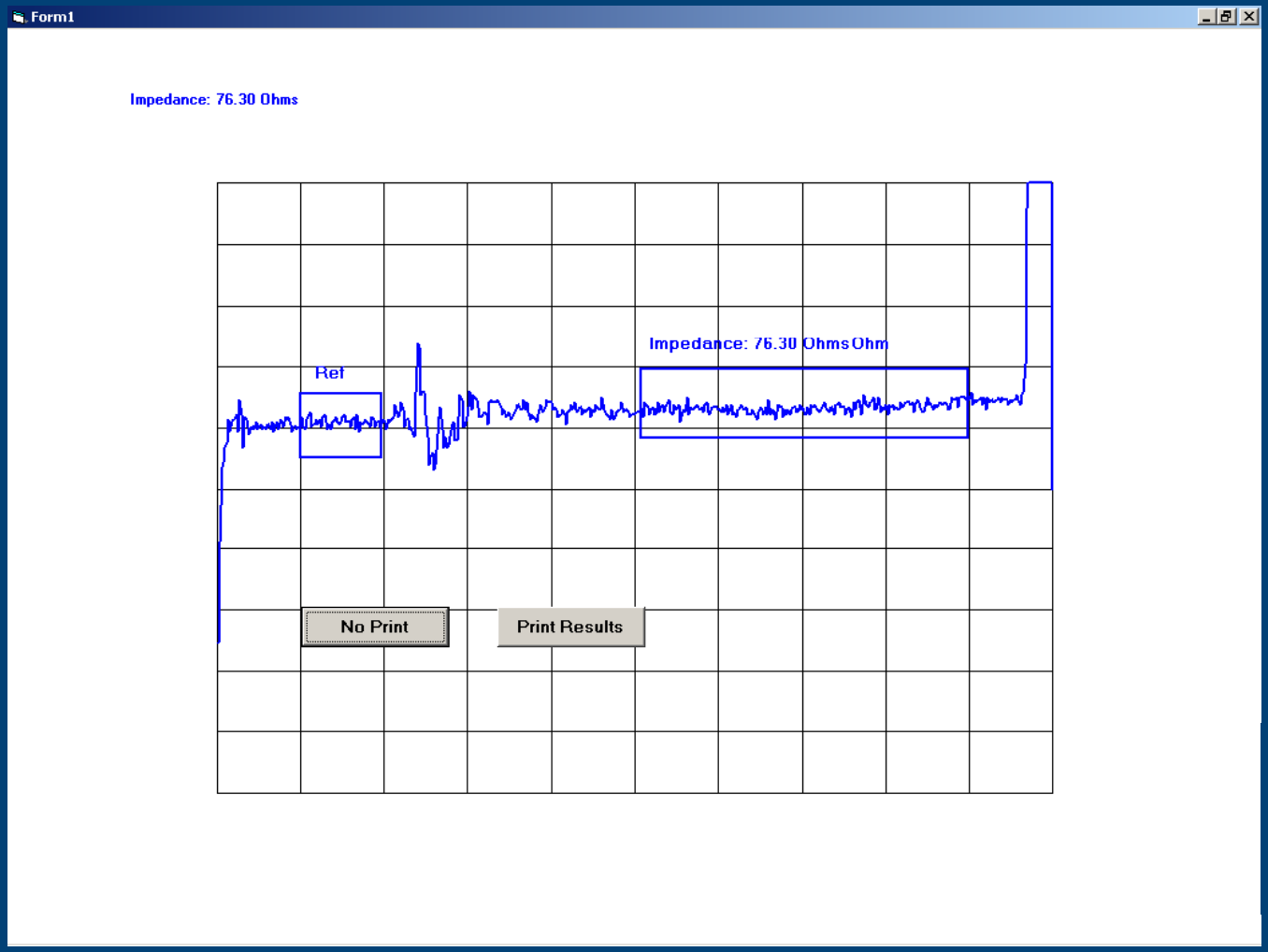
Belden 1694F at 3.47 x Diameter



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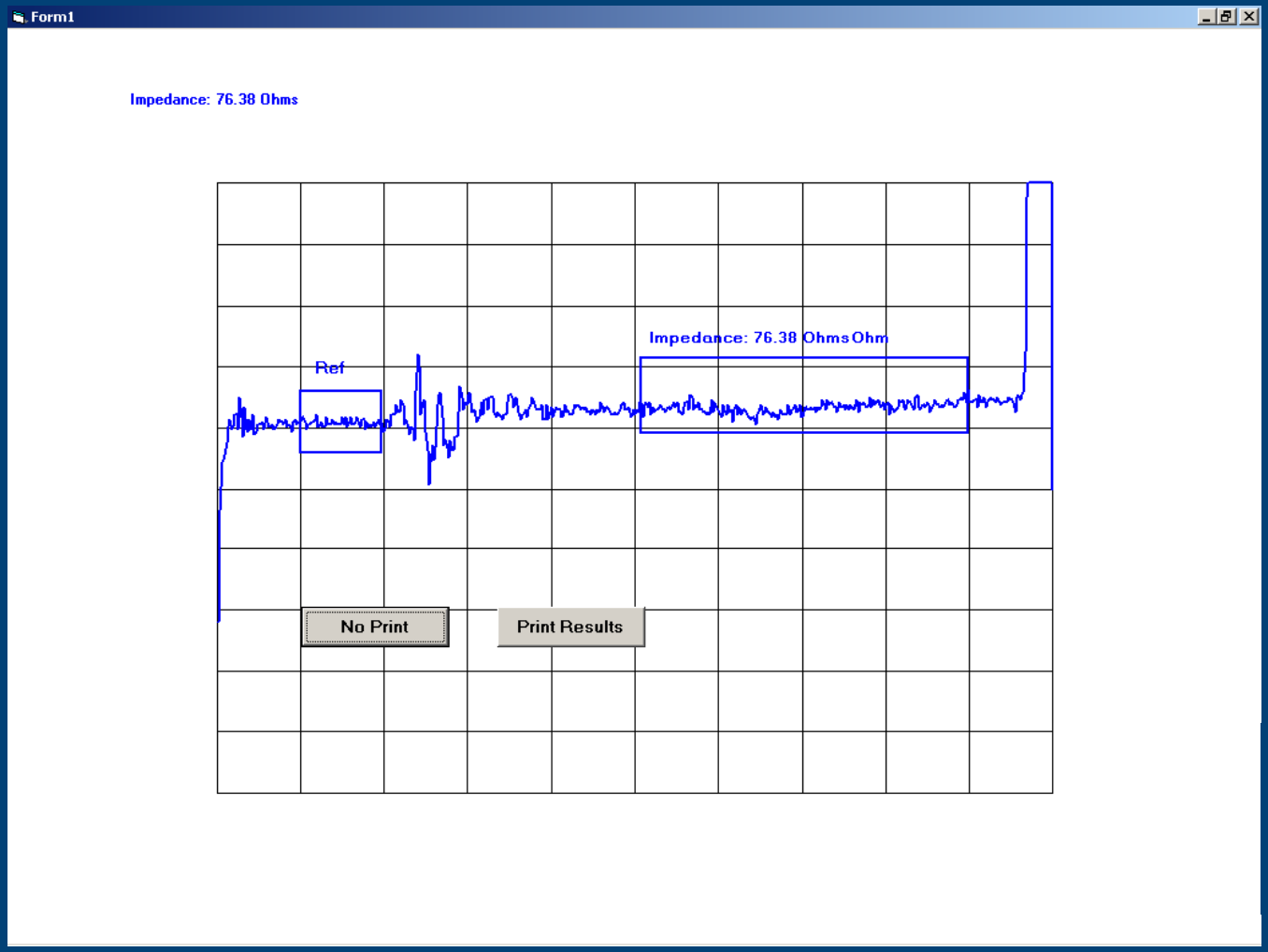
Belden 1694F at 2.85 x Diameter



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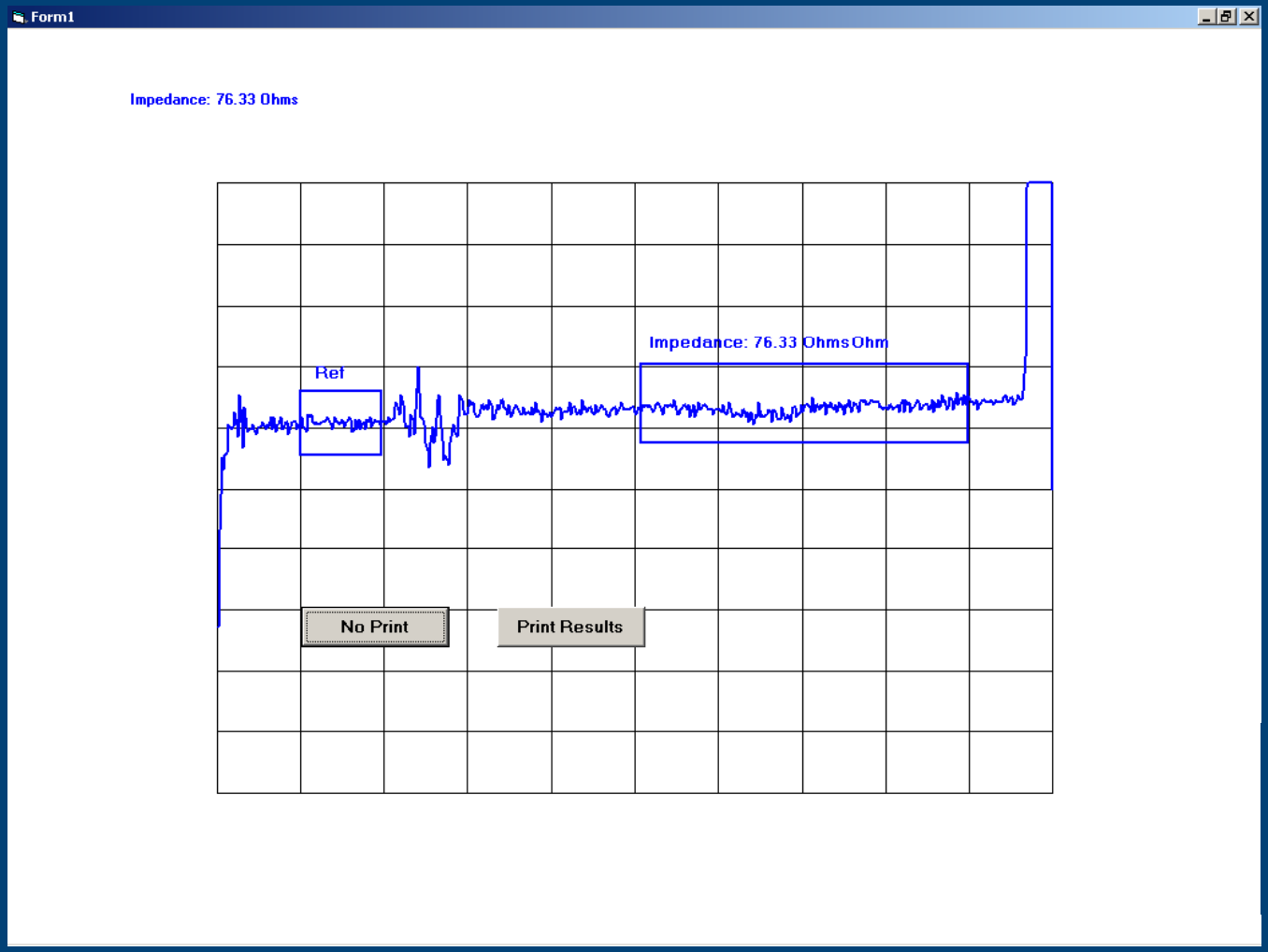
Belden 1694F at 2.31 Diameter



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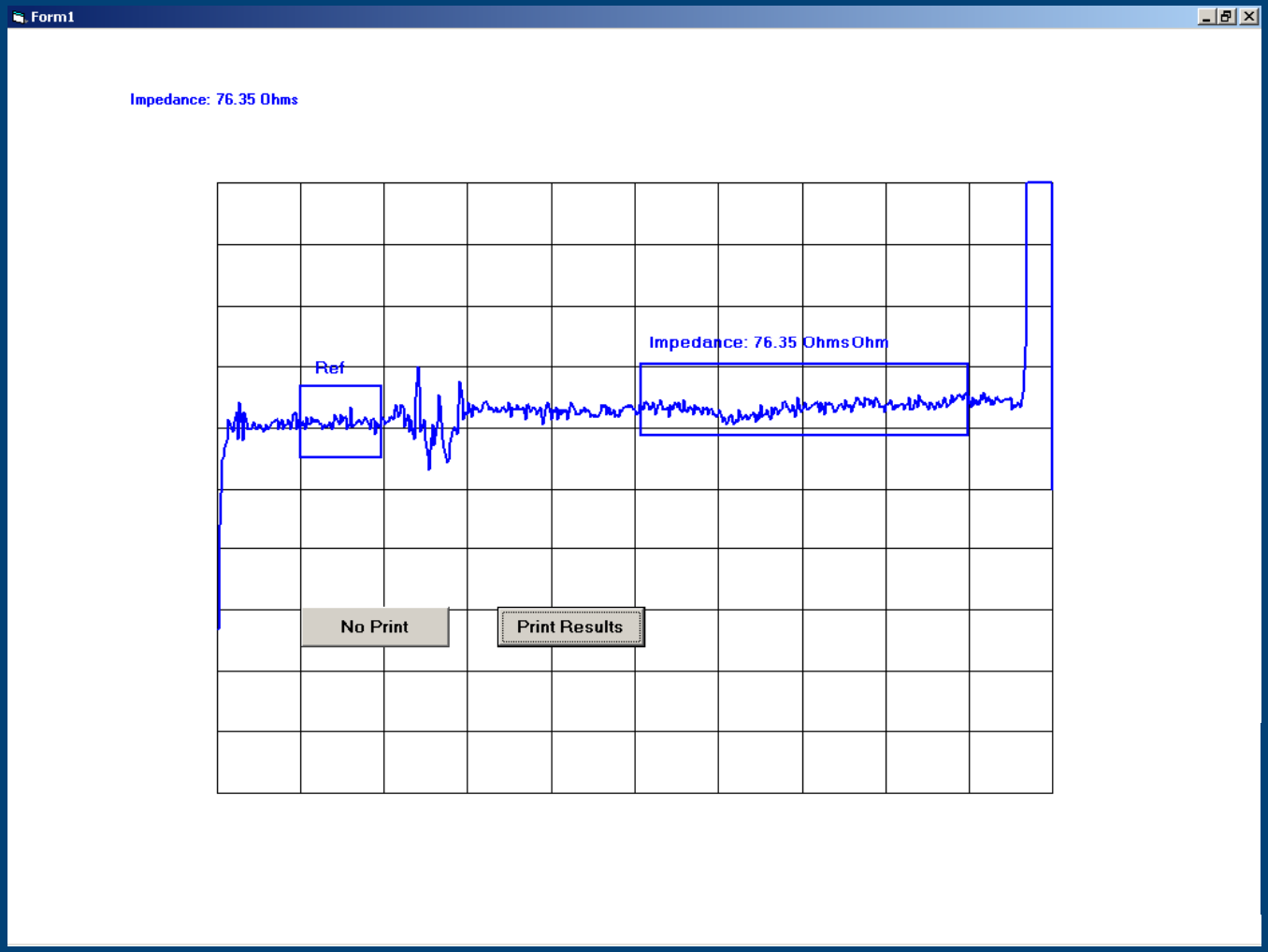
Belden 1694F at 1.73 x Diameter



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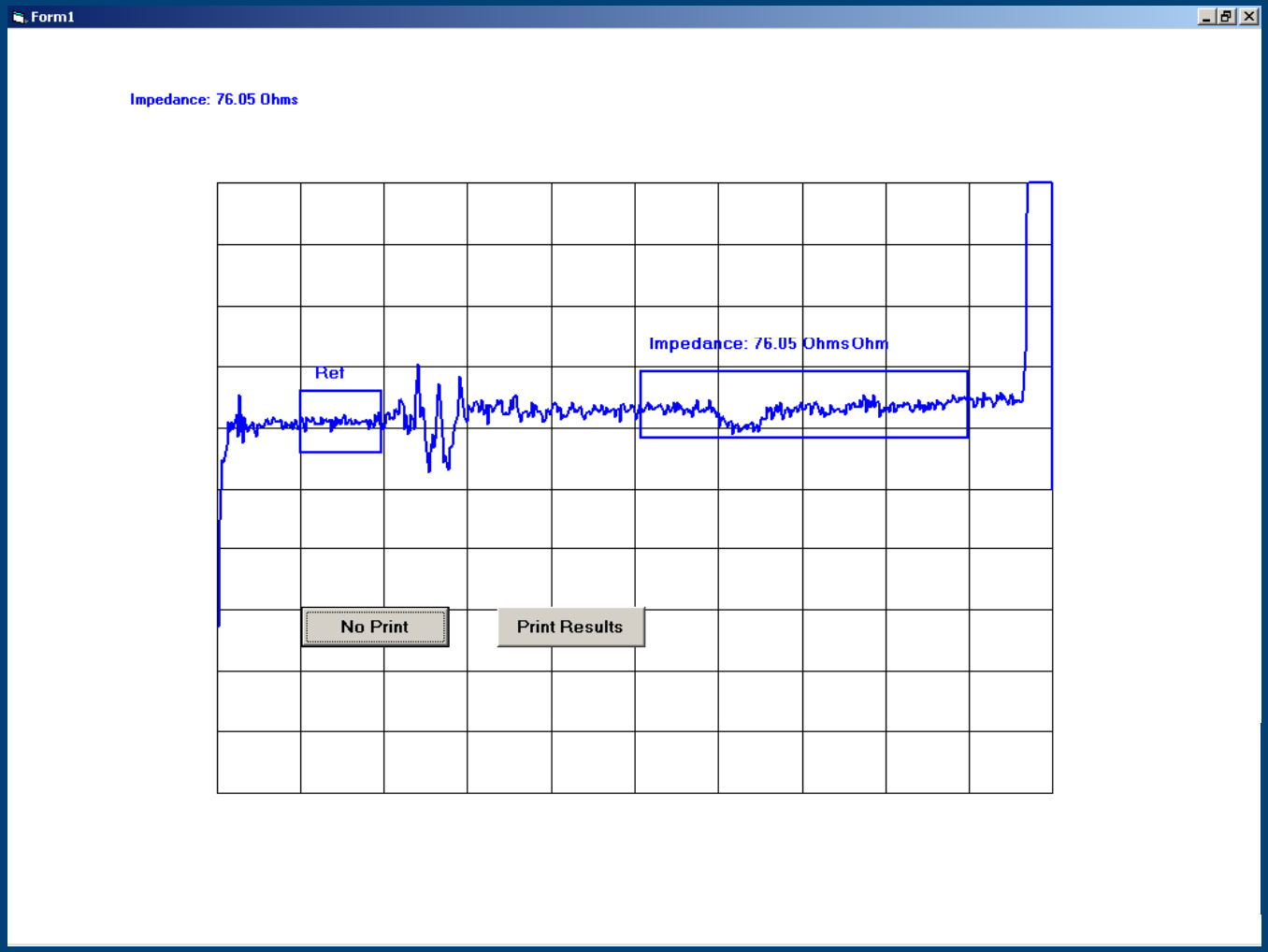
Belden 1694F at 1.16 x Diameter



Impedance 73.5Ω = RL -39.91 dB

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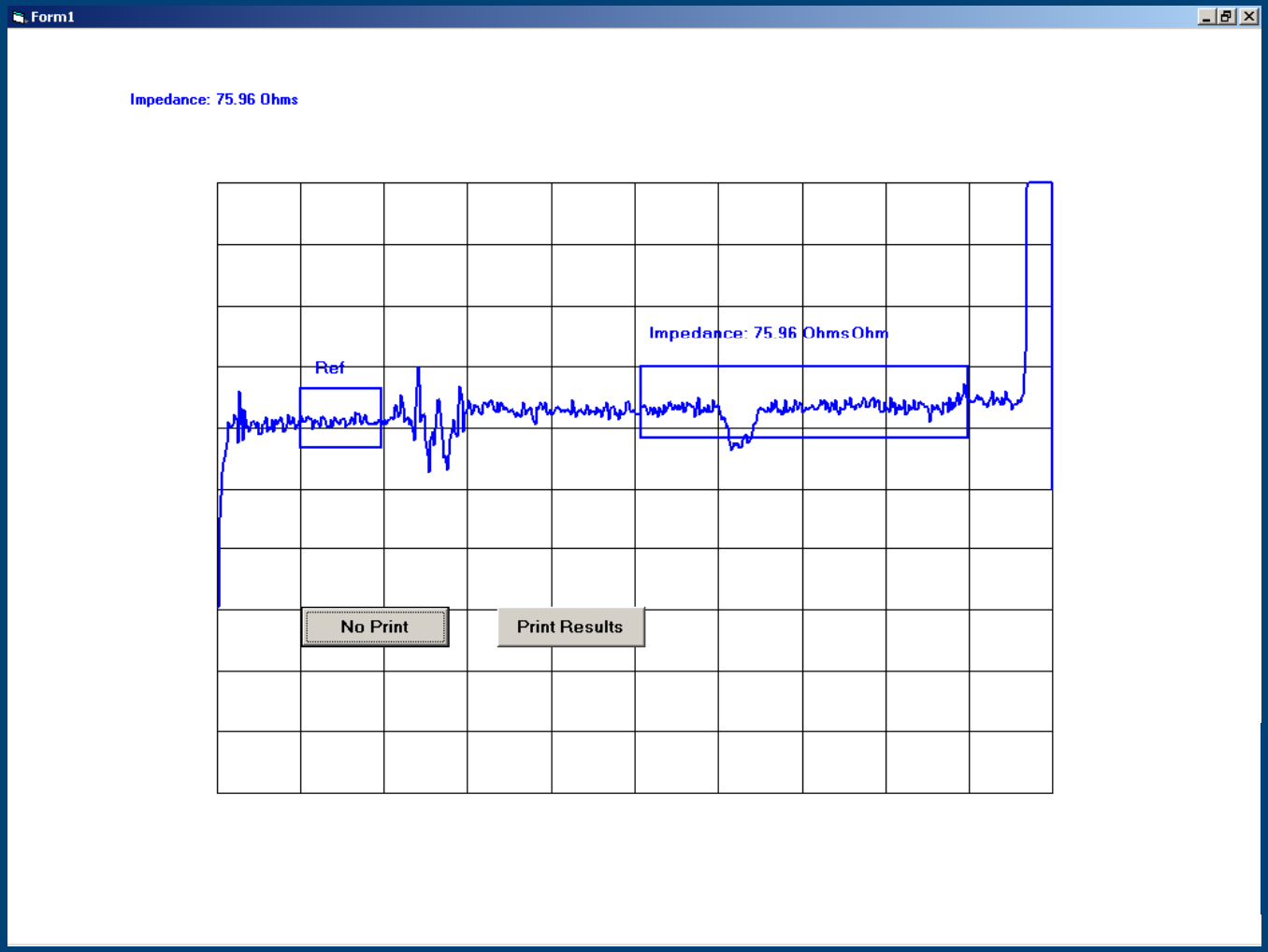
Belden 1694F at 0.58 x Diameter



Impedance 71.95Ω = RL -33.66 dB

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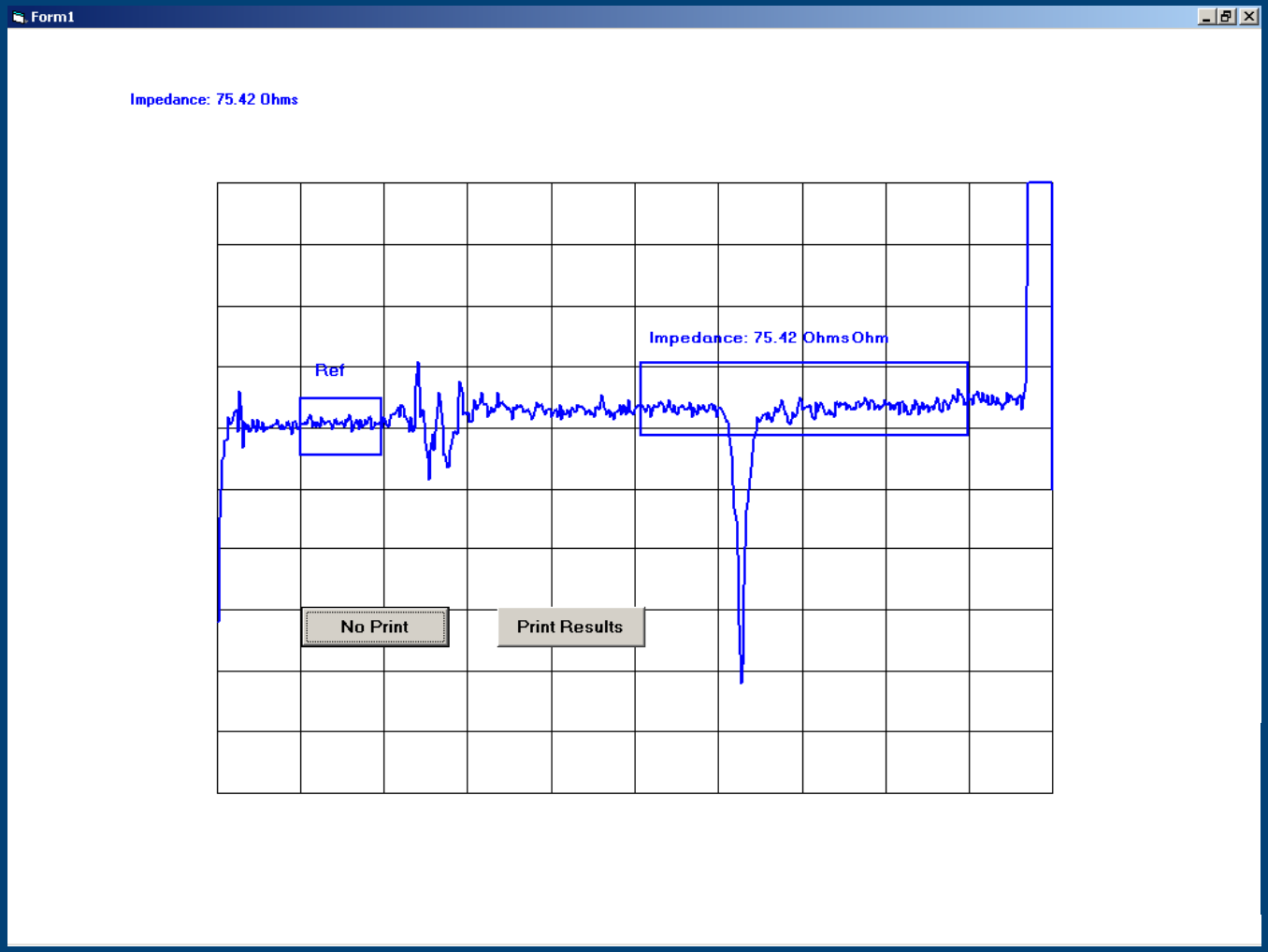
Belden 1694F Crushed with Pliers



Impedance 51.63 = RL-14.68 dB

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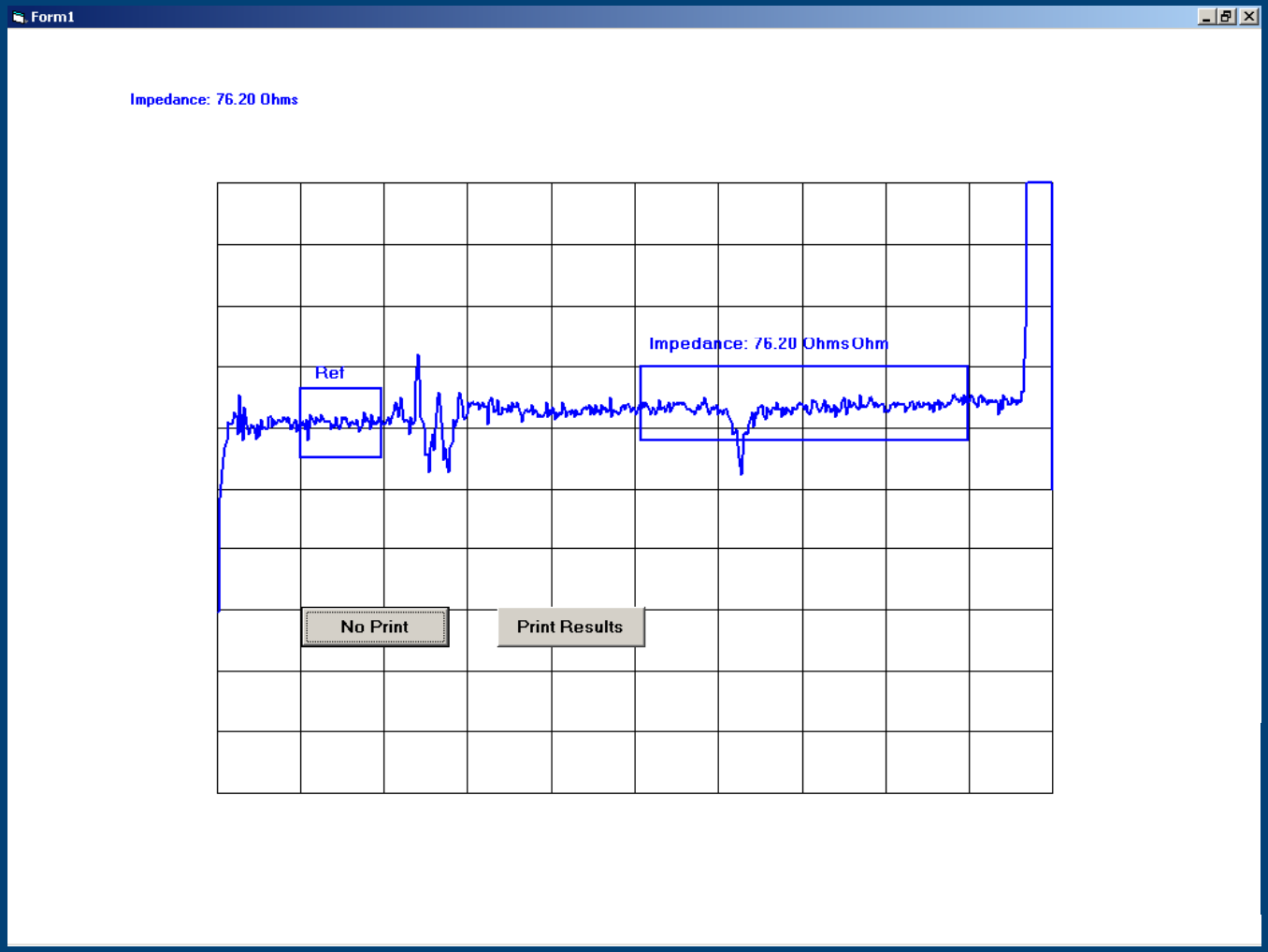
Belden 1694F Unbent by Hand



Impedance 70.92Ω = RL – 31.06 dB

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Belden 1505F

Circumference	Diameter	Radius	X 1505F Diameter
6 inches	1.908 inches	.954 inches	4.06
5 inches	1.592 inches	.796 inches	3.39
4 inches	1.272 inches	.636 inches	2.71
3 inches	.954 inches	.477 inches	2.03
2 inches	.636 inches	.318 inches	1.35
1 inches	.318 inches	.159 inches	1.18

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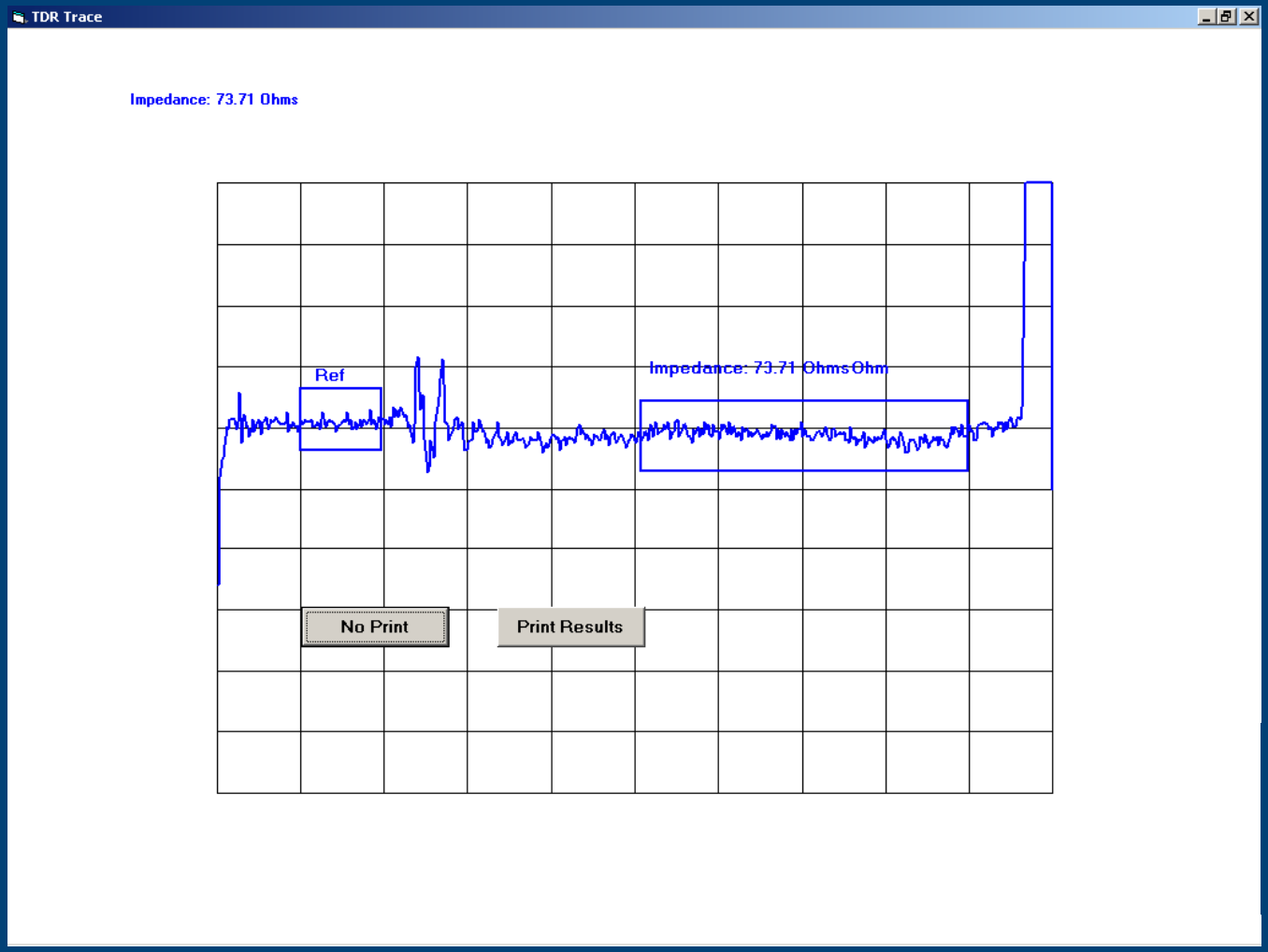
Belden 1505F at 4.06 x Diameter



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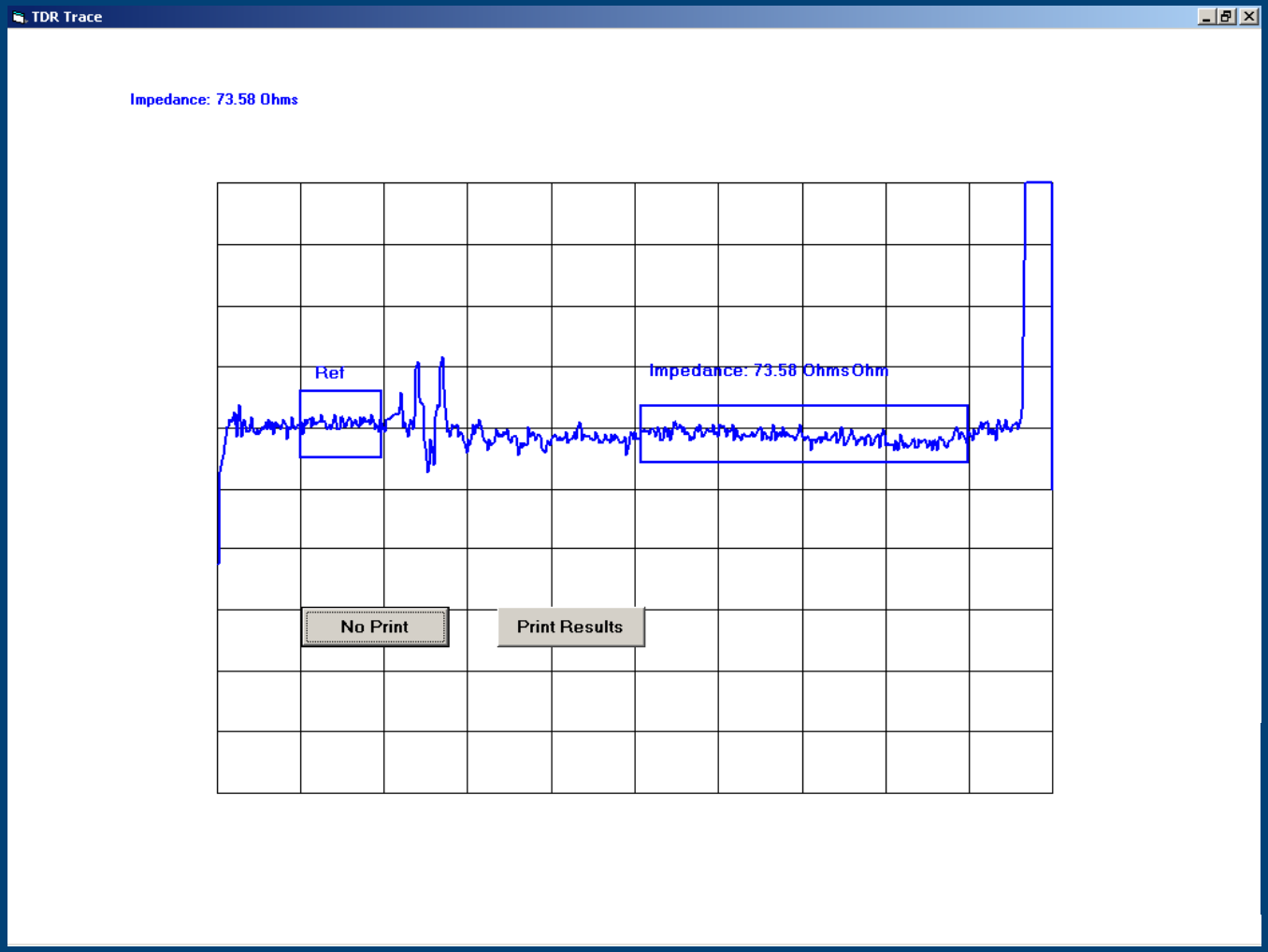
Belden 1505F at 3.39 x Diameter



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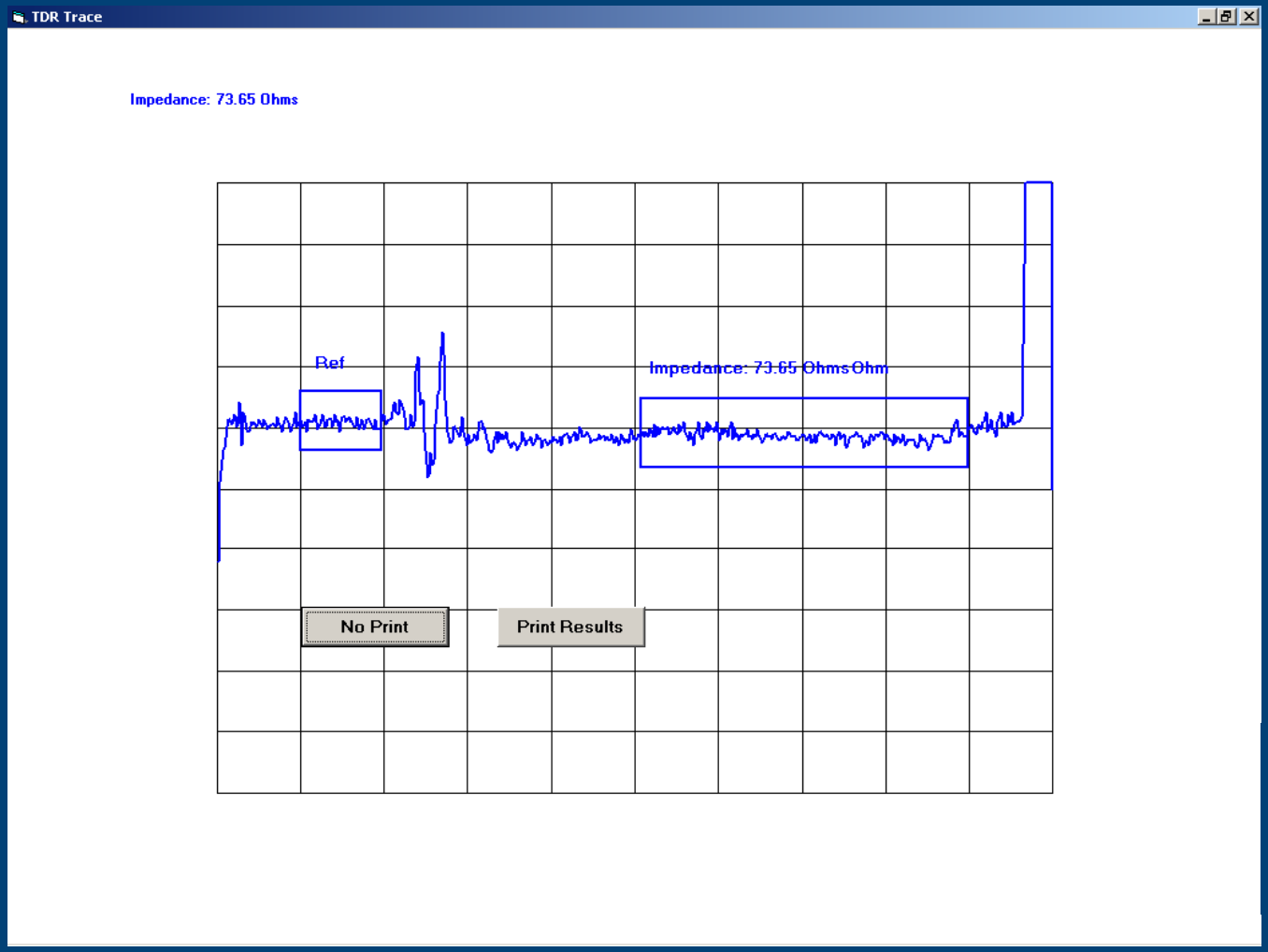
Belden 1505F at 2.71 x Diameter



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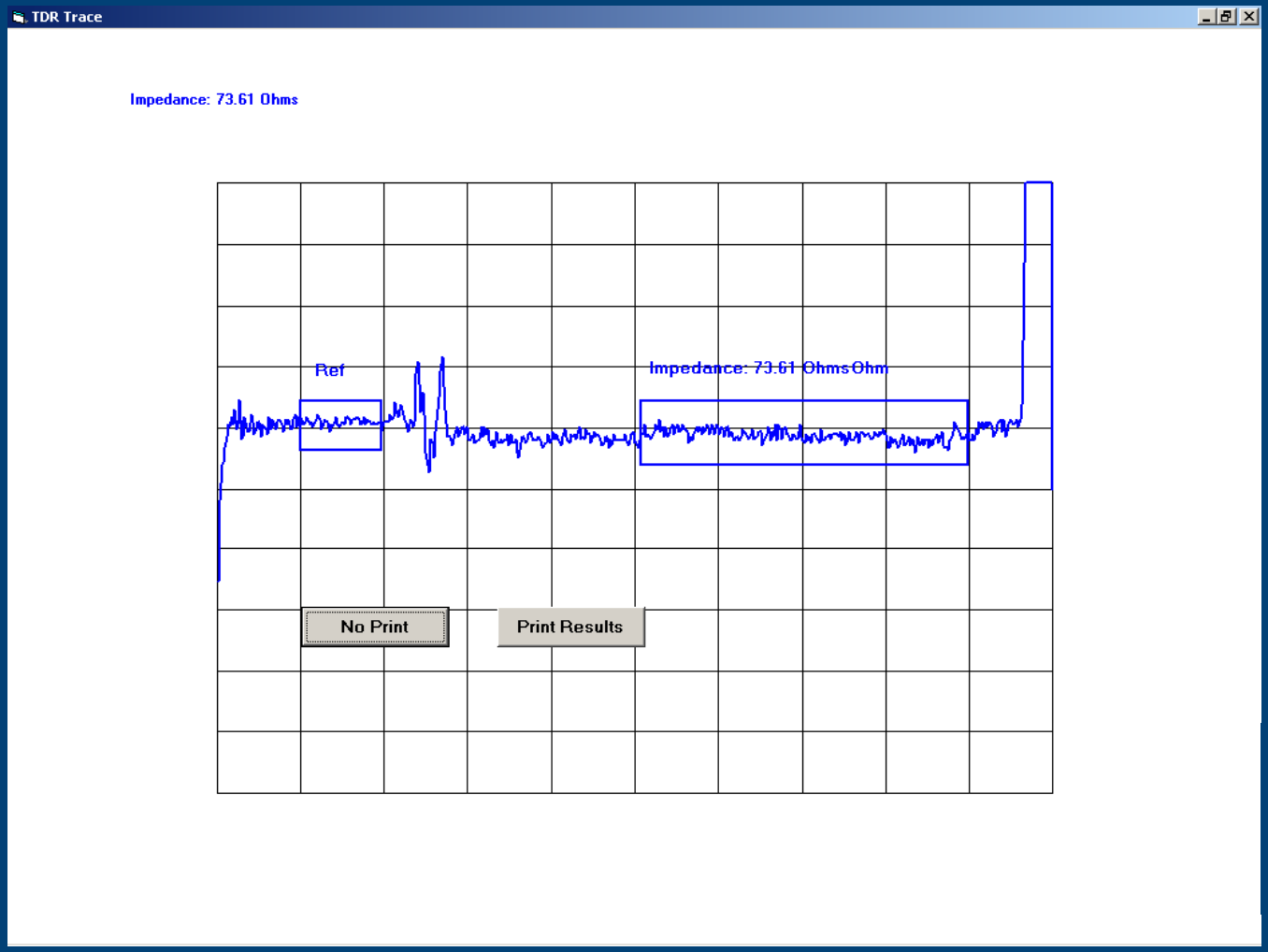
Belden 1505F at 2.03 x Diameter



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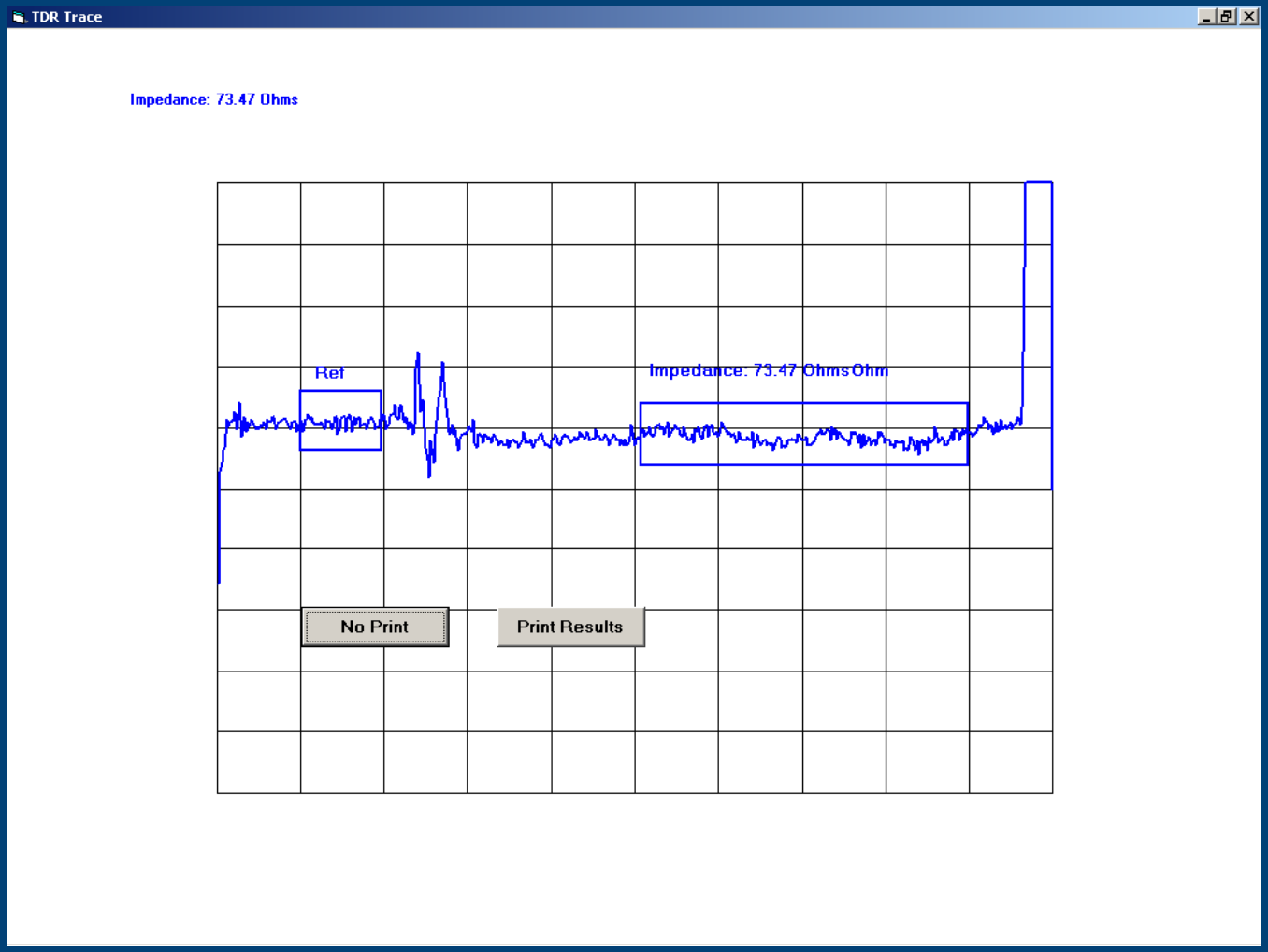
Belden 1505F at 1.35 x Diameter



Impedance 70.77Ω = RL -30.75dB

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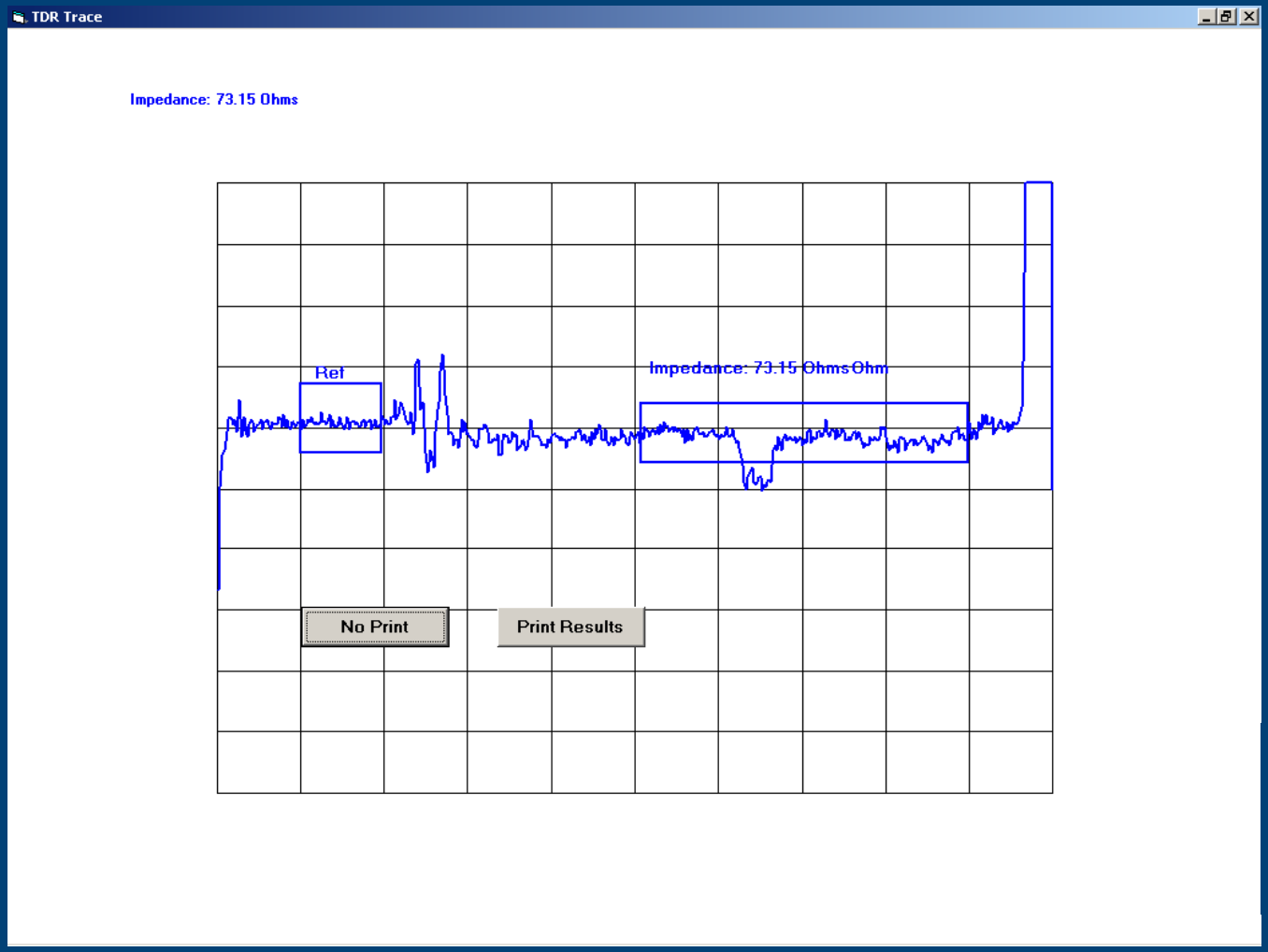
Belden 1505F at 1.18 x Diameter



Impedance 67.37Ω = RL -25.42 dB

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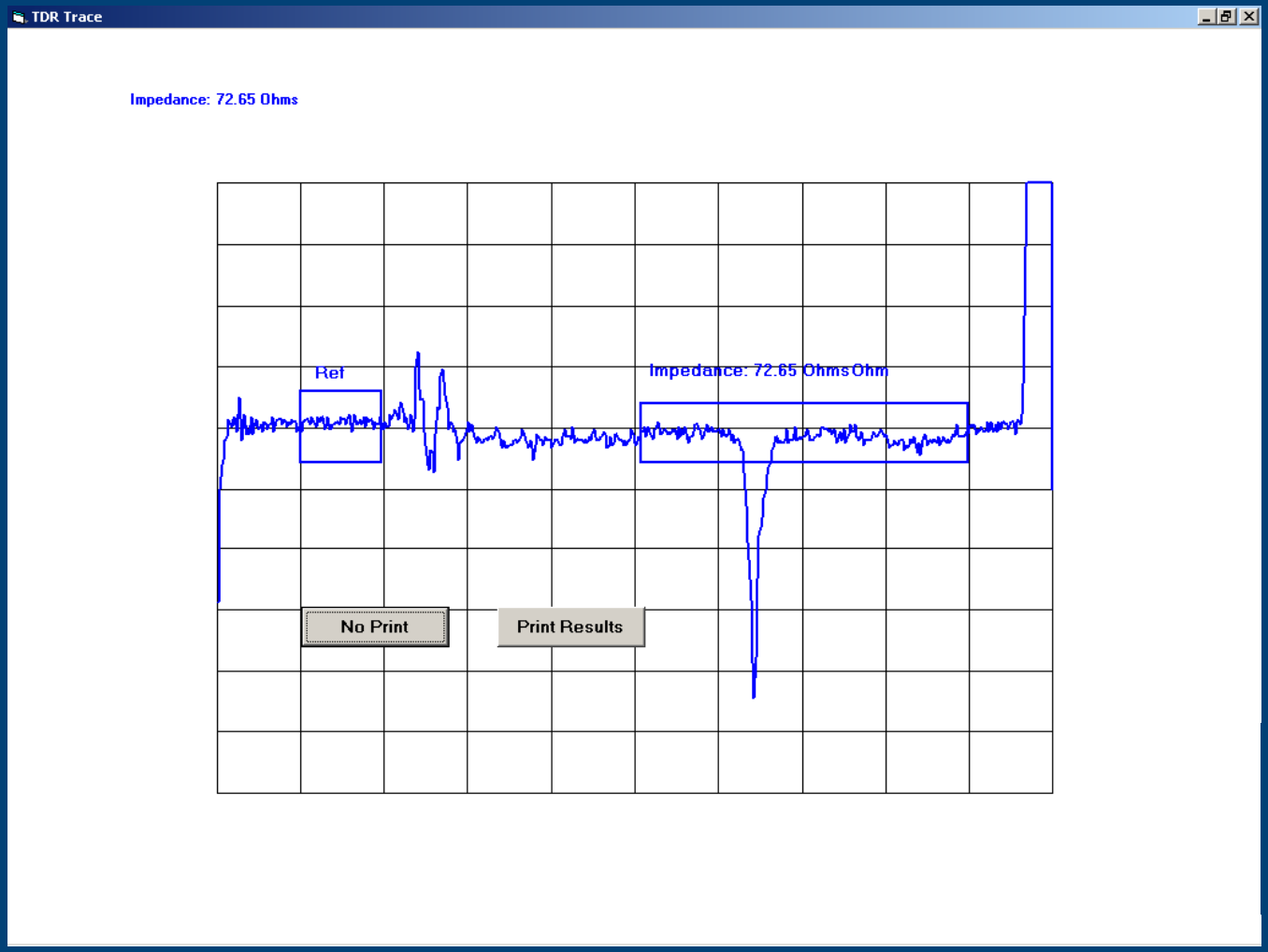
Belden 1505F Squeezed with Pliers



Impedance 51.63Ω = RL – 14.64 dB

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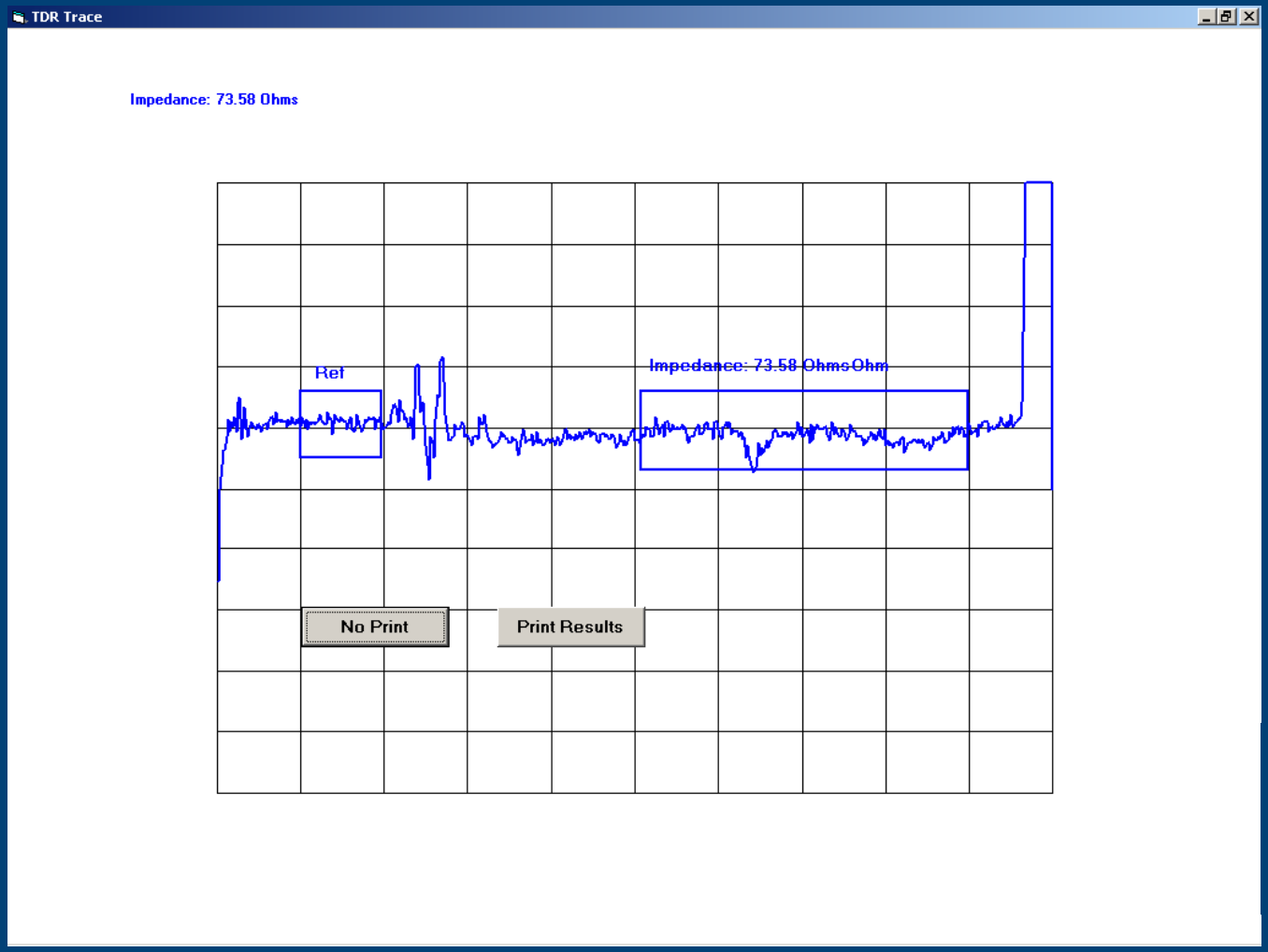
Belden 1505F Unbent by Hand



Impedance 68.48Ω = RL – 26.85 dB

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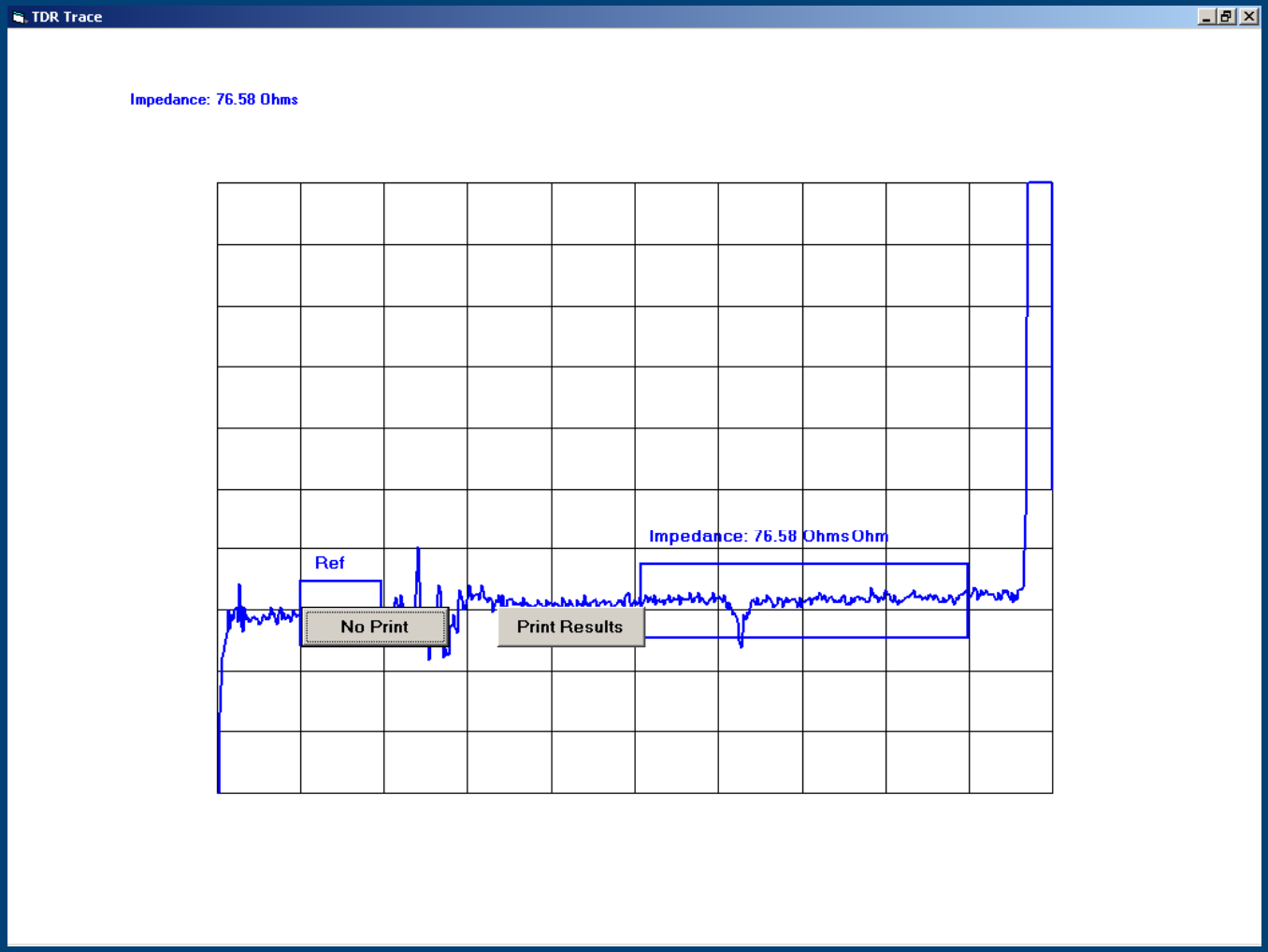
Belden 1505F 24-Hours Later



Impedance 71.95Ω = RL –33.66 dB

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Twisted Pairs

- Tektronix CSA8200
  - Communications Signal Analyzer
  - Differential
- Digital Audio Cables
  - 1800B Foil shielded 1 pair
  - 1800F Braid shielded flexible 1-pair

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Twisted Pair Requirements

- Twisted pairs
- Not as stable as coax
  - Even bonded pairs
    - ±15Ω on all data cables
    - 85Ω to 115Ω
      - 21.82 dB *(best generic case!)*
    - Best bonded pair ±7 Ω (in data cable)
      - 28.8 dB *(approaching coax performance)*
    - ±20% impedance on AES cable
    - 88Ω to 132Ω
      - 19.08 dB *(Belden typically -26 dB)*

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Belden 1800B AES 1-Pair

Cone Circumference	Equivalent Diameter	Radius	X Diameter
6 inches	1.908 inches	.954 inches	5.39
5 inches	1.592 inches	.796 inches	4.5
4 inches	1.272 inches	.636 inches	3.59
3 inches	.954 inches	.477 inches	2.7
2 inches	.636 inches	.318 inches	1.8
1 inches	.318 inches	.159 inches	.898

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BELDEN
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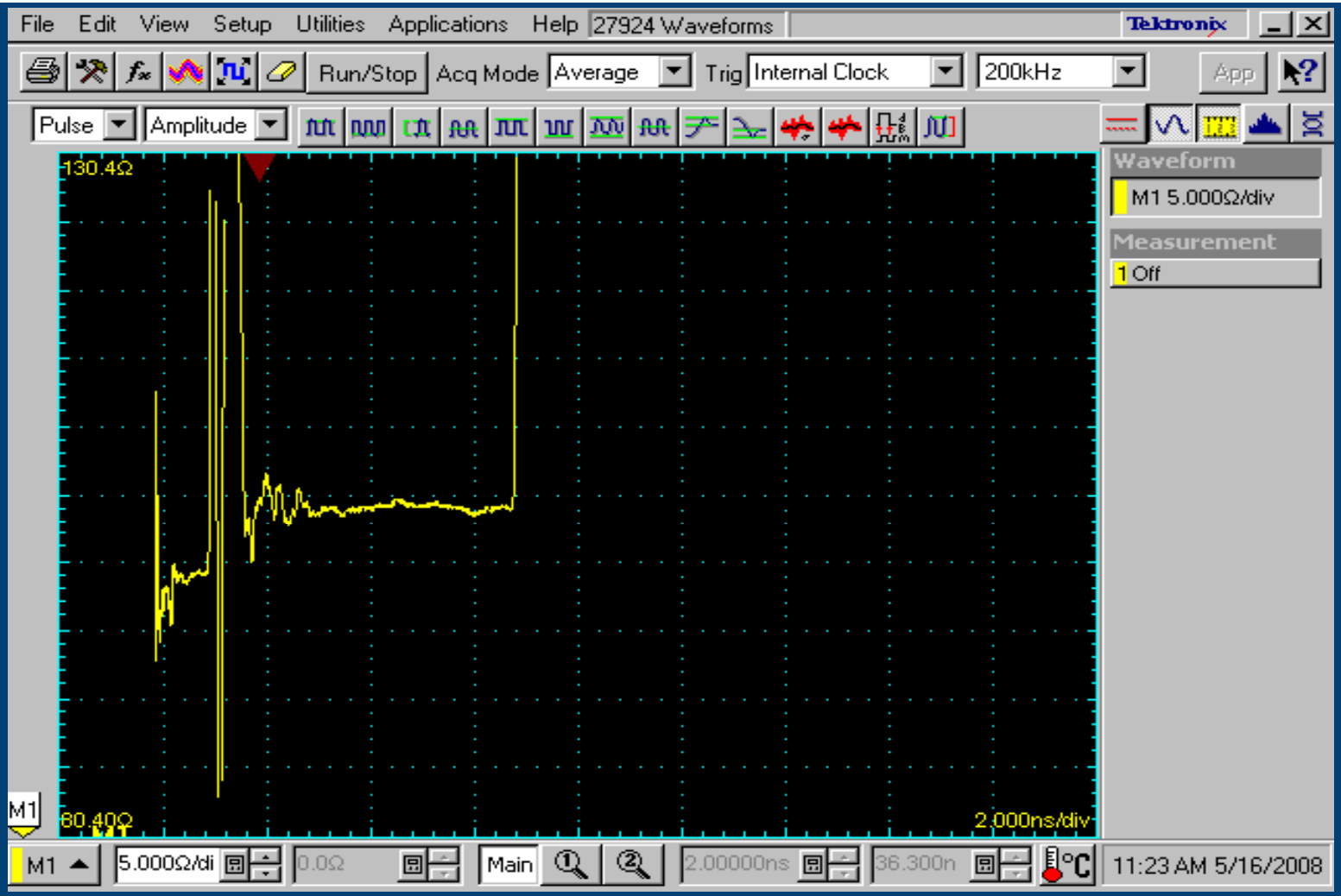
Belden 1800B Normal



Impedance 96.75Ω = RL -23.86 dB

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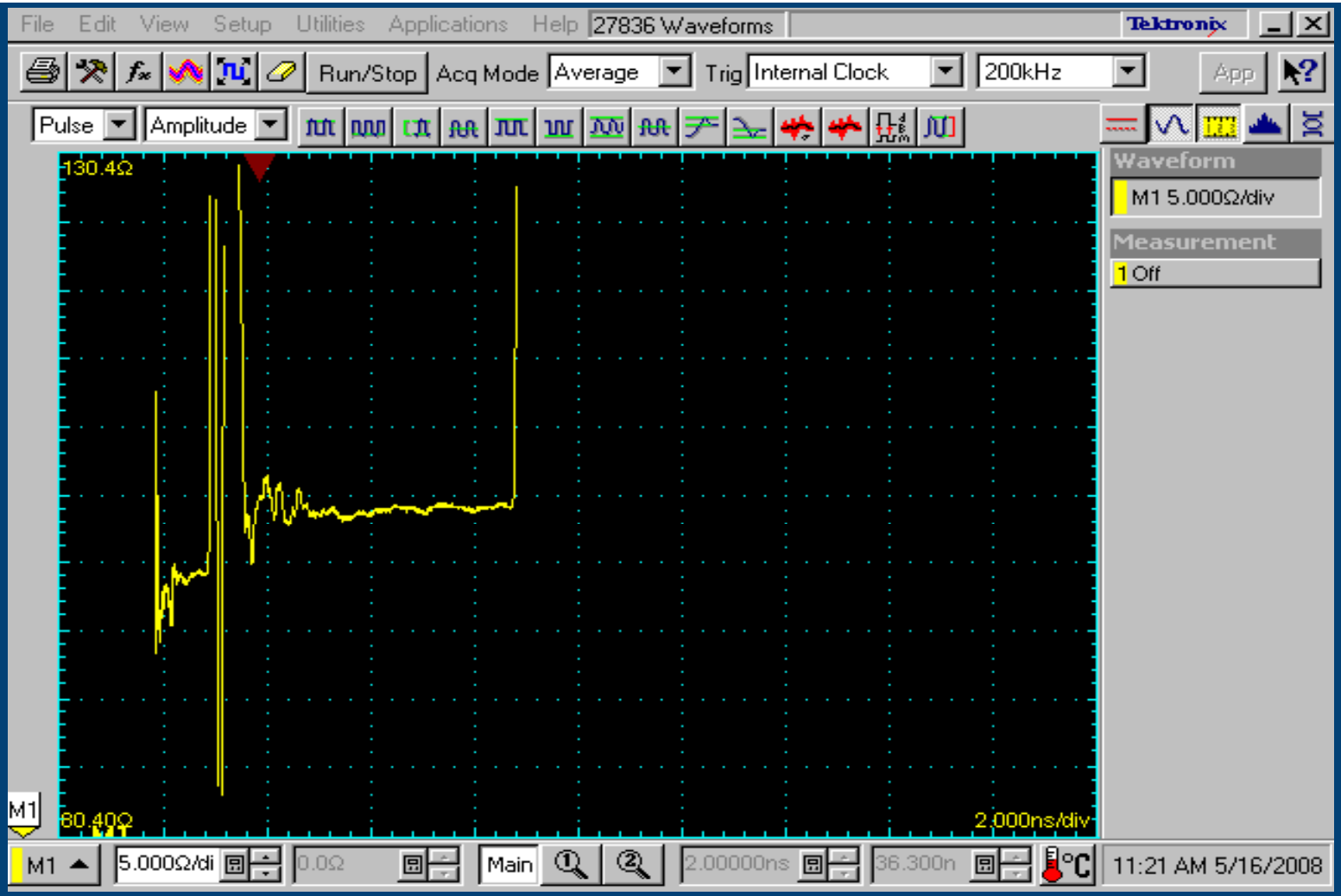
Belden 1800B Diameter x 5.39



Impedance 96.08Ω = RL – 23.41 dB

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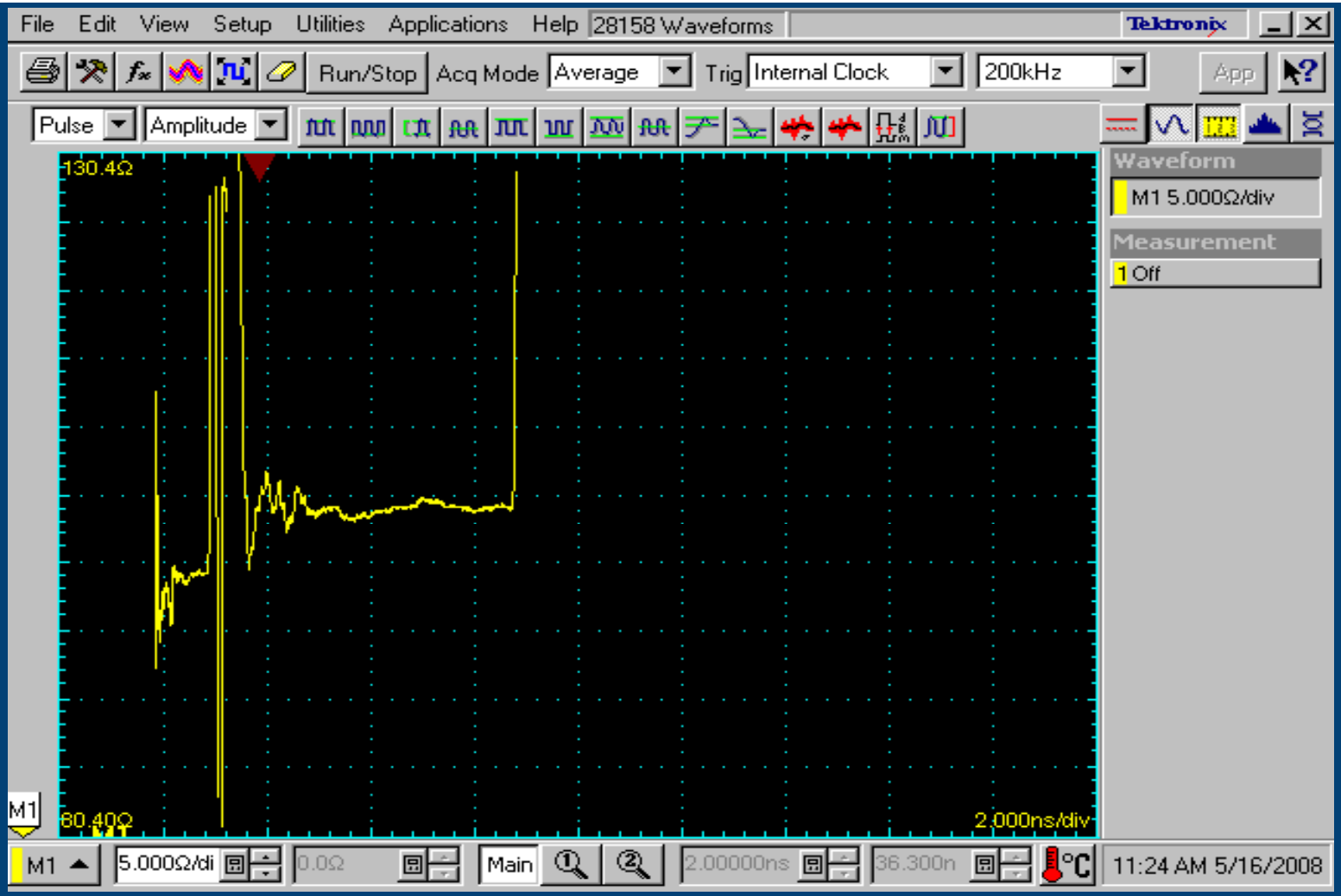
Belden 1800B Diameter x 4.5



Impedance 94.45Ω = RL – 22.38 dB

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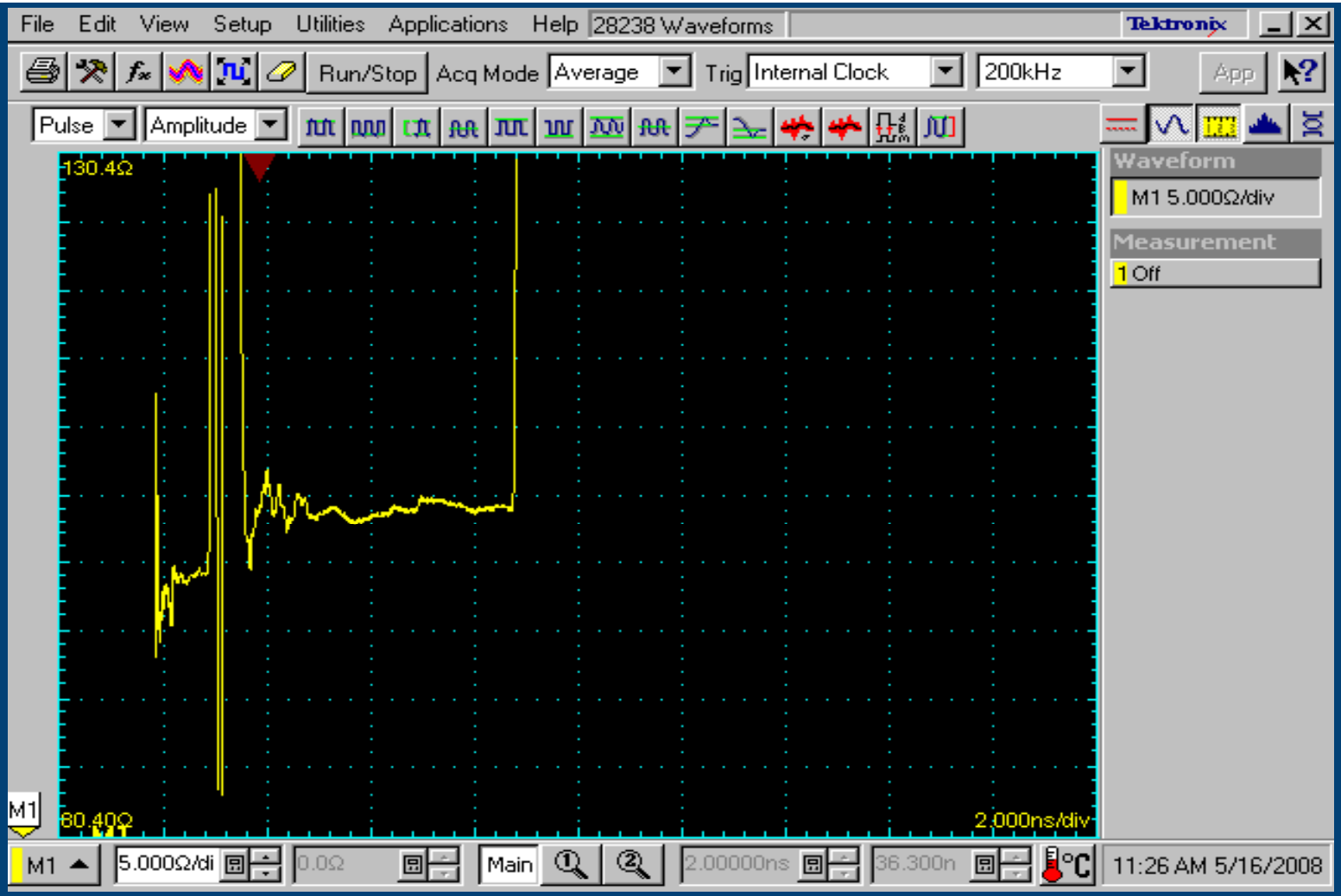
Belden 1800B Diameter x 3.59



Impedance 94.59Ω = RL -22.46 dB

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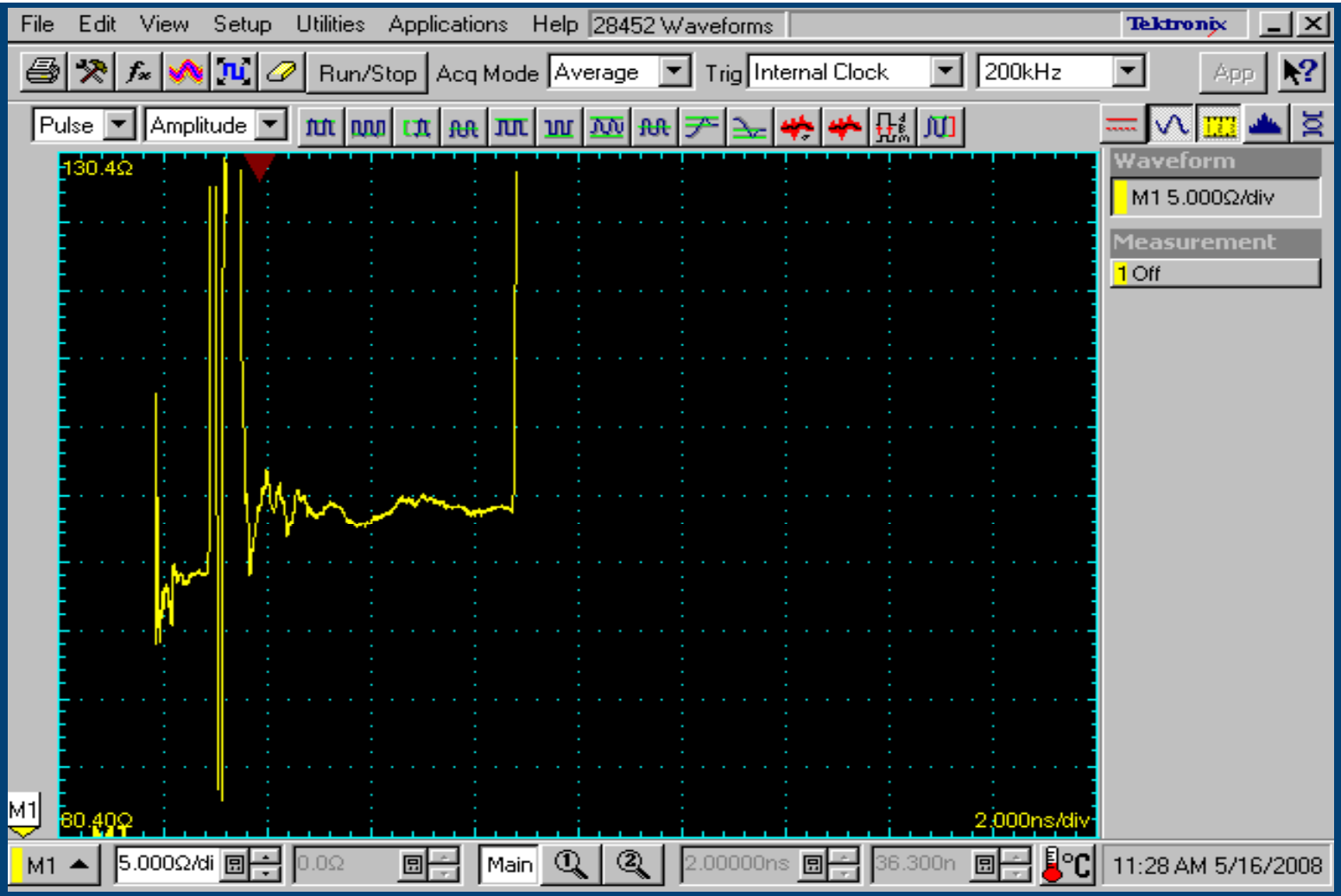
Belden 1800B Diameter x 2.7



Impedance 96.35Ω = RL -23.59 dB

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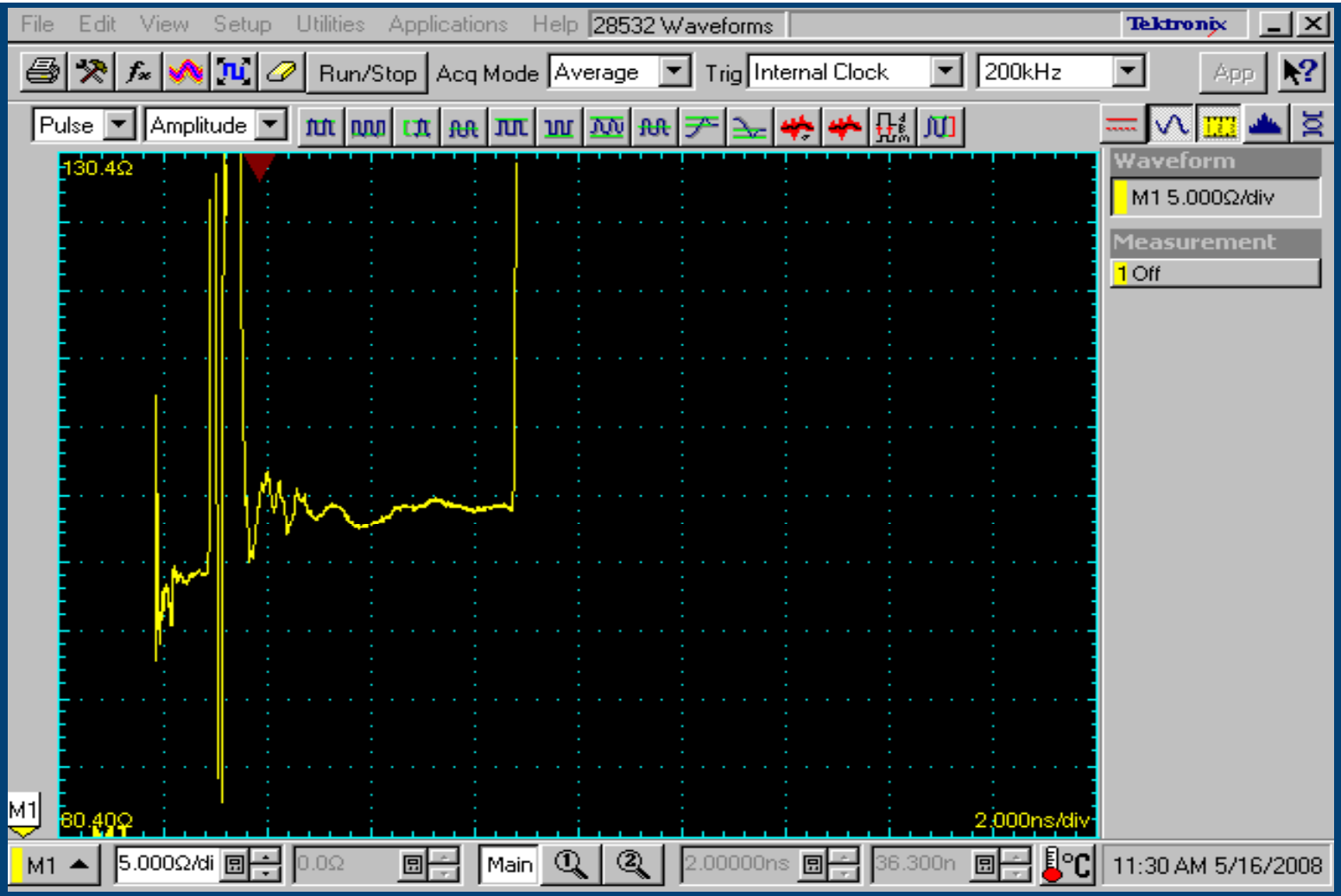
Belden 1800B Diameter x 1.8



Impedance 96.89Ω = RL -23.96 dB

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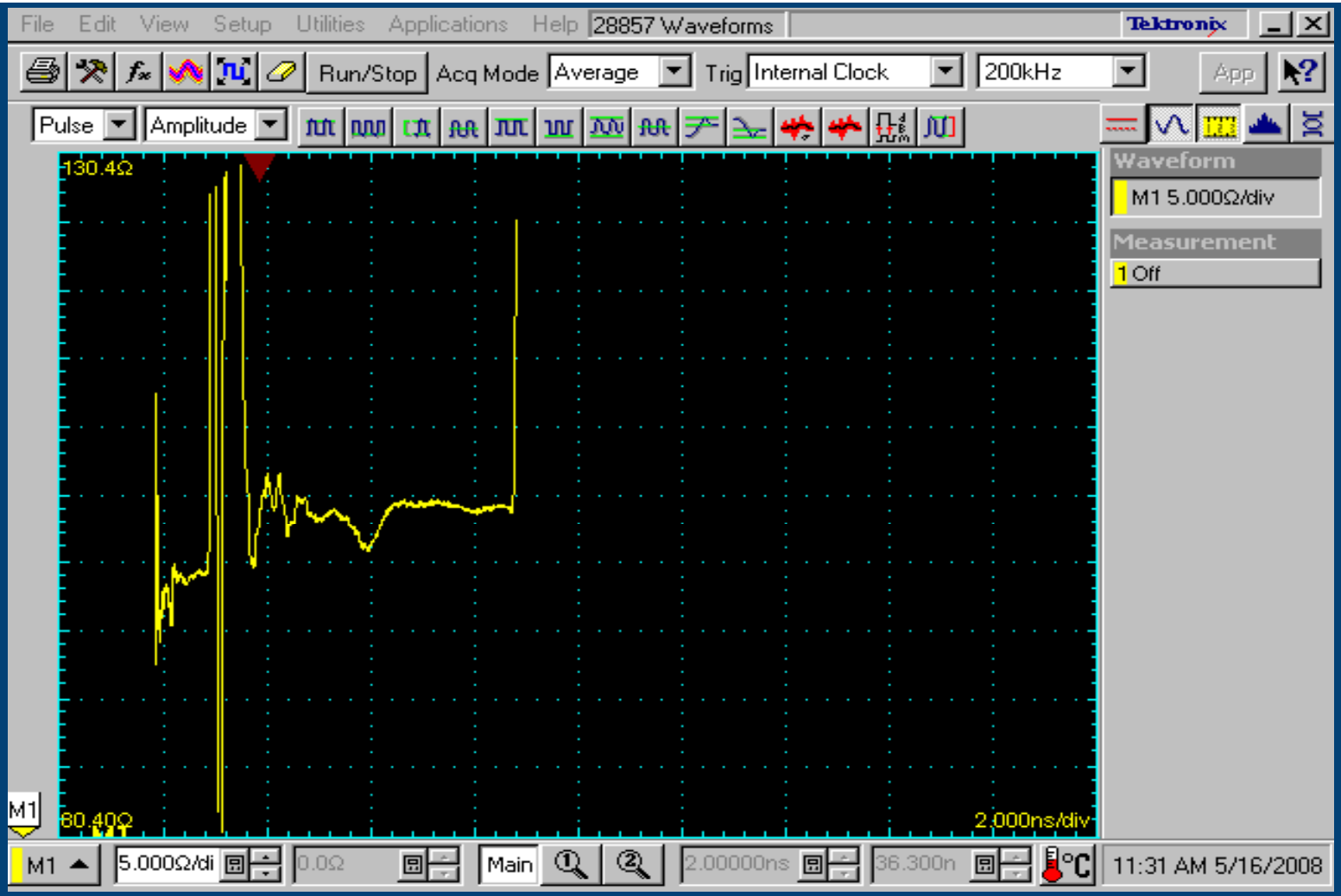
Belden 1800B Diameter x .898



Impedance 96.08Ω = RL -23.41 dB

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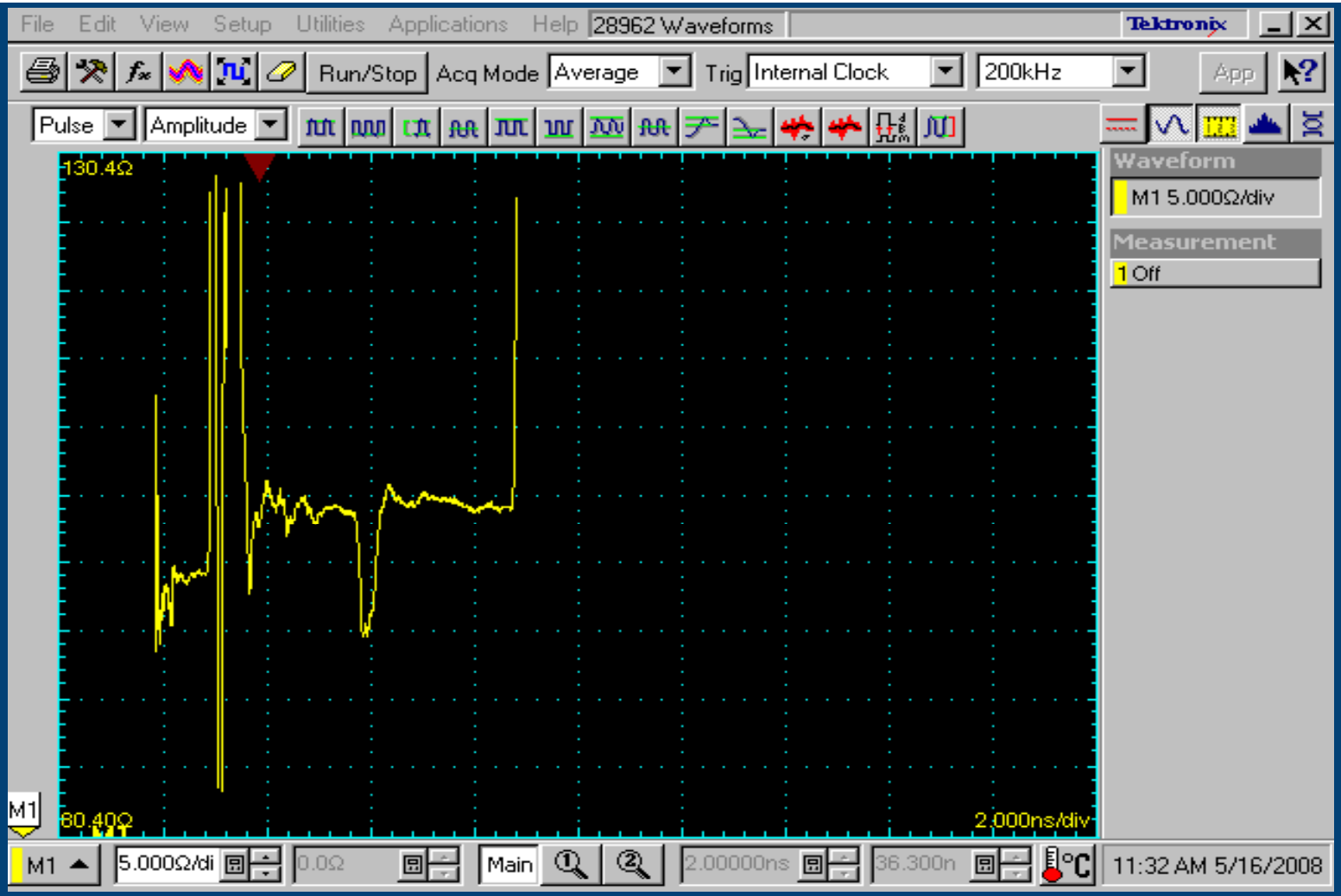
Belden 1800B Squeezed with Pliers



Impedance 83.99Ω = RL -17.45 dB

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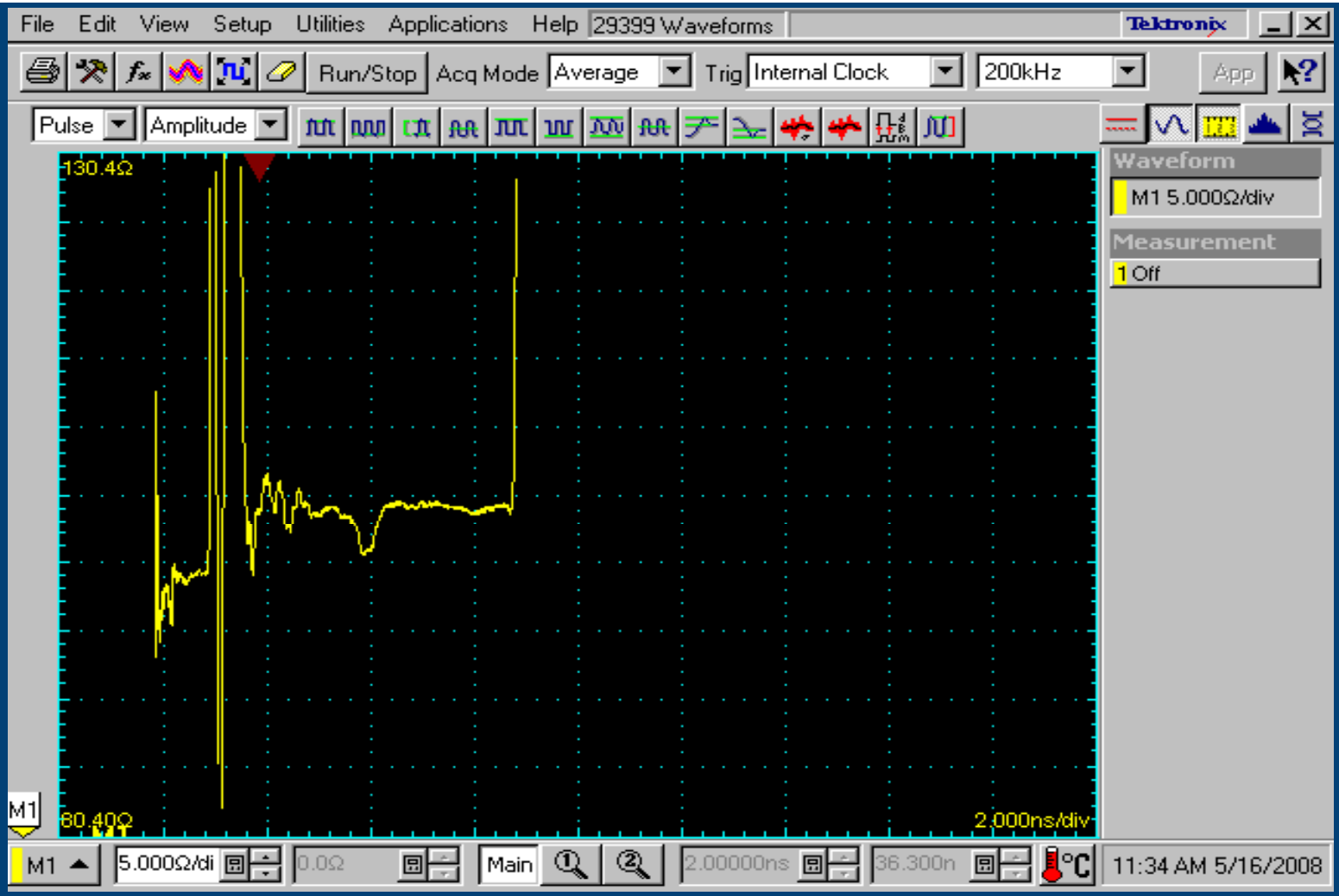
Belden 1800B Re-formed by Hand



Impedance 93.72Ω = RL -21.95 dB

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Belden 1800F

Cone Circumference	Equivalent Diameter	Radius	X Diameter
6 inches	1.908 inches	.954 inches	4.52
5 inches	1.592 inches	.796 inches	3.77
4 inches	1.272 inches	.636 inches	3.01
3 inches	.954 inches	.477 inches	2.26
2 inches	.636 inches	.318 inches	1.51
1 inches	.318 inches	.159 inches	.754

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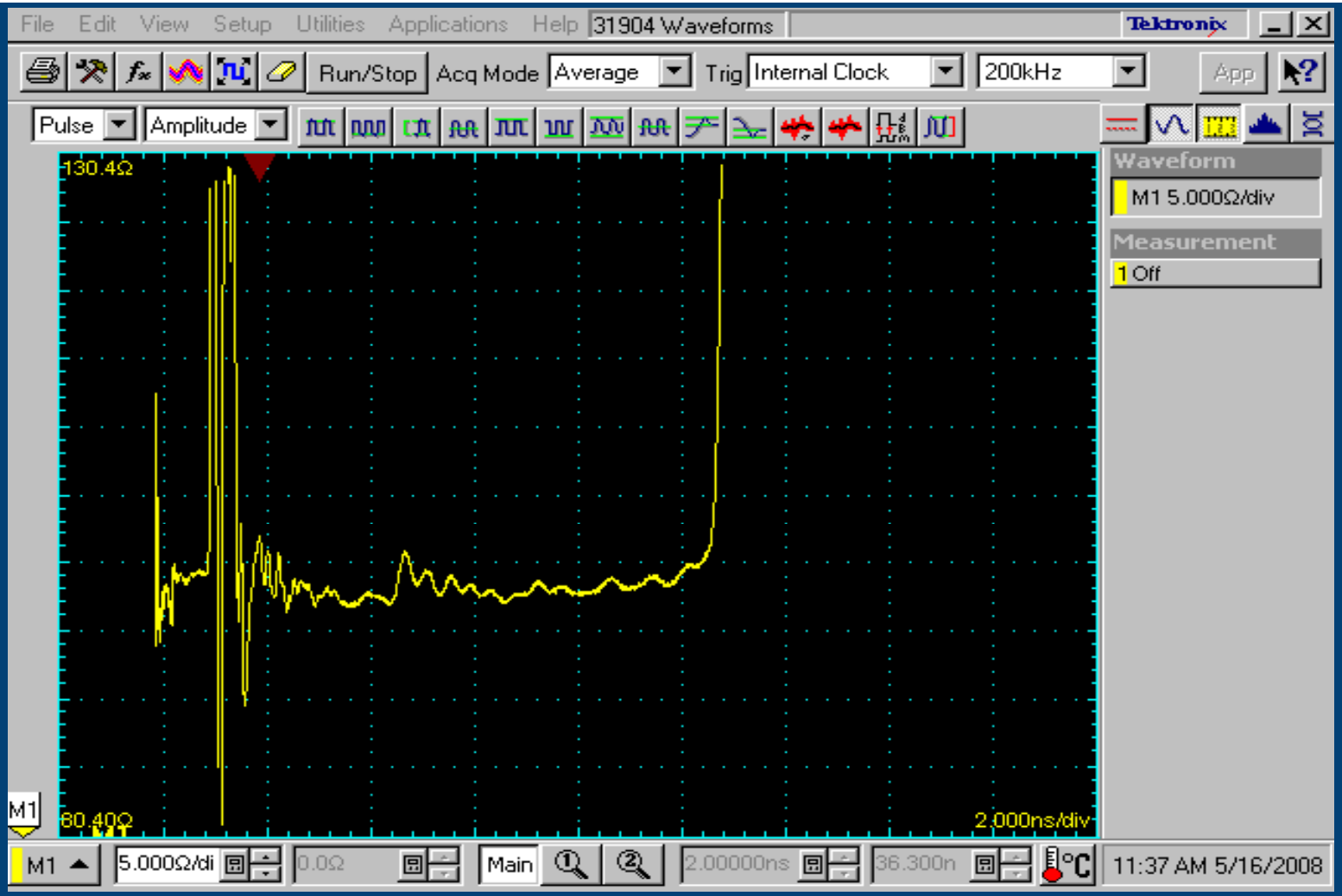
Belden 1800F Normal



Impedance 104.9Ω = RL -32.49 dB

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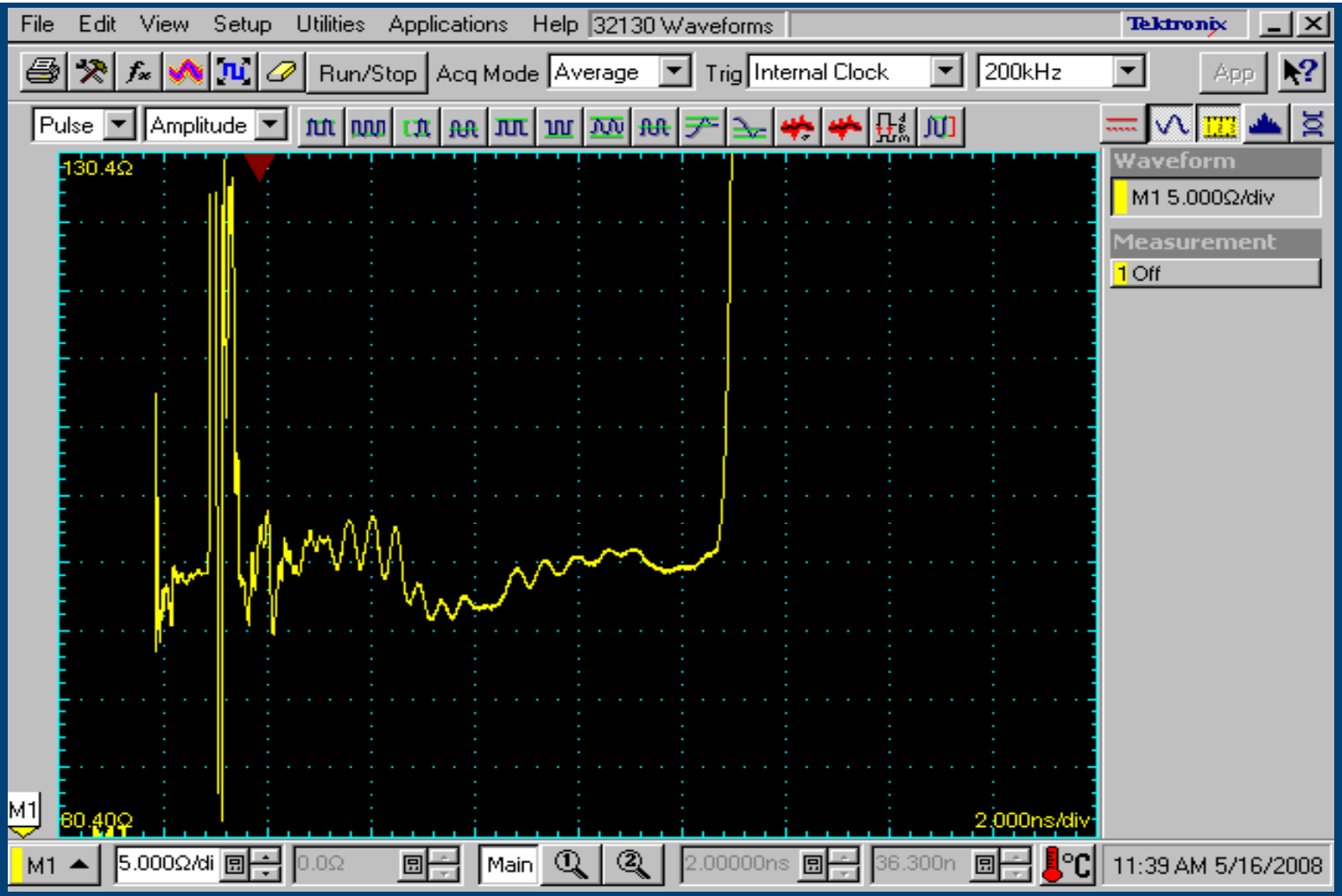
Belden 1800F Diameter x 4.52



Impedance 103.7Ω = RL -30.61 dB

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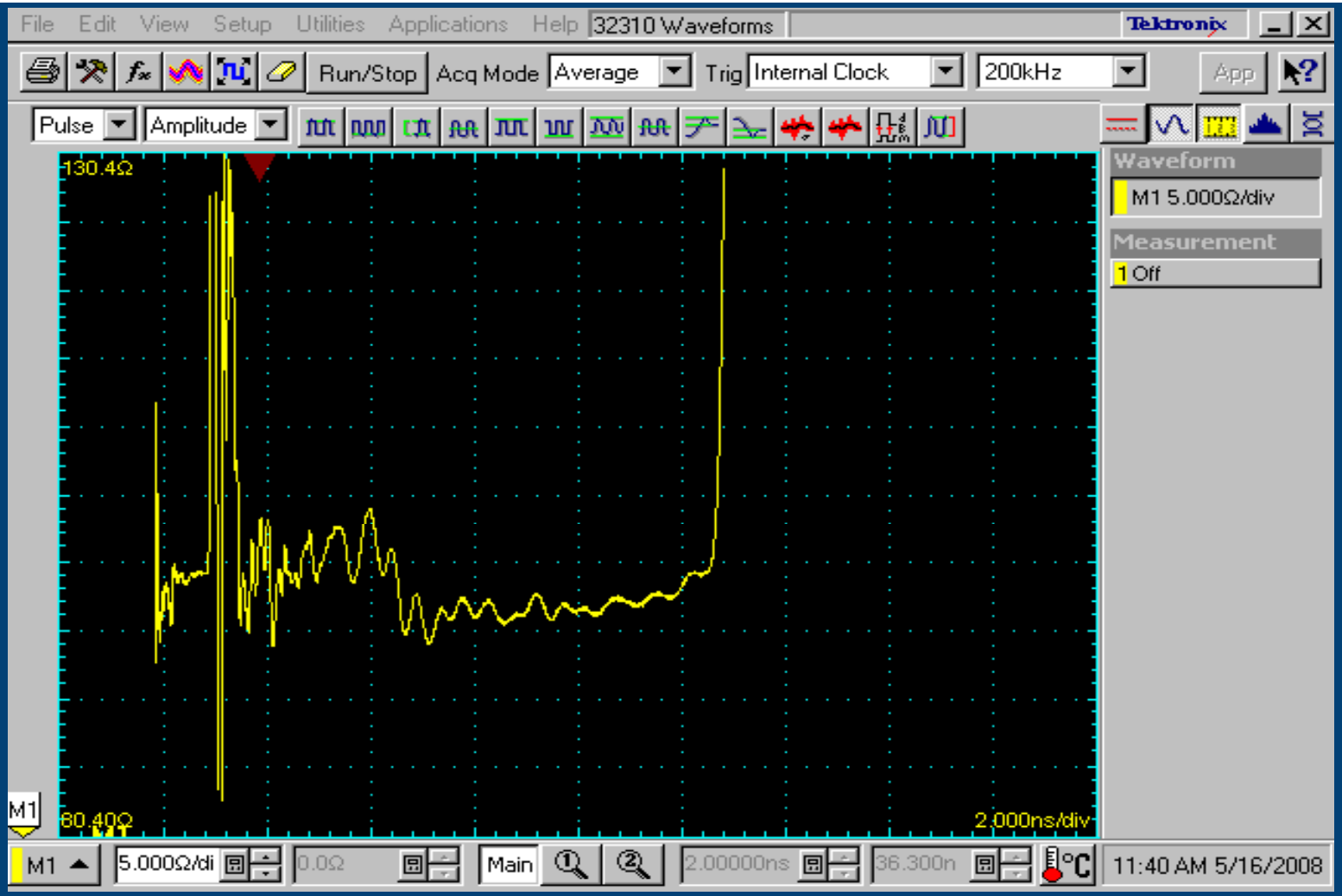
Belden 1800F Diameter x 3.77



Impedance 103.6Ω = RL -30.47 dB

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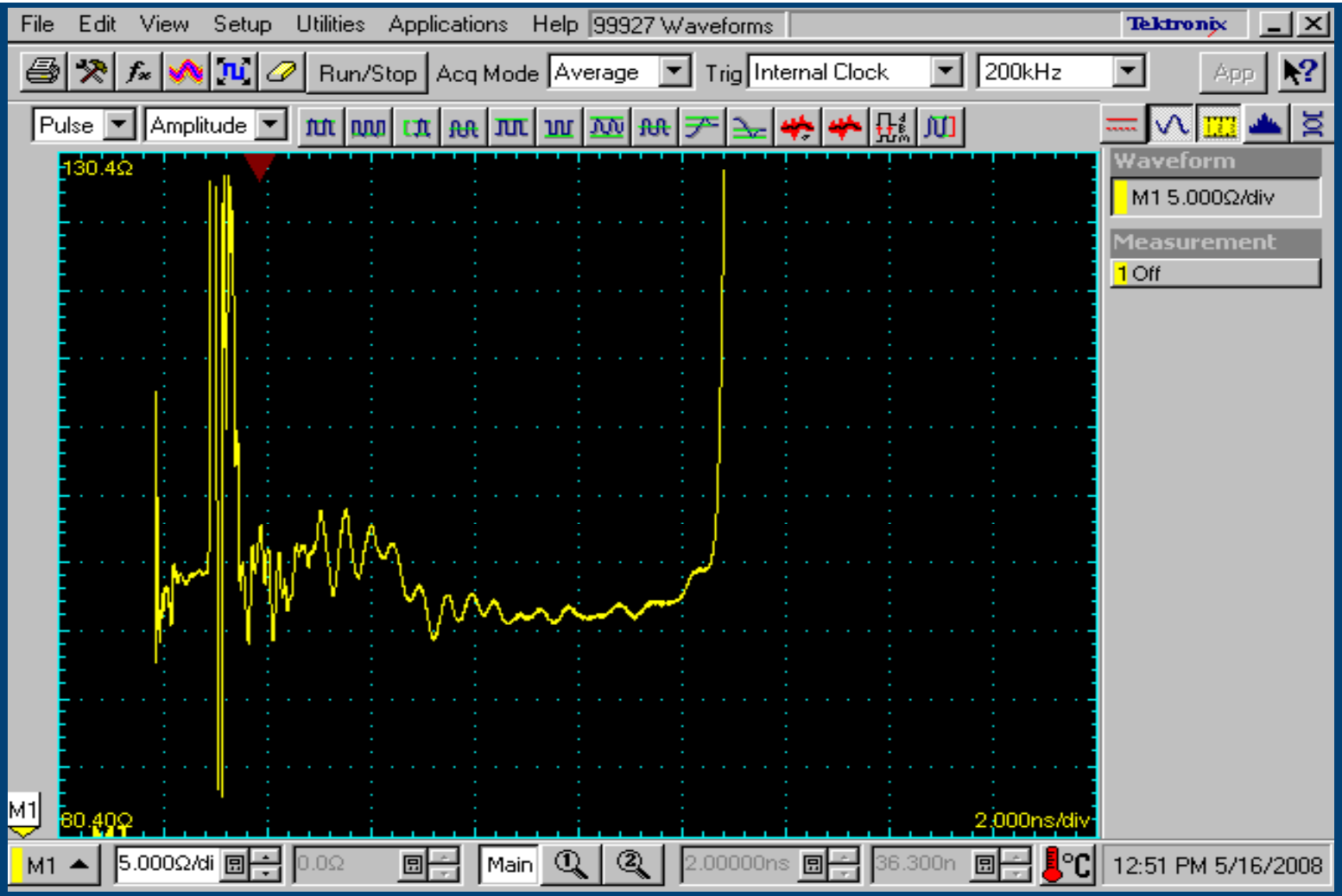
Belden 1800F Diameter x 3.01



Impedance 103.2Ω = RL – 29.93 dB

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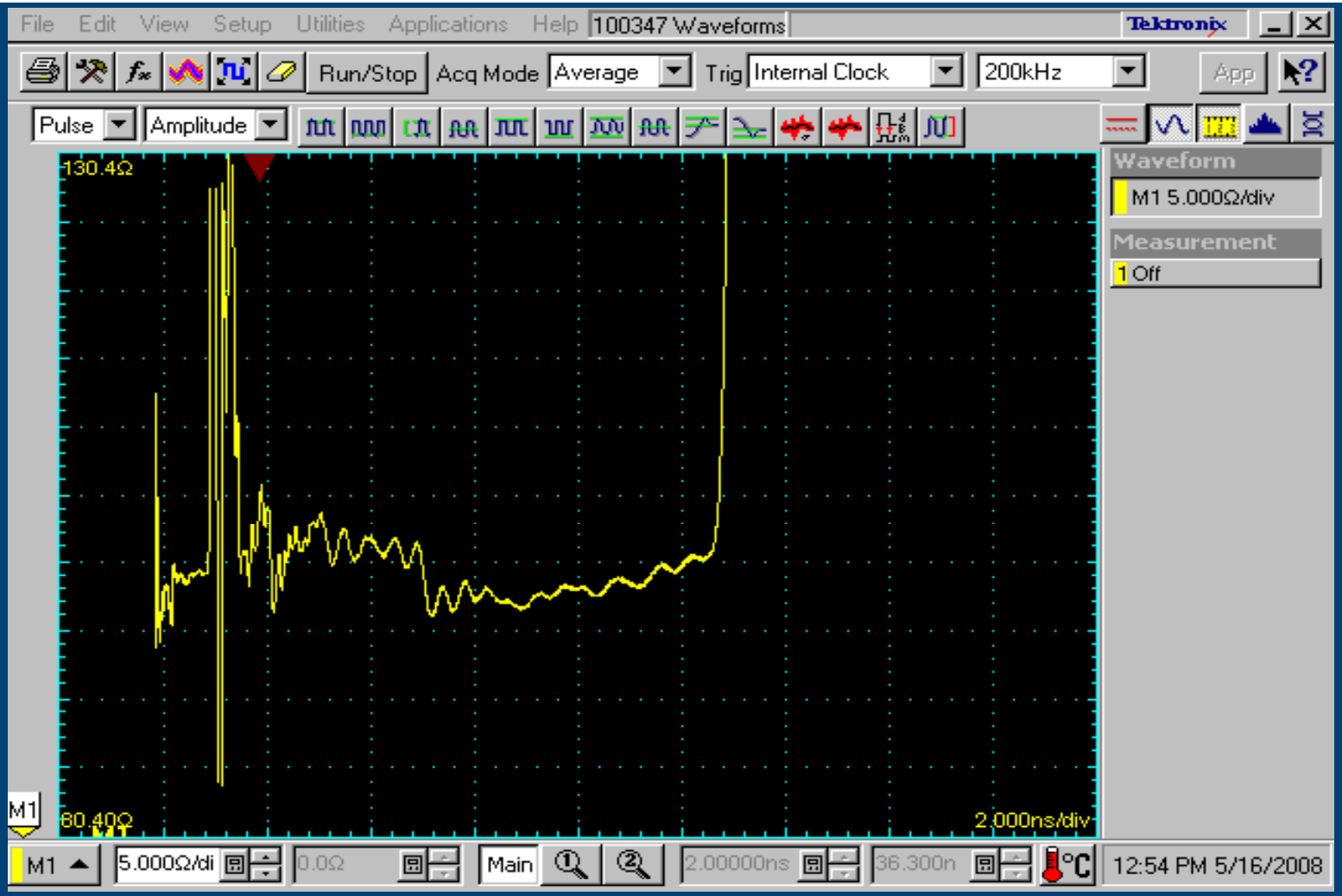
Belden 1800F Diameter x 2.26



Impedance 102.8Ω = RL – 29.41 dB

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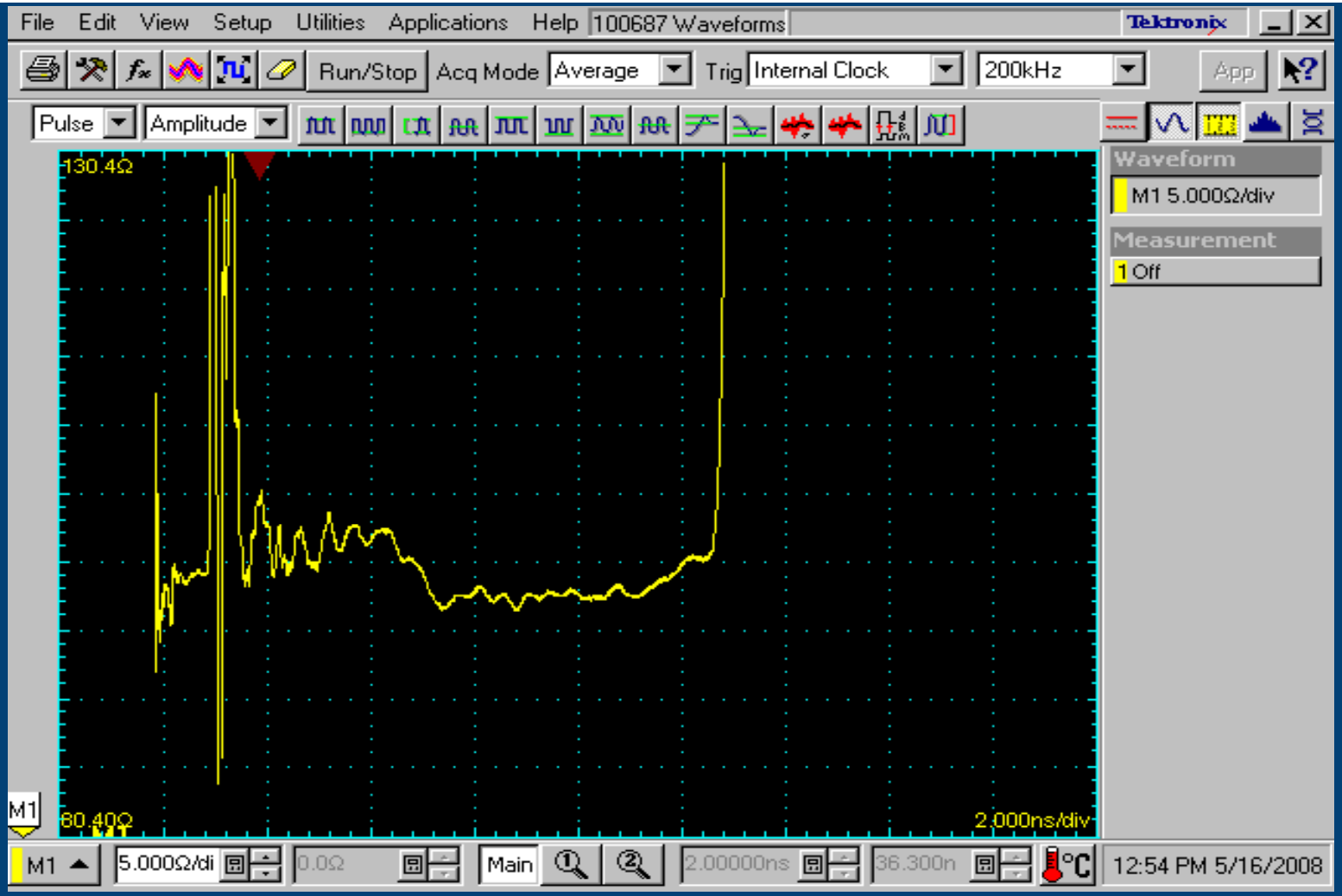
Belden 1800F Diameter x 1.51



Impedance 102.7Ω = RL – 29.29 dB

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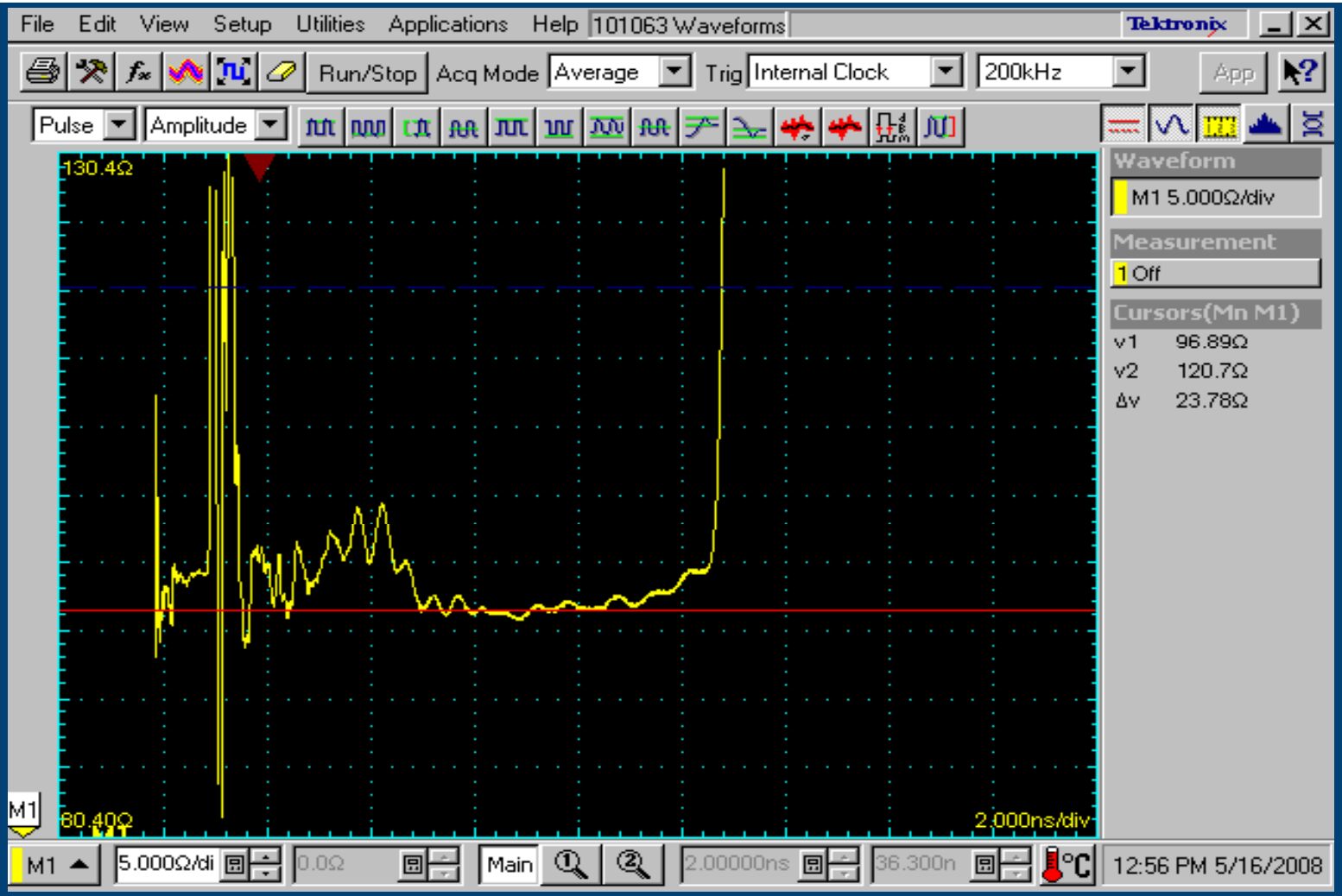
Belden 1800F Diameter x .754



Impedance 101.1Ω = RL – 27.5 dB

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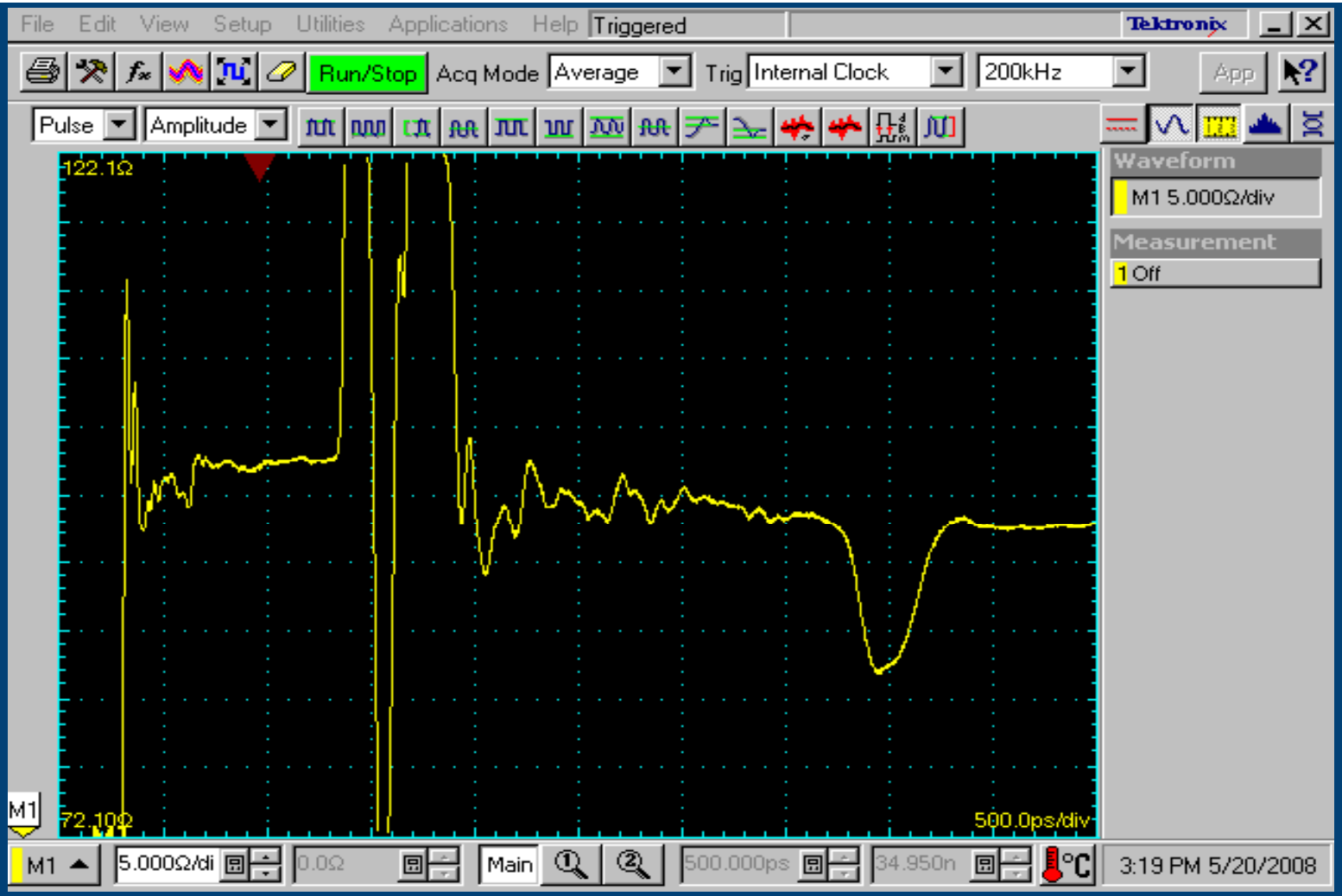
Belden 1800F Crushed with Pliers



Impedance 94.99Ω = RL – 22.71 dB

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Belden 1800F Unbent by Hand

Impedance 100.8Ω = RL – 27.2 dB

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A Word About Analog Audio

- Impedance of the pair is not important
  - Quarter wavelength = 2.25 miles
- Impedance variations mean nothing
  - Return loss variations mean nothing
- As long as you maintain “continuity” cable works.
- Cable can be bent in any way
  - As long as conductors do not break.

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Coming Next….

- Smaller and larger coax cables
- Plenum cables
- Reflection (return loss) in digital audio
  - How much is too much?
- Data cables
  - Cat 5e
  - Cat 6
  - Cat 6a
  - Bonded pairs vs. Unbonded pairs

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Conclusions

- Cable can withstand severe bending.
  - Quality cable can withstand bending of 2 x diameter, or even less.
  - Stranded/flexible cables are no better than solid.
  - With audio, flexible cables can outperform less flexible.
- Much performance returns when unbent.
- Jacket discoloring/whitening indicates abuse.
- Smaller cables seem to have great bend tolerance.
- While coax has more consistent impedance…
  - Bend recovery of coax and paired cable are virtually identical.
- Encourage other manufacturers to perform similar tests.

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