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SENDING ALL THE RIGHT SIGNALS

Coax versus Coax

Steve Lampen
Multimedia Technology Manager
Belden

The Inventors of Coaxial Cable

May 23, 1929

Lloyd Espenschied and Herman Affel

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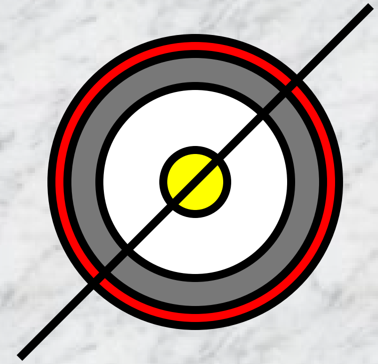
What is Coax?

- Coax is a cable construction where all components lie on the same axis



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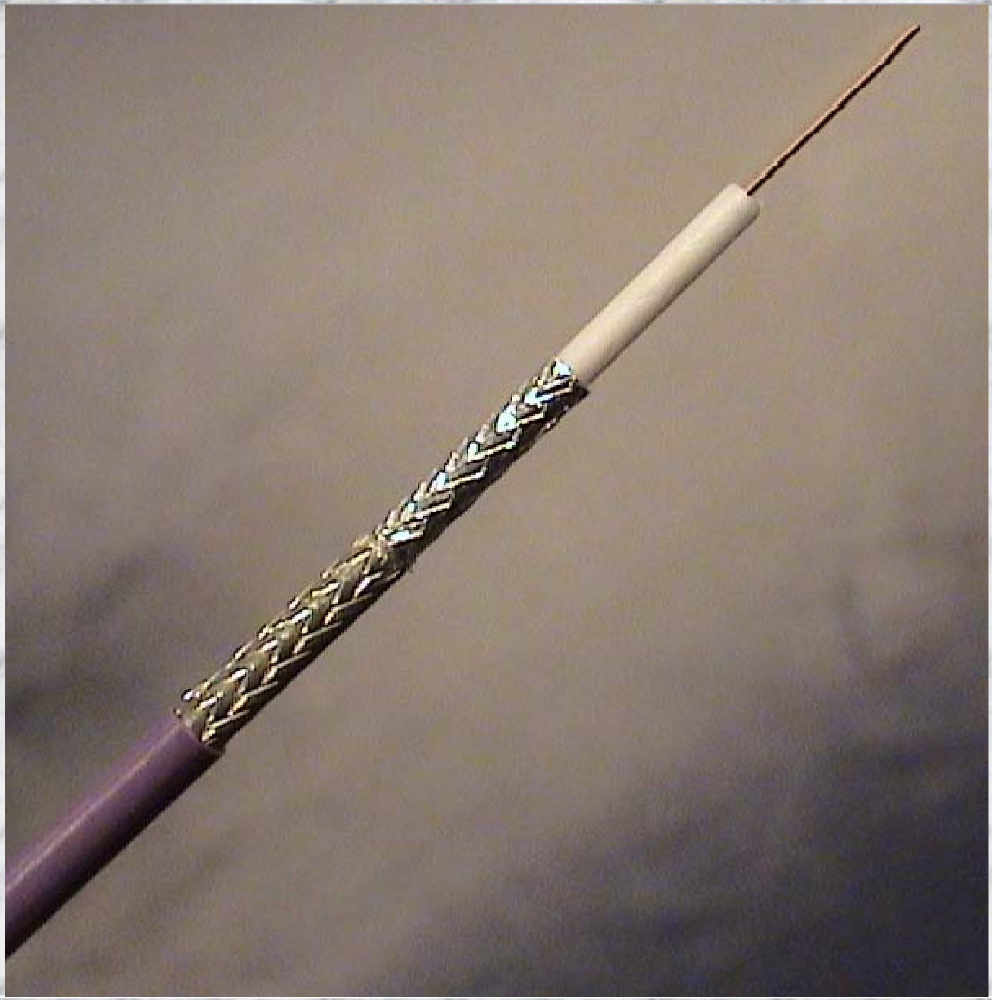
Coaxial Cable



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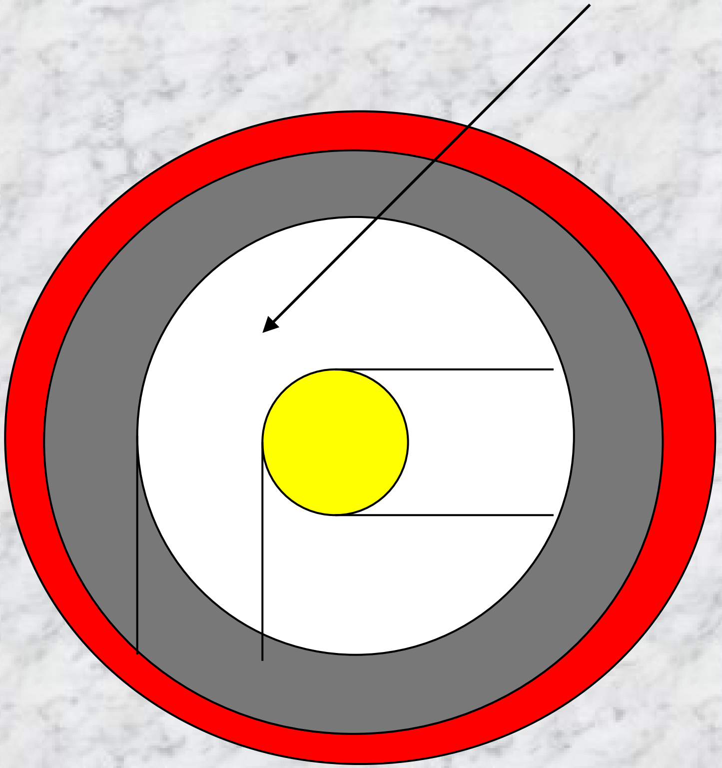
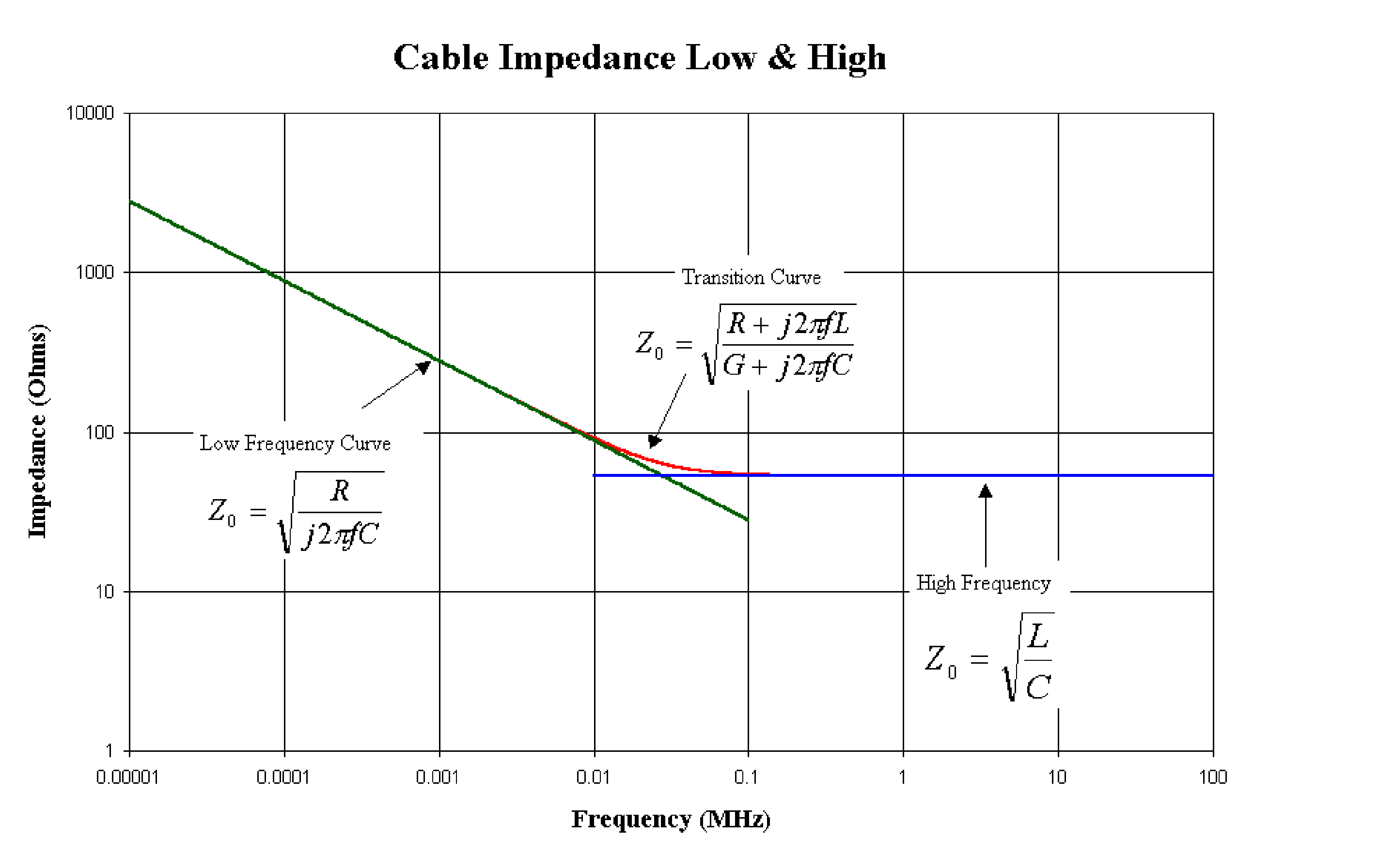
What is Impedance?



What is Impedance?

- Impedance changes with frequency
  - until resistance is a minor effect
  - until dielectric constant is stable
- Where it levels out is the “characteristic impedance.”

Characteristic Impedance



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When is Impedance Important?

- ***When a signal on a cable is at least one quarter of wavelength, then the impedance of the cable is important.***

- So what is a wavelength?

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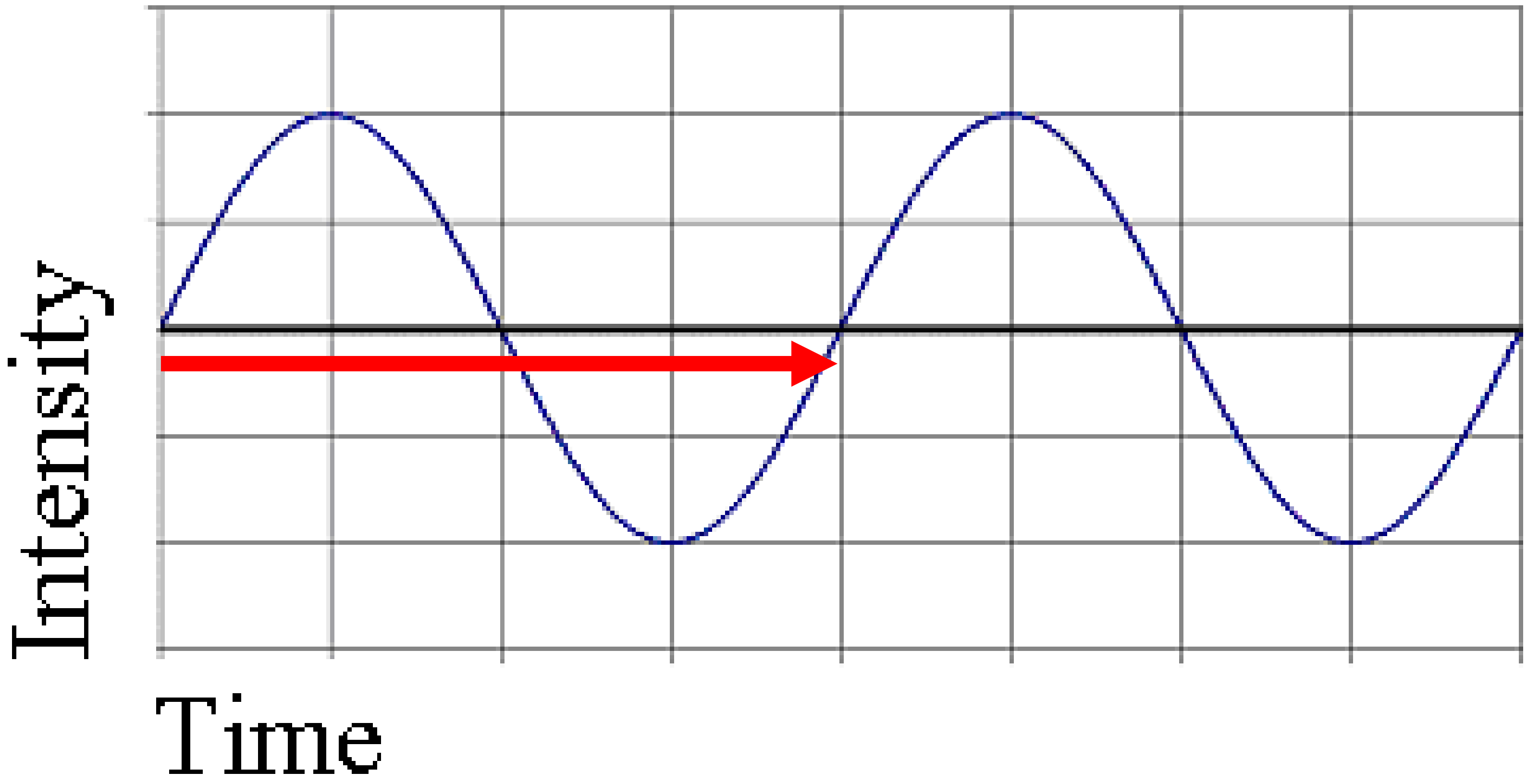
Wavelength



Wavelength

- Here is the formula for a wavelength:

  - $$W_m = \frac{300{,}000{,}000}{F}$$

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Wavelength

- Here is wavelength at different frequencies:

$$W_m = \frac{300,000,000}{1\ MHz} = 300m = \frac{300}{4} = 75m = 246\ ft.$$

$$W_m = \frac{300,000,000}{10\ MHz} = 30m = \frac{30}{4} = 7.\ 5m = 24.6\ ft.$$

$$W_m = \frac{300,000,000}{54\ MHz} = 5.56m = \frac{5.56}{4} = 1.39m = 4.6\ ft.$$

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Wavelength

$$W_m = \frac{300{,}000{,}000}{100\ \text{MHz}} = 3\text{m} = \frac{3}{4} = 75\text{cm} = 2.46\ \text{ft.}$$

$$W_m = \frac{300{,}000{,}000}{1\ \text{GHz}} = 0.3\text{m} = \frac{0.3}{4} = 7.5\text{cm} = 3\ \text{in.}$$

$$W_m = \frac{300{,}000{,}000}{10\ \text{GHz}} = 0.03\text{m} = \frac{0.03}{4} = 7.5\text{mm} = 0.3\ \text{in.}$$

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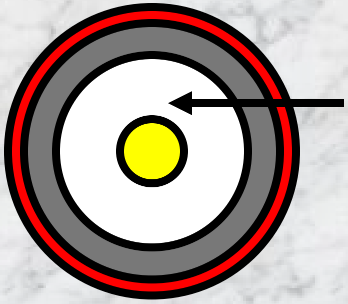
Wavelength

- Wavelength is also affected by the velocity of the dielectric.



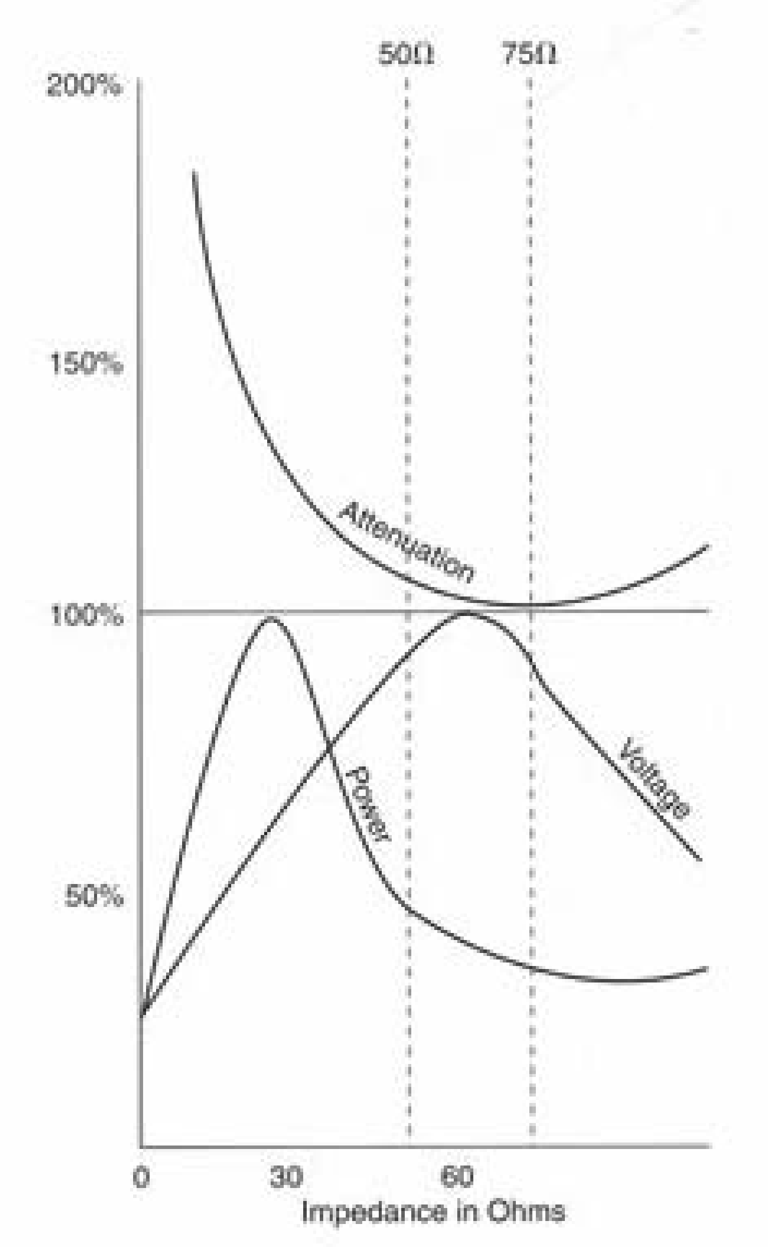
Velocity of Propagation = Vp

Polyethylene = 66%

Teflon = 70%

Foam = 78%, 84%, 86%

Why 50Ω? Why 75Ω?



Center Conductor

- Can be…
  - Bare copper
  - Tinned copper
  - Silver-coated copper
  - Copper-clad steel
  - Silver-coated copper-clad steel
  - …other combinations

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The Reason is "Skin Effect"

- As signals go higher in frequency, they tend to move to the outside of a conductor.

A Formula for Skin Effect

- Rough approximation (in inches).
- Copper conductors.

$$D_{in} = \frac{2.61}{\sqrt{F_{Hz}}}$$

Skin Effect

Frequency	Depth (mm)	Depth (in.)
DC	Entire conductor	Entire conductor
1 kHz	2.07mm	82.6 mils
10 kHz	0.663mm	26.1 mils
100 kHz	0.21mm	8.25 mils
1 MHz	65 microns	2.61 mils
10 MHz	41 microns	.825 mils
54 MHz	9 microns	.355 mils
100 MHz	6.63 microns	261 mils
1 GHz	2.06 microns	.0825 mils

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Size of a Conductor

Type	Conductor	Gage	Size (mm)	Size (in.)
RG-59	solid	24 AWG	0.51mm	.0201 in.
RG-59	solid	20 AWG	0.81mm	.0320 in
RG-6	solid	18 AWG	1.02mm	0403 in.
RG-11	solid	14 AWG	1.6mm	.0641 in.

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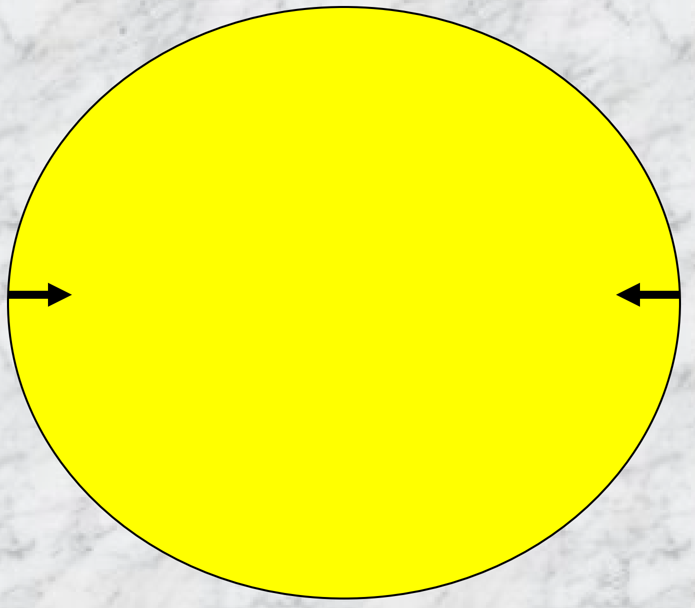
Skin Effect

- Skin effect appears all around the wire.
- Double the skin effect compares to diameter.



Skin Effect on 24 AWG Solid

- RG-59 = 0.51mm = .0201 inches

Frequency	Depth (mm)	Depth (in)	% of Conductor Used
1 MHz	65 microns	00522 inches	26%
10 MHz	41 microns	00165 inches	8.2%
54 MHz	9 microns	00071 inches	3.5%
100 MHz	6.63 microns	.000165 inches	2.6 %
1 GHz	2.06 microns	000522 inches	0.82%

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Skin Effect on 20 AWG Solid

- RG-59 =0.81mm =.0320 inches

Frequency	Depth (mm)	Depth (in)	% of Conductor Used
1 MHz	65 microns	00522 inches	16%
10 MHz	41 microns	00165 inches	5.2%
54 MHz	9 microns	00071 inches	2.8%
100 MHz	6.63 microns	.000165 inches	2.2 %
1 GHz	2.06 microns	000522 inches	0.52%

Skin Effect on 18 AWG Solid

- RG-6 = 1.02mm =.0320 inches

Frequency	Depth (mm)	Depth (in)	% of Conductor Used
1 MHz	65 microns	00522 inches	12%
10 MHz	41 microns	00165 inches	4.1%
54 MHz	9 microns	00071 inches	2.2%
100 MHz	6.63 microns	.000165 inches	1.8%
1 GHz	2.06 microns	000522 inches	0.42%

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Skin Effect on 14 AWG Solid

- RG-11=1.6mm = .0641 inches

Frequency	Depth (mm)	Depth (in)	% of Conductor Used
1 MHz	65 microns	00522 inches	8.1%
10 MHz	41 microns	00165 inches	2.6%
54 MHz	9 microns	00071 inches	1.1%
100 MHz	6.63 microns	.000165 inches	0.81 %
1 GHz	2.06 microns	000522 inches	0.26%

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Skin Effect

- Bare copper/silver-coated copper
  - Good at all frequencies
- Tinned copper
  - Only for low frequencies, easier soldering.
- Copper-clad steel/silver-coated copper-clad
  - Only for high frequencies (above 50 MHz)

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Copper-clad vs. Copper Clad

- Different thicknesses
  - ASTM B452
    - 40%
      - 10% of the conductor
    - 30%
      - 6% of the conductor
  - ASTM B869
    - 21%
      - 3% of the conductor

% of signal carried

Frequency (MHz)	Skin Depth (In.)	40% CCS	30% CCS	21% CCS
1	.00290	39.62	23.77	11.88
3	.00168	68.62	41.17	20.59
5	.00129 8	88.58	53.15	26.58
10	.000918	100	75.17	37.58
20	.000649	100	100	53.15
50	.000411	100	100	84.04
60	.000375	100	100	92.06

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Solid Copper versus Copper-Clad

% of conductor carrying signal

Frequency (MHz)	Bare Copper	40% CCS	30% CCS	21% CCS
1	100	39.62	23.77	11.88
3	100	68.62	41.17	20.59
5	100	88.58	53.15	26.58
10	100	100	75.17	37.58
20	100	100	100	53.15
50	100	100	100	84.04
60	100	100	100	92.06

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Dielectric Constant

- Different plastic have different performance as a non-conductor
- Dielectric Constant
  - PVC = 3-8
  - Polyethylene = 2.25
  - Teflon = 2.1
  - Chemically foamed polyethylene = 1.64
  - Gas Injected Foam Polyethylene = 1.54

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A Look Back at Wavelength

- Wavelength affected by Dielectric Constant.
- Cable at 100 MHz (1/4 wave = 75cm =2.46 ft.)
- Solid polyethylene = 66%
- 2.46 ft. X 66% = 1.62 ft. = 49cm

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Shields

- In coax, a shield is both a signal carrying and signal protecting layer.
- Shield can be:
  - Serve (spiral) : low frequencies
  - Braid: Excellent at low, good at high
  - French braid: Excellent at low, very good at high
  - Foil: Fair at low, excellent at high
- Combination shields
- Shields below 1,000 Hz.

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Transfer Impedance

Shield Type (aluminum braid)	**5 MHz**	**10 MHz**	**50 MHz**	**100 MHz**	**500 MHz**
60% braid, bonded foil	20	15	11	20	50
60% braid, tri-shield	3	2	0.8	2	12
60%/40% “quad” shield	2	0.8	0.2	0.3	10
80% braid, tri-shield	1	0.6	0.1	0.2	2
95% ***copper*** braid, foil	1	0.5	0.08	0.09	1

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Jacket

- Protects the insides.
- Keeps water, pollution, dirt out
- Non-migrating compounds
  - Maintains dielectric performance
- Identification printed on it
- Footage printed on it
- Colors
- What the connector holds onto

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How to Judge Performance

- Resistance
  - All copper –low resistance
  - Copper-clad higher resistance (x5, x7)
- Capacitance
  - Based on dielectric
    - Gas-injected foam = 16 pF/ft.= 53pF/m
    - Solid polyethylene = 20 pF/ft.= 76pF/ft.
  - Track impedance
- Transfer impedance

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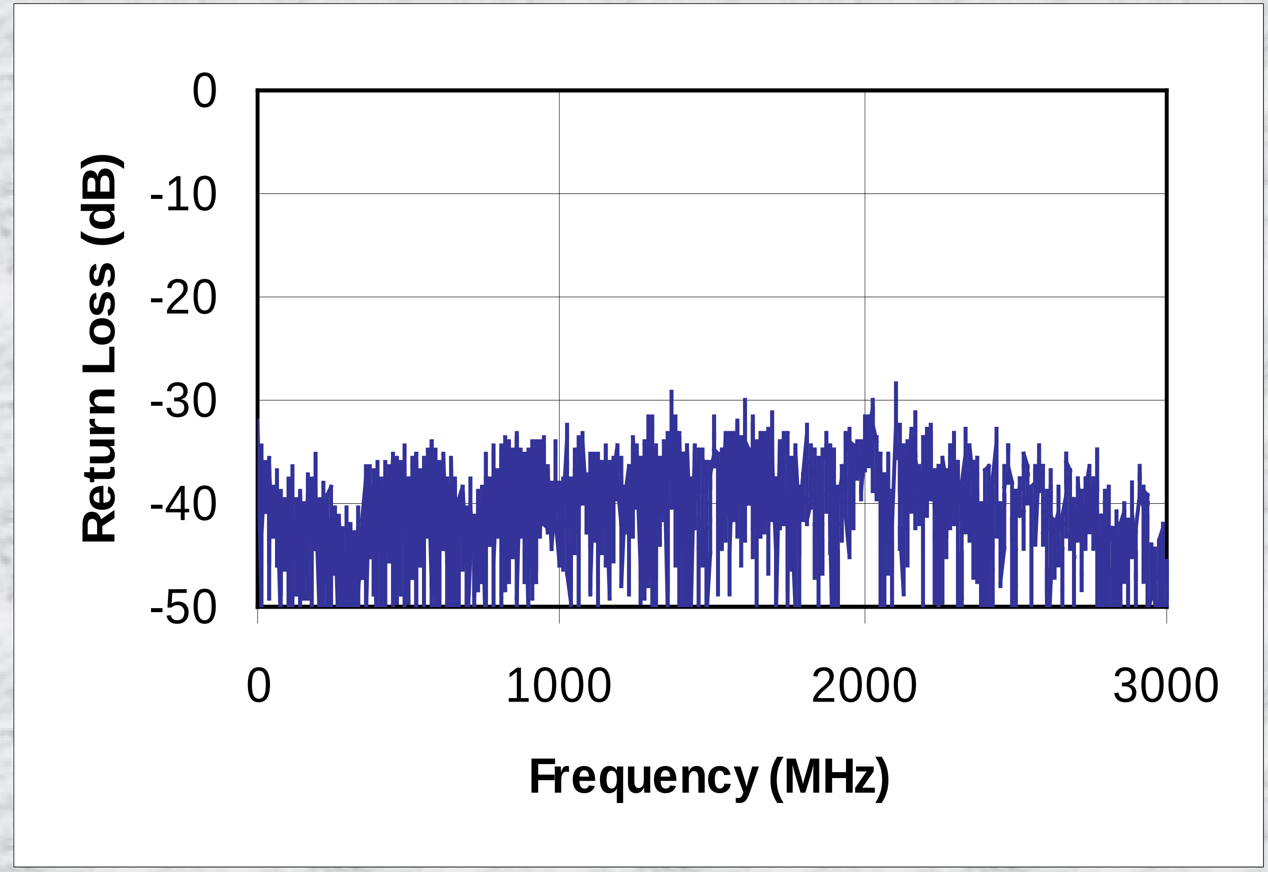
Return Loss

- The best way to determine performance.
  - Shows manufacturing defects
    - Wrong size components
    - Poor centering
    - Machine variations
    - Packaging and storage problems
  - Shows installation defects
    - Bend radius exceeded
    - Pull strength exceeded
    - Same as VSWR

Good Return Loss

New cable, 100 ft. (30.4m)



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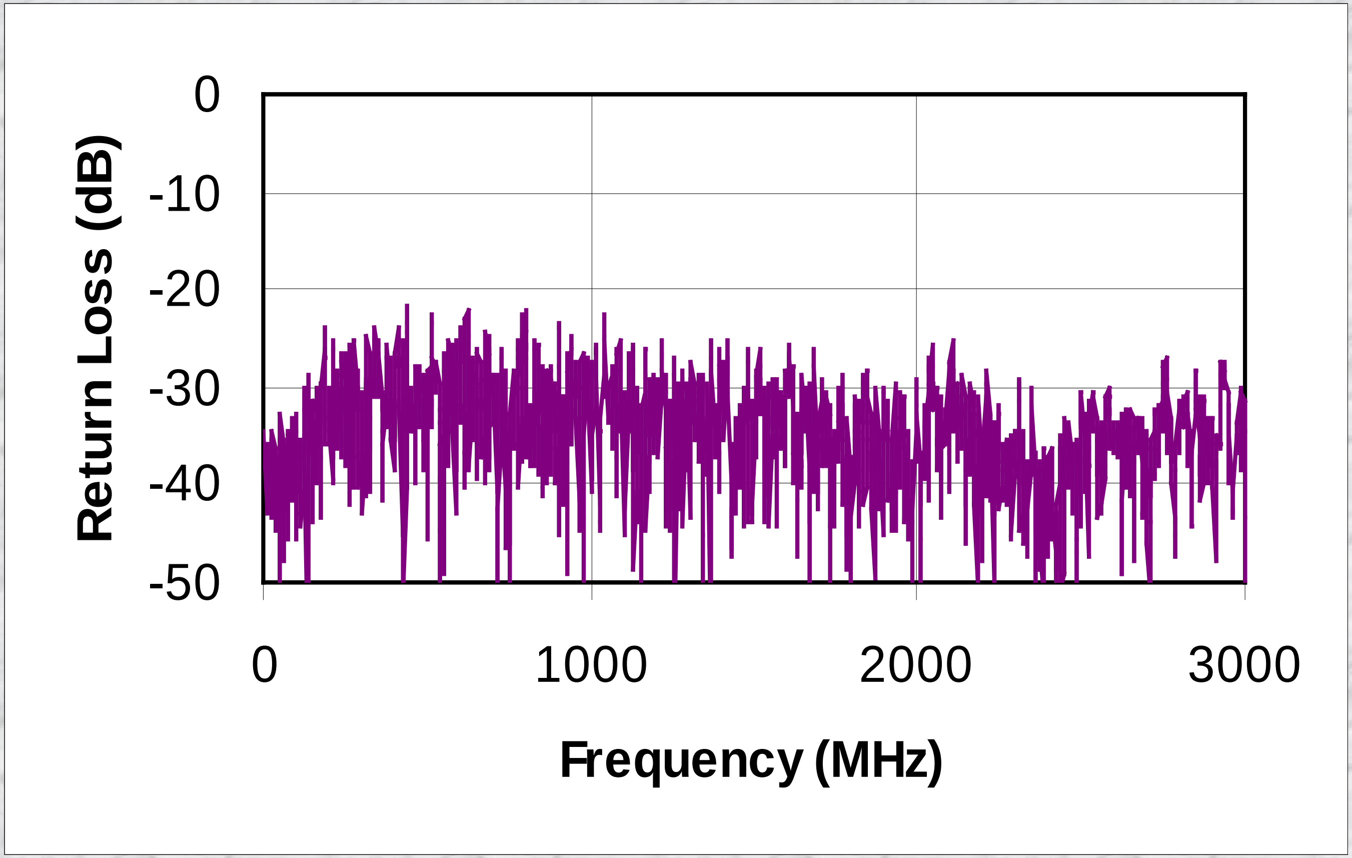
Bad Return Loss

"Mangled" cable, 100 ft. (30.4m)



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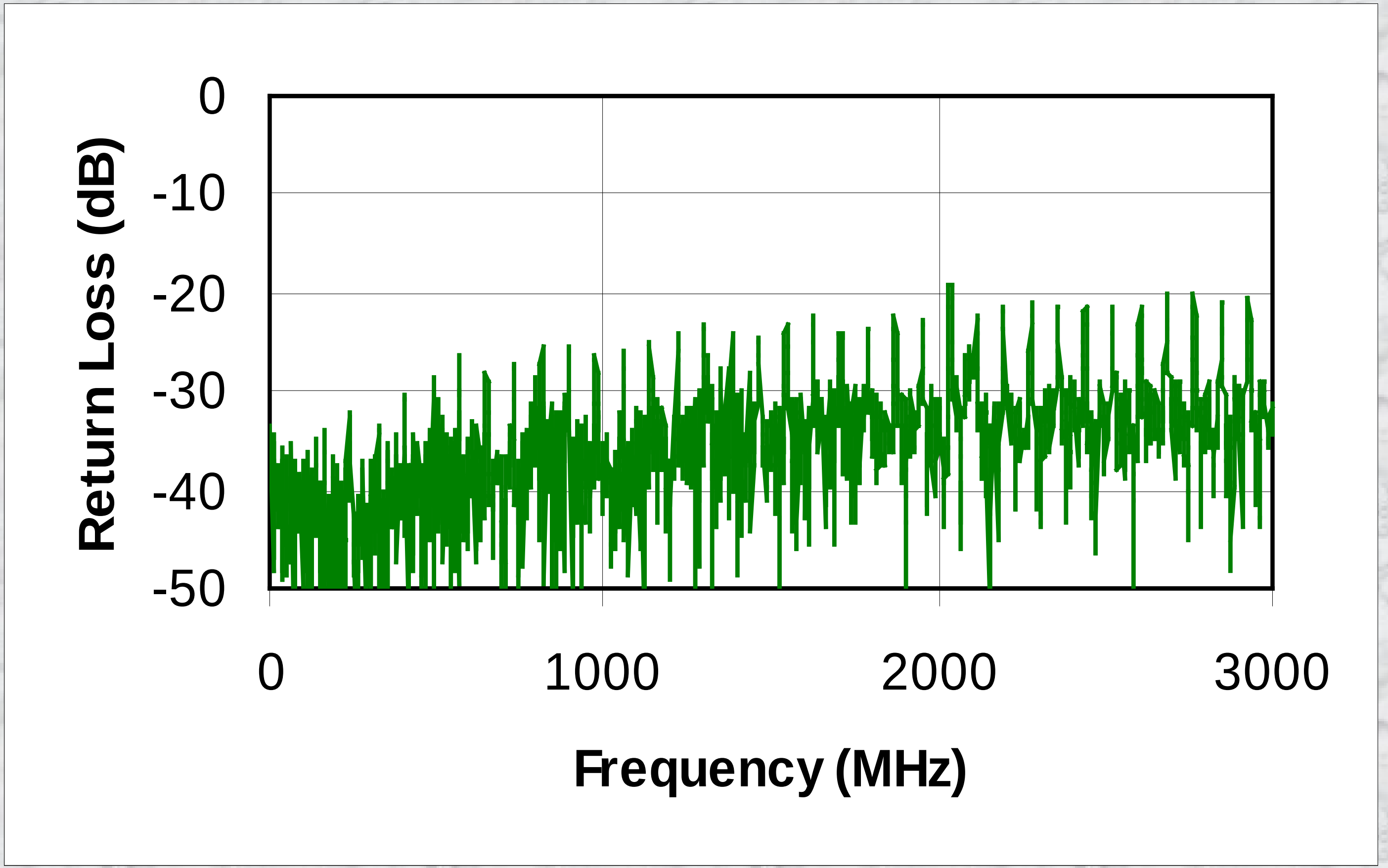
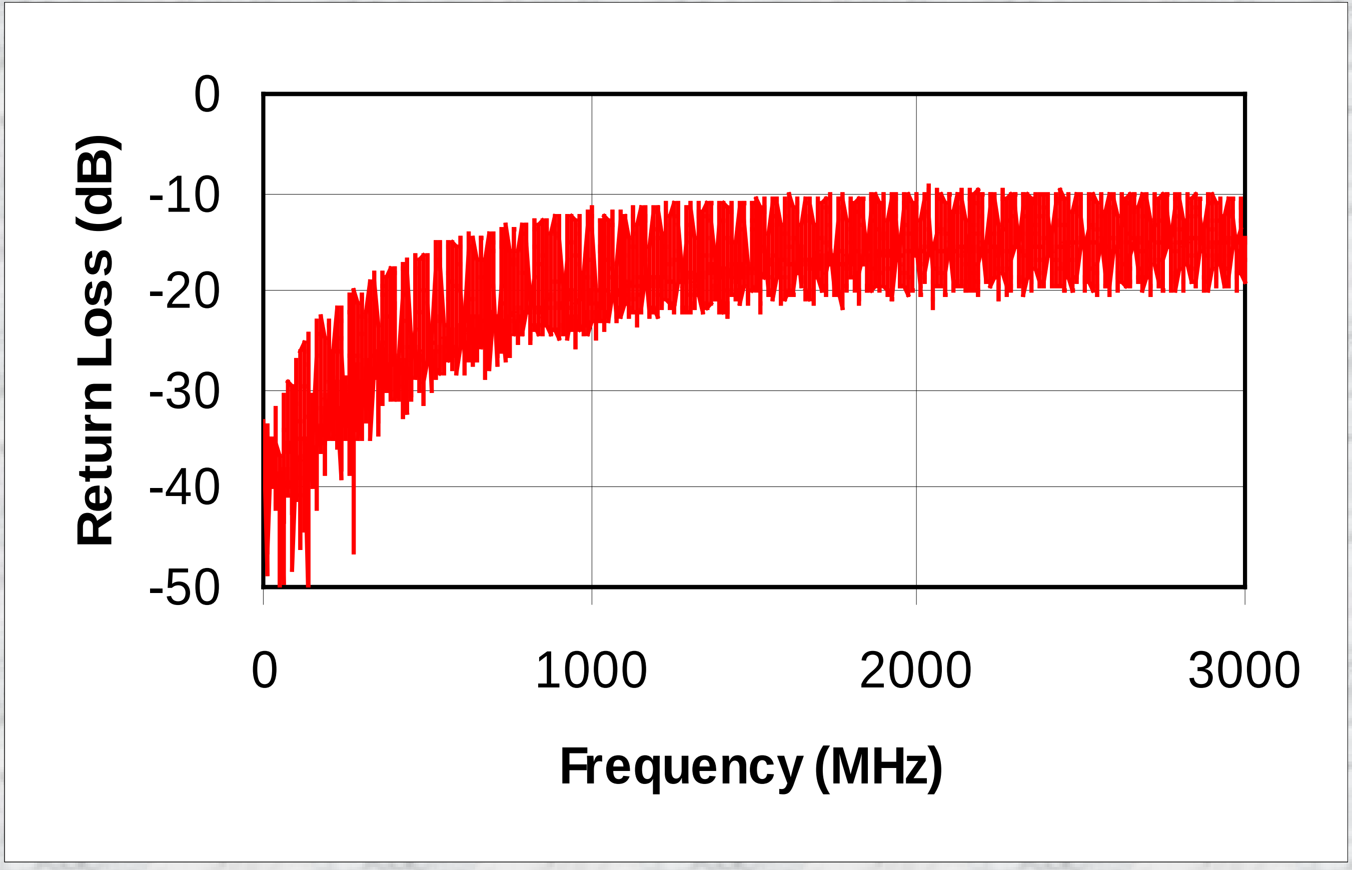
Periodic Return Loss

Crimped every 10 ft. (3m) in a 100 ft. piece. (30.4m)



Periodic Return Loss

10 connectors, 4 barrels (barrels wrong?)



Impedance Match

Return Loss	Match
-10 dB	90%
-15 dB	96.84%
-20 dB	99%
-25 dB	99.68%
-30 dB	99.9%

For More Information...

www.belden.com

9,000 pages of information

1,000,000+ hits per week

Connector cross-reference

Samples: 1-800-BELDEN-1