Maximizing HD Cable Performance

Talk by Stephen H. Lampen, Multimedia Technology Manager, Belden.

Introduction

Belden world's largest manufacturer of *signal* wire and cable. Started in 1902. At least 28 factories around the world, 13 in US, 15 outside US. Just bought a factory in China (series of 3 factories), and he will visit it in August.

He invented his job. With Belden 16 years. His dream job: worldwide schmoozing with engineers about wires. Ex broadcast engineer. Specializes in audio and video cable.

Makes 6000 products, has 6000 employees around the world. Take his card, consider sending a resume to Belden. Only places he's had translators is in China and Mexico.

Started in radio. Worked at Sutro tower as specialist.

Talk

How to put in cable so things work as well as possible. In this school, we have analog which doesn't have to be that exact. Not so in digital.

Cost of copper up to $4 per pound. Used to be much cheaper. Despite lots of sources of copper and lots of countries. Largest copper mines in world are in Chile. Cost went up due to speculation. Copper sulfate (peacock ore) is greenish.

Copper as a mineral only occurs in one place: in a supernova explosion – causes everything heavier than iron to be produced.

Lloyd Espenscheid and Herman Affel worked for Bell labs trying to put many telephone calls on one cable. May 23, 1929. Could shift frequencies (multiplexing) to handle multiple calls; these guys invented that. Tried to put 10 phone calls on twisted pair which was pretty primitive back then. Not electrically stable; specs are variable. Want stable pair of wires electrically. Lloyd had an idea: invented idea of putting one wire inside another wire (coaxial cable). Stability due to being locked together physically.

Picture of telephone pole in 1910 or 1915 showed dozens of wire pairs. Later went to coaxes, and a local pair going to the central office (CO).

What is Coax?

A cable construction where all components lie on the same axis.

How to Determine Impedance (of Coax)

Characteristics include:

- size of center conductor (AWG)

- distance from center conductor to shield
- dielectric constant of material in-between

These guys tried 10 to hundreds of ohms, looking for attenuation, power handling and voltage handling.

A formula takes these three things and calculates impedance.

If step on cable, change distance between center conductor and shield. Deformation: changing the physical attributes of the cable.

Three curves of power, voltage, and attenuation created by these guys at Bell Labs. If making cable just for power handling, ideal would be 30 ohm impedance. For voltage, would be 60 ohms. For minimum attenuation, would be 75 ohms. Video is one volt and not much power, so mostly concerned with attenuation. Wireless engineers chose 50 ohms so are stuck with a 3 dB extra attenuation, and at 50% power.

If a RF guy, if you could change transmitter output, antenna, and cable impedances to 30 ohms, would double your power output.

But, building 30 ohm coax is a problem. Ratio of sizes. Huge difference in sizes.

$100 million atom smasher at Lawrence Berkeley Laboratories designed it for 30 ohm coax. Belden first refused to make it since 90% of the cable was unusable. They made it anyway and the scientist paid a lot of money. Nowadays get about 50% yield on making 30 ohm coax.

Theoretical cable impedance by frequency. A low frequency curve (line at a negative slope), a high frequency curve (line at a more shallow or horizontal slope). No cable has a specific impedance; it is frequency-dependent. For low frequency, the resistance in the wire is a major factor. For high frequencies, just depends on L and C, due to skin effect. **Characteristic impedance** of the cable is the flat high-frequency curve.

Input impedance of coax is the lawn chart. Manufacturers don't want to show this. It is the real world. It varies all over the place This is a manufactured product with lots of moving parts in the machine that makes it. **Average impedance** of coax you will see; it is a nice flat line and is what the manufacturers send you.

Average crappy coax is +/- 3 ohms, best twisted pair is +/- 7 ohms.

What is Return Loss?

Ask about return loss when talking with manufacturers.

Loss (attenuation):

- caused by impedance variations
- structure of a cable
- associated connection parts

Signal to reflect (return) back to the source. This is the loss. A ratio of direct vs. reflected.

Measured in dB (since is good way of expressing direct vs. reflected). The higher the number, the less return loss.

Structural Return Loss

Same as return loss, just measured differently. Came from the cable TV industry; they use cheap cable even though they use high frequency (cable up to 1.0 GHz, satellites up to 2.5 GHz). The analyzer is matched to the cable impedance and the reflected signal is measured. Needed to know what the effect of clamps is onto the cable.

Compared with return loss: analyzer set at the desired impedance and the reflected signal is measured.

Actual Cable Tests

All 100 feet cables off the same reel. Belden 1505A. Same connectors on all cables. 1505A used to be the most popular video cable until the 1605A came out. Popular for home since they fit all sorts of connectors.

Results in chart called a grass chart. Object when making cable is to make the grass as low as possible (least variance between high and low return loss). -30 dB means that 99.9% of signal got to destination. -40 dB means 99.99%. -20 is 99% got to destination and 1% reflected. Is this good? If cables lose signals because of resistance, turns to heat and leaves the cable (microwatts of heat). With return loss, signals come back to the sender of the signals. Sender wasn't designed to handle reverse flow. How many cars going the wrong way does it take to cause a traffic problem? One. In the old days, the sender chips would shut down. This is especially critical in digital; chip struggling but still producing a picture, then within 10 feet fall off the cliff. #1 greatest improvement of chips is their ability to withstand reflections.

Red line on chart is Belden's guarantee on return loss. -23 dB from 5 MHz to 850 MHz, and -21 dB (99.5%) from 850 MHz – 3 GHz.

Blue line: SMPTE 292M requirement for return loss at no time should be worse than -15 dB. This is 96.84%, but it is really bad. At 3% reflection, are seriously compromising ability of chip to feed the line.

Machine outputs 200 feet per minute of cable. 30 seconds later makes a big difference. Plotting first 100 feet versus next 100 feet shows that the return loss vs. frequency differs between the two sections of cable from the same run right next to each other. Every three months, overhaul the machines: throw out all moving parts and replace them. Costs $10 million per year, but the cable is much better out of a new machine. Most competitors will run the machine until the cable is out of spec, but that means that the cable just before it isn't much better than spec.

One of the most damaging things to do to a cable is a torsional twist (coiling it in a tight twist). Force is hundreds of pounds per square inch.

After mangling the cable, the return loss plot ranged in between -20 and -30 dB. If you saw the cable you would refuse to use it because it was so obviously damaged.

Periodicity

Problems worse than this but can't see them at all.

Small change happening over and over. Effect adds up. Half-wavelength, and harmonics. Spikes of return loss.

How we created periodicity: standard BNC crimp tool, crimped cable every 5 feet, 19 crimps. Crimp tool is about the size of the coax, so could barely tell the crimps were there. By choosing every 5 feet, are picking a specific frequency, plus all the harmonics of that frequency. This results in return loss at those harmonics that don't meet the guarantee.

Wire ties can do this.

If crimped every 10 feet, made the problem even worse since now have picked a lower fundamental frequency. The higher harmonics even go worse than the SMPTE standard.

If use hand-tied wire ties (gun used for above examples), turns out much better, might throw away 2 or 3 dB.

Why lose anything for a wire tie? If you have to use them, tie them by hand, don't put them at the same distance apart (vary the frequencies), make them variable (even though uglier).

Periodicity vs. Impedance

The impedance varies greatly when the dielectric of the cable is squished.

Periodicity continued

Another solution: Velcro wire ties. Use only as much tension as the Velcro will hold.

Another solution, use plastic hangars. See web site at www.aifittings.com

Foam Density

Bubbles in the foam of the cable have impact on density and deformation. Solid polyethylene turns white when you add air to it. Also, greatly increases the volume (like whipping egg whites). The more air Belden adds to the dielectric, the more they charge you. With the air, can go farther at higher frequencies.

How Much Air?

Velocity of Propagation	*% Air*
78%	43.75%
80%	49.8%
83%	58.93%
86%	66.51%

Stiff is good in cables.

Installation Parameters

Deformation: step on the cable, run over it, put equipment on it, pulling it through conduit

Need crush resistance. Look at random mangulation.

Bend radius: low density foam, bending puts stresses on the center.

Need high-density hard-cell foam.

Crush Resistance

IEC 60966-1 clause 9.4 crush test.

- 100 mm (4") square steel plate
- pressure 0.2 inches (5 mm) per minute
- increase until 3 ohm change in impedance, as measured on a TDR (time domain reflectometer)

Read the pressure at this point.

Results are

Cable Sample	*Average Crush Resistance*
Belden 1505A	275 pounds
Manufacturer X equivalent	164 pounds
Manufacturer Y equivalent	165 pounds
Belden 1694A	405 pounds
Manufacturer X equivalent	206 pounds
Manufacturer Y equivalent	213 pounds

The other cables are cheaper.

Cost of wire and cable is maybe 5% of an installation cost, maybe up to 10%.

EN50289-3-5 test on 1505A off the shelf. Shows chart of impedance vs. frequency.

Pull Strength and Tension

Pull strength elongates center, braid is like those Chinese finger traps (squeezes the dielectric).

Determine the spec. Manufacturer's suggested tension: 40% of breaking strength is maximum pull tension.

Cable	*Pull Tension*
8281	116 pounds
1505A	47 pounds
1694A	69 pounds

1505 has a 20 gauge center conductor. Use braid and foil on high frequency cable.

Pull strength on Cat 5 is 25 pounds.

Can't tell pull strength by feel. Must measure them. Use scales. Kellems grip pulls all the set of cables equally.

Defect Rate

Defect rate vs. sigma quality level.

At 5.4 sigma = < 57 PPM in 1995.

75% of manufacturers don't even measure this. He has seen only one Chinese manufacturer to measure sigma out of thousands.

Connectors

Analog video uses 50 ohm connectors. NTSC wavelength 234 feet (¼ wavelength 59 feet). PAL wavelength 54.5 meters (¼ wavelength 13.6m). SDI is at 135 MHz. Wavelength 7.3 feet (2.2 m) (¼ wavelength of 1.8 feet). Third harmonic 405 MHz: wavelength 2.4 feet, ¼ wavelength 7.3 inches.

A defect would have to be at least a quarter wavelength long to show up.

How many harmonics to include in order to get a square wave signal? Industry says that 3rd harmonic is enough to indicate a square wave (fundamental plus 3rd harmonic). SMPTE goes to the 2nd harmonic, which is odd since square waves are made up of odd harmonics.

HD SDI – 750 MHz. Third harmonic is 2.25 GHz. Wavelength 5.3 inches, ¼ wavelength 1.3 inches.

A length of 1.3 inches isn't much longer than a couple of connectors, so must use connectors with proper impedance.

DIN 1.20.3 push lock pull unlock connector wanted to replace BNC.

Super HD

Clock at 1.5 GHz. For 1080p/60. Third harmonic 4.5 GHz. Wavelength 2.6 inches, ¼ wavelength .656 inches.

Belden now tests digital cable. -23 dB 5 MHz – 1.6 GHz, -21 dB 1.5 GHz – 4.5 GHz.

Connectors and Barrels

Cut 100 foot cable into 5 pieces, use 10 BNC connectors and 4 barrels.

Return Loss and Connectors

Chart

Cable/BNC	*1-20 MHz*	*20-300 MHz*	*300-2GHz*
75/50	>-30 dB	-24 dB	-7 dB
75/~75	>-30 dB	-25 dB	-12 dB
75/75			-21dB

Coax Cable Stripping

Machine $18000 computer controlled to strip coax. Doesn't put on the connector. Can buy these on ebay for $3000.

Cable Clones

Faraday Technology (UK) faradaytech.co.uk or faradaytech.com

These emulate cable length. 10 m, 20 m, 50 m. Designed for various standard cables like 1694A, 1505A. Put cable in circuit, run HD, look at bit errors. About $200 each.

Digital Headroom Meter

4Sight HRM-1500. Shows direct energy, reflected energy, signal strength. $1500. 4sightproducts.com jim@dtvengineering.com

Gefen HD-SDI Generator

EXT-HDSDI-GEN for $2655. Still patterns, moving patterns, audio tone generator, closed caption, time code generator, 2 video outputs. About size of hand.

Belden Return Loss Guarantee

SMPTE spec says -15 dB return loss (VSWR 1.43:1). This VSWR would blow up a transmitter.

Belden HD cable, non-plenum and plenum.

Return Loss Testing

Network Analyzer: fixed bridge, not variable bridge (SRL), S11 reflection measurement from port 1 to port 1.

Units used today: HP (Agilent) 8714ES. Option 1EC system impedance 75 ohms, Option 100 RL and fault location.

Look at white paper entitled *Return Loss Headroom* on the Belden web site for the math on this.