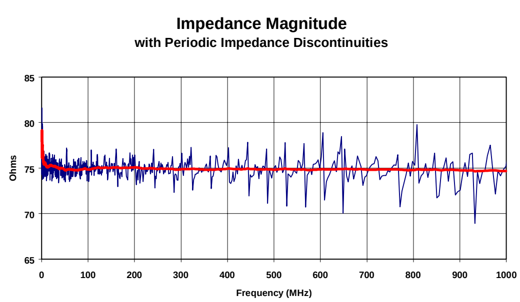
Precision Video Coaxial Cables
Part 2: Return Loss

Martin J. Van Der Burgt
Senior Product Engineering Project Manager
Belden Electronics Division

Abstract: *Over the years, engineers have come to identify coaxial cables typically in one of two ways: either by impedance or RG-type. The impedance refers to the characteristic or nominal impedance of the cable. Recently, some manufactures have begun to specify tighter requirements on the cable. This paper will examine the nature of return loss as the preferred specification requirement, rather than characteristic impedance, and to what extent the values are relevant.*

Review: In Part 1, it was shown that characteristic impedance is not a true representation of the performance and/or quality of a transmission line. This is best illustrated in GRAPH 1. This cable has had a periodic discontinuity introduced into the cable. (A slight compression at 10 foot intervals.) Notice that the input impedance shows the defect, but characteristic impedance does not. A TDR measurement may show some of the defects, depending on how far into the cable you look or the type of TDR used, but the resultant impedance value from this type of measurement may not.



GRAPH 1

Therefore, the characteristic impedance value alone – or its tolerance – does not tell the whole story of cable quality or performance. A specification for impedance variation, both magnitude and phase, is required to demonstrate this capability.

Magnitude and Phase Together: Since both impedance magnitude and phase can be affected within the cable, it makes sense to look at both to determine the true performance of the cable. What measurement and specification will do this best? In this paper, the use of the reflection coefficient will be discussed in more detail, using the measurement of Return Loss, to ensure cable performance and minimize impedance variations within the cable.

Impedance Variation: When signal traveling in a coax encounters an impedance mismatch or variation, a portion of the signal will be reflected back to the source. This reflected signal has magnitude and phase and is measured as the reflection coefficient.

$$\Gamma = |\Gamma| e^{j\phi} = \frac{Z_{02} - Z_{01}}{Z_{02} + Z_{01}} \quad (1)$$

Where: Γ is the reflection coefficient
ϕ is the phase angle

By measuring these signal reflections it can be determined what is happening within the coax. The actual impedance mismatches can be calculated. It is desired that the reflection coefficient magnitude be as small as possible, resulting in minimal signal reflected back to the source due to impedance variations.

As can be seen from the simulations in Part 1, the best way to improve (minimize) the reflection coefficient magnitude is to reduce variation from the characteristic impedance value, and vice-versa. This is achieved by having minimal impedance variation, both magnitude and phase, along the length of the cable.

From the impedance formulas in part one, it can be shown that three values effect impedance of a coaxial cable: conductor diameter, insulation diameter (or distance between conductors), and dielectric constant.

$$Z_0 = \sqrt{\frac{L}{C}} = \frac{1}{2\pi}\sqrt{\frac{\mu}{\varepsilon}} \ln \frac{D}{d} \quad (2)$$

While the dielectric constant and center conductor diameter are primarily set in the manufacturing process, there are many things in both manufacturing and installation that can affect the impedance at any point in a cable due to insulation diameter variations.

The types of variation are periodic and random. Periodic variations have a tremendous effect on signal reflection. The signal traveling within the cable occurs at a certain wavelength(s). If the periodic variation causing the signal reflection is associated with this same wavelength(s), every reflection will cause a small percentage of the same signal to be reflected back to the source. The result is like that of a notch filter, effectively making the cable useless at that frequency. For cable, this effect is most dramatic when the variation occurs at the ½ wavelength of the frequency.

$$\frac{\lambda}{2} = \frac{C * Vp}{2f} \quad (3)$$

where: λ = wavelength
C = speed of light
Vp = velocity of propagation
f = frequency in Hz

If the variation is random in nature, many different wavelengths will be effected rather than one specific frequency.

<u>Manufacturing:</u>
Almost every manufacturing operation has a cyclical process within it, something that repeats itself in a periodic manner. Items like: capstans, sheaves, pulleys, gears/motors/drives, package reels, etc. If not in excellent operating condition, these can act in concert to randomly increase the impedance variation within the cable. If one element is poor, it's repeating periodic problem can have tremendous implications.

<u>Installation and Handling:</u>
Other periodic issues encountered every day are evenly spaced tie wraps, ladder trays, and other means used to neatly dress cable installations. Also, exceeding the maximum recommended pull tension, minimum bend radius, stepping on cables, etc. all have an effect on the cable impedance at any particular point. Belden products help the user to minimize these effects by using a gas-injected foam high density polyethylene dielectric material in our precision video cables. These cable constructions have as much as twice the crush resistance of similar commercially available products.

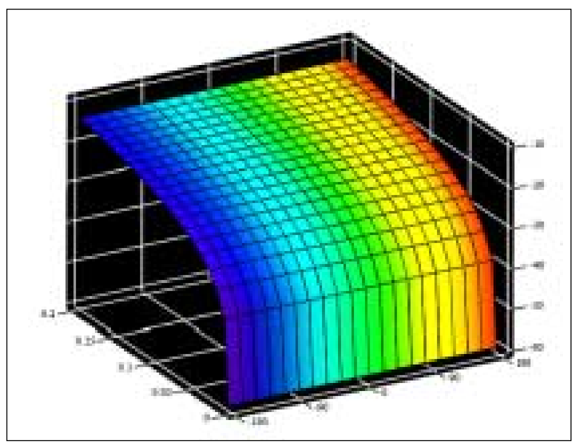
Return Loss Defined: A better specification as to the quality and consistency of the transmission line is return loss (RL) or *voltage* standing wave ratio (VSWR). This more accurately captures the reflection coefficient in an easy to interpret value. While you may not have heard of the reflection coefficient, you have most likely heard of RL or VSWR. These are the more common forms of reporting the reflection coefficient value. In video cables, the term RL is typically used. The measurement and calculation are in reference to a fixed, or constant, impedance. In the case of video coax, this fixed impedance reference is 75 ohms.

From the reflection coefficient, we define the RL (return loss) or SWR (standing wave ratio) as:

$$SWR = \frac{1+|\Gamma|}{1-|\Gamma|} \quad (4)$$

$$RL = -20\log|\Gamma| \quad (5)$$

This graph shows that the reflection coefficient phase angle has no effect on the Return Loss Value. Further, as the reflection coefficient decreases, the return loss value becomes smaller.



GRAPH 2

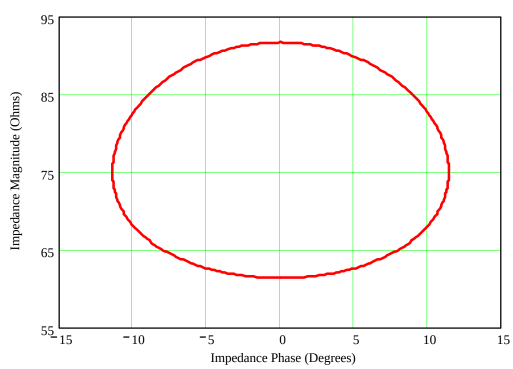
x: Reflection Coefficient Phase
y: Reflection Coefficient Magnitude
z: Return Loss

(Note: RL is a negative number, therefore smaller is better. However, it is normally expressed as a positive number. A larger absolute value number is better.)

As was demonstrated in Part 1 in the impedance simulations, minimal variation in the impedance magnitude and phase will reduce the reflection coefficient magnitude.

What is the limit of impedance assuming a reflection coefficient magnitude of 0.10? (For reference, a 0.1 reflection coefficient is a RL of 20dB or a VSWR of 1.22:1.) This is a respectable value that is typical of standard grade coaxial cables.

This graph shows the circle that will contain the impedance values at a specific reflection coefficient value, in this case 0.10. Notice that the impedance magnitude at any frequency can vary +/- 15 ohms and the phase angle can vary +/- 12 degrees. These would be actual limits for the INPUT IMPEDANCE, not the characteristic impedance.



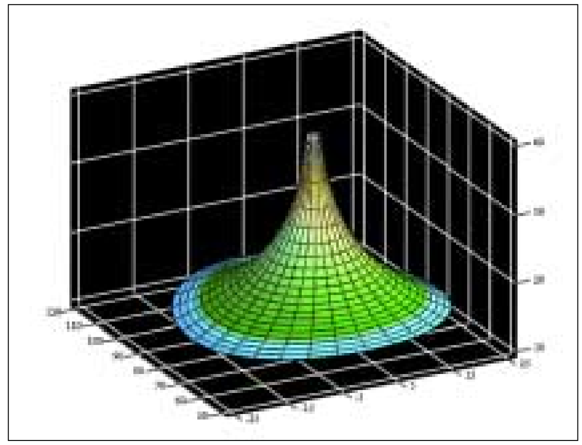
GRAPH 3

The characteristic impedance would ideally be a dot at 75 ohms and 0 phase. As you can see, it is not a true representation of the cable's possible performance and quality.

Return Loss Values: The RL simulation shows us that RL is directly proportional to the reflection coefficient. Therefore, limiting RL will limit the impedance variation.

In GRAPH 4 we see that as the RL value gets better, the impedance magnitude and phase are limited and restricted to values approaching 75 ohms and 0degrees. Thus, specifying RL limits the impedance variation as well!

This is actually a "stack" of the ellipses shown in GRAPH 3. We previously showed the limit with a reflection coefficient magnitude of 0.10. This reflection coefficient magnitude is equivalent to -20db RL.

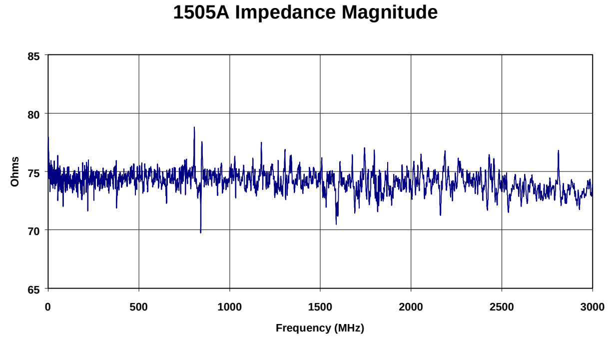


GRAPH 4
x: Impedance Phase
y: Impedance Magnitude
z: Return Loss

RL essentially locks in the impedance magnitude and phase. The better the RL, the better impedance stability within the transmission line. Therefore, a specified limit on RL ensures impedance stability.

Actual Cable Measurements: RL vs. Frequency is an easy to interpret 2-dimensional (X-Y) chart. Recalling the actual cable measurements from Part 1 for impedance (GRAPH 5 and GRAPH 6 below), what is the expectation for the RL value of this cable?

GRAPH 5 is the same trace shown in Part 1. The impedance magnitude is 75 +/- 3 ohms. Notice the spikes at ~ 750 MHz. We will talk about these later.

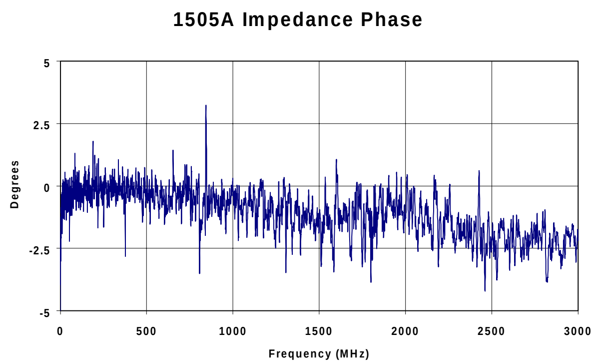


GRAPH 5

This is a fairly typical trace for Belden 1505A. Because the cable RL value is so low, that means the reflection coefficient is also low, 0.05 or less as can be seen from our model in GRAPH 2.

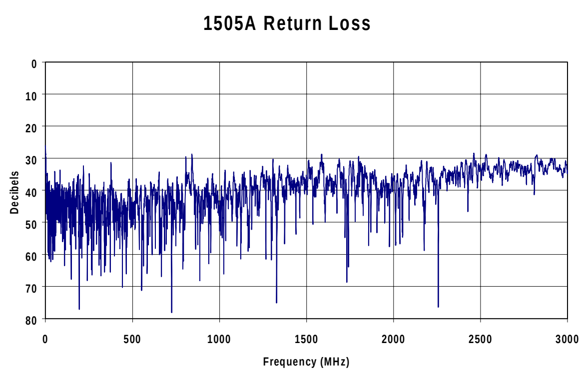
Looking back at our models for impedance magnitude and phase, you can see that the impedance must be very near 75 ohms and the phase very near 0 for this to be true. That is why the comment was made in Part 1 (Specmanship) about Belden's characteristic impedance being much tighter than the specification.

GRAPH 6 is the same trace shown in Part 1. The impedance phase angle is 0 +/- 3 degrees. Notice the spikes at ~ 750 MHz. This will be covered later.



GRAPH 6

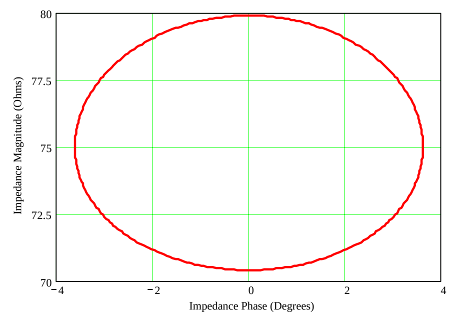
With impedance magintude of 75 +/- 3 ohms and impedance phase of 0 +/- 3 degrees, we can interpret from our funnel graph (GRAPH 4) that the RL should be about 30db.



GRAPH 7

GRAPH 7 is the actual RL data from the same sample of Belden 1505A. The cable is ~30dB maximum, as the model predicted.

Lets look at it another way. If the cable is better than 30dB Return Loss, what is the limit of the impedance phase and magnitude? Our formulas predict that the impedance must be contained within the circle in GRAPH 8.



GRAPH 8

The earlier traces in GRAPH 5 and GRAPH 6 show impedance magnitude of 75 +/- 4 ohms (grass) and an impedance phase of +/- 4 degrees. Yes, the actual data fits within the theoretical calculated limits.

Notice that even with 30db RL (VSWR 1.07:1) the impedance phase and magnitude can still vary by 5 ohms and/or 3.5 degrees.

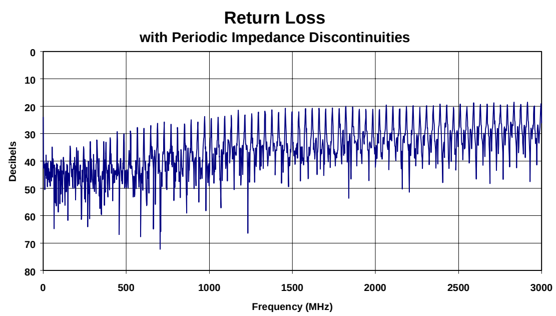
However, the RL minimum specification limit locks in the impedance magnitude and phase, and guarantees the reflection loss level within the cable.

Return Loss Performance: Also note the "spikes" at ~ 750 MHz in GRAPH 7. See how they correspond to the impedance phase and magnitude spikes in GRAPHS 5 and 6? These are easily seen and interpreted on the RL graph.

You can also see that a limit on RL will limit the impedance variation as well.

Remember the earlier trace with good characteristic impedance, but several impedance variations within the cable (GRAPH 1)? Even though the characteristic impedance meets the requirement, what does the RL look like?

GRAPH 9 is another example of how RL easily captures and shows the effects of impedance mismatch within the cable. Notice the nice “comb effect” filter caused by the 10 foot periodic discontinuities. The 10’ interval corresponds to approximately a 40 MHz harmonic spike, because the spike corresponds to the 1/2 wavelength (see equation 3).



GRAPH 9

Which specification better represents the performance of the cable? The characteristic impedance did not relay this information. The characteristic impedance tolerance did not prevent this condition.

Only a RL specification will assure a user that this will not occur. (Attenuation may also show this effect if it is large enough.)

So, by specifying a tolerance on characteristic impedance and an absolute minimum value for return loss, together these attributes guarantee cable performance.

Specmanship: As is demonstrated in this paper, Return Loss is the critical attribute in determining cable performance, not impedance. Therefore, impedance and other electrical attributes are sampled for verification, whereas return loss ideally should be 100% tested on each package reel.

Belden tests EACH reel for RL as the final quality and performance verification prior to applying the plastic wrap and/or placing the reel in the box to send to the customer. *(Some manufacturers test RL on a process or master reel following the jacket operation. This test, on a 10,000 foot reel of cable, is not sufficient to determine the performance and quality of all the cable on the reel. It also does not protect the customer from possible damage done during the spooling or packaging of the cable.)*

Belden has the following return loss specifications on the Precision Video Cables:

Min. Return Loss: 5 - 850 MHz 23db
850 - 3000 MHz 21db

The RL specification limit is at the above listed values to statistically ensure that all cable will meet the requirement. The standard deviation on RL is typically quite large due to the “grass”, or random variation, nature of the data. These limits represent a 6 sigma level of quality. 100% of the frequency range, 100% of the product.

It is highly suggested that the cable be swept to AT LEAST the “third harmonic” of the SDI or HDTV signal. This translates to 2.25 GHz for HDTV. Belden sweeps all these cables to the maximum available testing range, which is 3.0 GHz for 75 ohm products.

Structural Return Loss: Another method of measuring impedance variation is Structural Return Loss (SRL). SRL measures the return loss with a bridge, or via softeare compensation, to match the equipment to the cable’s impedance, not a fixed 75 ohm standard. This method measures the loss (variation) within the cable, but not the total loss of the system since it does not take into account any cable impedance mismatch (offset). Because SRL is not a true representation of the total system performance, consider this when the cable specifications state SRL.

Conclusion: The major concern of the engineer is the signal loss. Signal loss occurs two ways: attenuation and Return Loss. The other concern of the engineer is signal distortion, mainly due to capacitance. Notice that impedance is not listed! It is a means to an end - which is RL.

Characteristic Impedance is an averaged, fitted, or summation of the high frequency input impedance response. It is a typical or reference value that should reasonably represent the cable's design features.

Return Loss is a measurement of the reflected signal losses in a cable due to impedance mismatches within the cable. It is a true representation of the cable's manufactured and installation quality and expected performance.

The SMPTE specifications only require the cable to meet 15db RL. It is Belden's position that cable from the manufacturer must have additional headroom to account for the rigors of installation and other possible RL problems introduced within the physical layer (installation, poor terminations, etc.)

About the Author:

Martin J. Van Der Burgt

Marty is a Senior Product Engineering Project Manager for Belden Electronics Division. His experience encompasses project management and product development positions. He currently has responsibility for all design and development efforts, and manages the day-to-day activity of product engineers, for Belden's entertainment, service provider, and industrial product areas. Marty received his Bachelor of Science Degree in Electrical Engineering (BSEE) from Marquette University, Milwaukee, WI in 1992 and has been with Belden since that time. He is a member of several professional organizations and standards bodies, and has had several articles on Audio/Video and RF topics published in trade magazines: most recently, a co-authored tutorial on "High-Definition Cabling and Return Loss" in the January 2001 SMPTE Journal. Marty also holds a FCC Amateur Extra Class amateur radio license. He and his wife Beth live in Richmond, IN.

Marty Van Der Burgt

Graphs and data formatted by Carl W. Dole.