Return Loss

Abstract

When there are faults on a cable, they cause distortion to any signal passing along the cable, some of that distortion takes the form of a reflection, or a return, of part of the signal's energy. This is return loss. It is proportional to the severity of the fault.

By

Mark Govier, February 2025

Description of "Return Loss"

Impedance mismatches cause reflection, or return, of part of the energy of a signal, this manifests itself as a wiggle on the trace of a TDR screen. Return Loss is a way of expressing how bad an impedance mismatch is. Let me first explain some fundamental principles of signal transmission on cables.

Fundamental Cable Parameters

Whenever an electrical signal is applied to a cable, that signal starts propagating along the cable at the speed of light in that cable. This is an identical situation (mathematically) to the propagation of a loud sound in a valley or the waves on a pond surface. These waves, which carry energy, reflect when they encounter a change of impedance of the cable, like sound reflecting at a cliff or a water wave bouncing off a harbour wall.

For this paper, accept that the speed of light in the cable (its velocity factor or velocity of propagation) is determined by the dielectric constant of the insulation between the conductors.

Also accept that there is another characteristic of all cables which is their characteristic impedance often simply shortened to "impedance". You may also have heard of impedance matching; this is where the characteristic impedance of the signal source is matched to that of the cable and the cable to the load at the far end. For example, in a radio system the transmitter, connectors, cable and antenna will work best when all are exactly 50-ohm characteristic impedance.

Velocity of Propagation

V_P or VoP is determined solely by the dielectric constant of the insulation between the conductors of a cable. There is no element of the VoP which depends on any other variable.

$$V_P = \frac{1}{\sqrt{\epsilon}}$$

Where epsilon is the effective dielectric constant ($\epsilon_0 \epsilon_r$).

Dielectric Material	Dielectric Constant ϵ_r	Velocity Factor	Velocity of Propagation
Polyethylene (PE)	2.3	0.659	65.9%
Foam Polyethylene	1.3 - 1.6	0.79 - 0.88	79% to 88%
Air Spaced Polyethylene	1.3 – 1.4	0.84 - 0.88	84% to 88%
Solid PTFE	2.07	0.695	69.5%
Air Spaced PTFE	1.2 – 1.4	0.85-0.90	85% to 90%
Polyurethane foam	1.03 – 1.18	0.90-0.95	90% to 95%
Polystyrene foam	1.02 – 1.05	0.97 – 0.99	97% to 99%

So, you can see that many of these have a range of values. Particularly "foam" dielectrics where the density of the foam or other "non-solid" insulation is critical.

Characteristic Impedance of a Cable

The characteristic impedance of a cable is dependent on the geometry of the conductors but is also dependent upon the dielectric material. For a fuller explanation see chapter 10 of the TV220E user's guide. But for a coaxial cable, where D is the diameter of the shield and d is the diameter of the core, then the characteristic impedance is given by:

$$Z_0 = \frac{1}{2\pi}\sqrt{\frac{\mu}{\epsilon}}\ln\frac{D}{d} \approx \frac{59.9\Omega}{\sqrt{\epsilon_r}}\ln\frac{D}{d}$$

Fundamentally the speed of propagation depends on the dielectric material and the characteristic impedance on this and on the geometry. Changes of dielectric material or physical shape of the cable will result in a change of "characteristic impedance".

Return Loss

This is loss of signal, signal that does not reach the destination, delivered into the load, due to reflection or "return". An echo. These echoes are due to the signal encountering a discontinuity of impedance and a proportion of the energy being reflected to the source. This is exactly how an audio echo or the reflections of radio waves that are used for RADAR are reflected.

Let us first consider the perfect case, where everything is impedance matched: All the energy of the signal leaving the transmitter is transferred to the cable and apart from cable losses (due to capacitance and series resistance), all the remaining energy is coupled from the cable to the perfectly matched load. In this case there is ZERO reflection.

If the signal you put into the cable is a pulse, then this pulse will travel to the far end, deliver all its remaining energy to the load and be gone; dissipated as heat having done its job conveying information or power from one end of the cable to the other.

Now consider the case where the far end of the cable is disconnected, i.e. there is no load to absorb the energy conveyed along the cable. In this case the pulse of energy (attenuated and stretched by the cable's capacitance, inductance and resistance) will reach the far end and have nowhere to go. What happens? The energy is reflected but how much and in what polarity?

Reflections

It is easy to work out how much when you already know the formula for the "reflection co-efficient". I will just give this here:

$$\Gamma = \frac{Z_L - Z_0}{Z_L + Z_0}$$

Where Z_0 is the source impedance and Z_L is the "load" impedance.

So, you can see that the case where both impedances are "matched" the top of the equation tends to zero, so the reflection co-efficient is zero. But when Z_L tends to infinity (open circuit) then the reflection co-efficient tends to +1 (reflections are shown above the line on a TDR for "high" impedances). Similarly, if the far end were shorted, i.e. zero impedance then the reflection co-efficient will tend to -1 (reflections shown below the line on a TDR). Sometimes this is expressed as a "percentage" so a figure ranging from -100% to +100% where zero is the ideal "perfectly matched" condition.

Decibel Return Loss (dB RL)

But in the realm of TDRs, we commonly concern ourselves with the relative loss of power that does not reach the destination, because it has been reflected. The equation for return loss (RL expressed in dB) gives larger positive values for "low" reflection and RL tends to zero as the reflected energy approaches ±100% of the incident energy (short circuit or open circuit). Though it is normal in TDRs to ignore the sign as the direction of the excursion above or below the trace is thought information enough for the user.

$$RL = -20 \log_{10} \Gamma$$

Return Loss is a measure of the severity of a fault at a particular location on a cable. But between the TDR and the event there is also normal signal loss in the cable due to resistive and dielectric losses that are unavoidable. Let us account for that…

Event Return Loss (ERL)

When an event is spotted with a TDR – a wiggle on the trace – then we can apply our knowledge of the loss per unit length of that cable type (this figure must be measured and is often input to the cable library from the cable manufacturer's datasheet) to correct for this loss in the signal "there and back" to the event.

When we do this, we can express the result as event return loss or ERL. This allows us to normalize for the losses along the cable and then be able to better compare the true severity of different events along a cable whether they are near to the tester or closer to the far end of the cable.

By using ERL, the technician can quickly find the worst service affecting faults and correct these first.

ERL is in effect a convenient way of displaying the normalized impedance of the cable at an event. Here the normalization is correction for the approximate signal loss between the event itself and the measured reflected energy.

ERL could, if wanted, be converted to "impedance", but it is only a rough estimate as there are so many variables between the source and "event".

Testing Past the First Fault

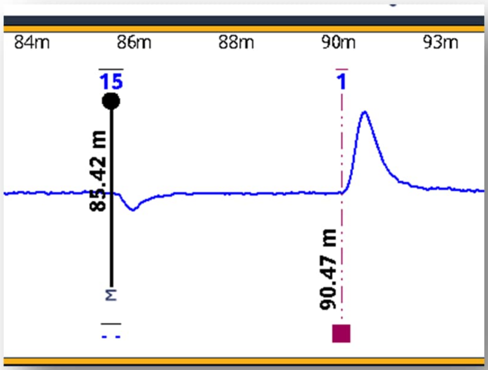
Is it possible to test beyond the first fault in a cable if some of the energy of the test pulse has been reflected? The formula to calculate the actual loss of signal power at a reflection is given by:

$$Power\ Loss = -10 \times \log_{10}(1 - \Gamma^2)$$

As Γ can range from -1 to +1 with zero being the default "good" condition, you should be able to see that $1-\Gamma^2$ will be small for bad faults, tending exponentially faster towards zero as an open circuit or short circuit is approached. It is surprising how little signal is lost at a small event.

Consider for example connecting a mismatched coaxial cable, such as 75Ω to 50Ω.

- Reflection co-efficient (Γ) is 0.20
- Return loss is roughly 14 dB
- Power loss is just 0.2 dB



This screenshot from a Tempo TV220E TDR shows the transition from 75Ω to 50Ω and the open "end-of-cable". The event return loss figures are above each marker.

This insignificant power loss of 0.2dB is similar to the loss (around 500MHz) in roughly 1 to 1.5m of RG6U cable.

If you want to learn more of the theory behind this, please refer to your favourite electromagnetic engineering and transmission line textbooks. Some useful examples are:

- The Physics of Vibrations and Waves, H. J. Pain, Wiley
- Engineering Electromagnetics, William H. Hayt, Jr, McGraw-Hill

Summary of Return Loss

Return Loss is a simple way of numerically expressing signal loss due to reflection from impedance discontinuity in a cable. It is normally expressed in decibels representing the reflection co-efficient at some event. Event return loss is a way of expressing this but making allowance for the signal loss to and from the event thereby giving a better estimate of the relative impedance mismatch at the event.

To see the full manual for the TV220E/EX products where there is a fuller description of how return loss is derived, please visit:
TV220E CableScout Time Domain Reflectometer (TDR) – Tempo Communications

Tempo Communications

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