Reflection coefficient is the basis of several measurements common in the wire and cable industry. It however is not generally understood and is not widely accepted as a method of evaluating cables. In this paper we will discuss reflection coefficient, and its application in testing cables.

**Reflection Coefficient:** Reflection coefficient (Rho) is the ratio of the amplitude of the reflected wave and the amplitude of the incident wave. Or at a discontinuity in a transmission line, it is the complex ratio of the electric field strength of the reflected wave to that of the incident wave as shown in Equation 1.

\[ \rho = \frac{V_R}{V_I} \]  

(1)

Where \( \rho \) = Reflection Coefficient, \( V_R \) = Reflected Voltage, and \( V_I \) = Incident Voltage.

When an electrical signal is transmitted down a transmission line, the electrical wave travels without interference as long as there are no discontinuities within the line. Discontinuities are changes in the impedance within the transmission line, and acts as a barrier to the flow of the electrical signal. These barriers cause the electrical signal to bounce back towards the signal source. This is called a reflected wave and is in the opposite direction of the signal being transmitted. The amount of reflected signal is a function of the change in impedance within the transmission line as shown in Equation 2.

\[ \rho = \frac{Z_R - Z_I}{Z_R + Z_I} \]  

(2)

Where \( \rho \) = Reflection Coefficient, \( Z_R \) = Reflected Impedance, and \( Z_I \) = Incident Impedance.

Given a 50 and 75 Ohms system, the reflection coefficient can be calculated based upon a theoretical reflected impedance. Graphs 1 & 2, show the reflection coefficient of 50 ohm and 75 ohm transmission lines where the reflected impedance is plus or minus twenty five ohms. This change in impedance is not a change in the characteristic impedance, but is an instantaneous reflected impedance based upon the transmission line characteristics at a frequency over the length of the cable.

As can be seen from the graphs, there is a direct correlation to the change of impedance and the reflection coefficient.

When the cable impedance equals the input impedance there is no reflected signal, and Rho is 0.

If the cable impedance is higher than the input impedance the reflected signal is positive. In the case
of an open circuit the impedance is infinitely high and the reflected signal is equals the input signal and has the same polarity. Thus $V_R$ and $V_I$ are equal in magnitude and of the same polarity so the resultant Rho is $1$.

If the cable impedance is lower than the input impedance the reflected signal is negative. In the case of a short circuit the impedance is infinitely low and the reflected signal equals the input signal but is opposite in polarity. Thus $V_R$ and $V_I$ are equal in magnitude and opposite polarity so the resultant Rho is $-1$.

Thus Rho has a possible range of $+1$ to $-1$.

It is also worth noting, that a lower cable impedance has a greater effect on Rho than a high impedance. From the 50 Ohm reference to the 25 Ohm reflected signal Rho has a magnitude of $.333$. When the impedance mis-match is from the 50 Ohm input impedance to a reflected impedance of 75 Ohms Rho has a magnitude of $.2$. One can surmise that a high impedance is more desirable than a low impedance.

In the same light, looking at a 75 Ohm input impedance and given the same ± 25 Ohm reflected Impedance, Rho ranges from $-.2$ to $+.14$. Thus it is more difficult to maintain a low Rho on a 50 Ohm cable than it is on a 75 Ohm cable. This partially accounts for the different impedance tolerances between 50, 75 and 100 ohm cables.

Rho Measurements can be made with various techniques. Most often it incorporates one of two methods. The most common method is using a network analyzer, and the other method is using a Time Domain Reflectometer (TDR).

**Network Analyzer:** When making measurements using a network analyzer the cable under test is connected to an output port on the analyzer. Most modern network analyzers have a two port interface and the cable is connected to the $S_1$ port. The far end of the cable is terminated with a load to match the impedance of the cable. This may be an external load or it may be connected to the $S_2$ port on the analyzer. A sinusoidal signal is sent down the cable at a known impedance and power level, at a specified frequency. The analyzer can automatically step through a specified frequency range measuring the reflected power at each frequency, giving an overall frequency response or sweep trace for the cable.

Because of the step frequencies there are discrete frequencies for the measurement. The spacing of these frequencies will tend to clip the high points off the data. For example if a measurement is made over the frequency range of 5 MHz to 5000 MHz and the number of points set on the analyzer is 201. The step frequency is $(5000 - 5) / 200$ or 24.975 MHz. If there is a peak at 1015 MHz. The analyzer is going to make a measurement at 1004 MHz (40 points * 24.975 + 5 MHz) and 1028.975 MHz (1004 + 24.975). Because these frequencies are not exactly 1015 the peak is going to be clipped and the analyzer is going to report a lower value than is actually present. By increasing the number of points to 1601 the step frequency is 3.121875. Then the analyzer is going to measure 1013.365625 and 1016.4875. This will increase the resolution because the measurements are much closer to the actual spike.

**Time Domain Reflectometer:** The TDR works in much the same way as the network analyzer in that it sends a signal out one port and detects the signal that is reflected back to that port. The big difference is the TDR sends a fast rise time pulse down the cable and then measures the signal that is reflected. The rise time of the pulse determines the bandwidth of the TDR measurement. The faster the rise time the higher the bandwidth of the pulse, and is determined by:

$$BW = \frac{35}{Rt}$$

Where $BW=$Bandwidth, $Rt=$Pulse Rise Time

A rise time of 17.5 picoseconds, typical of Tektronix TDR’s, gives a bandwidth of 20 GHz.

**Return Loss:** Having built a foundation of Rho we can now look at some of the more common methods of interpreting reflected signals. Return Loss (RL) is used most often in the 75 ohm broadcast and CATV markets, and is the accepted method of evaluating the sweep characteristics of cables. RL is the power level of the reflected signal as compared to the input power of the incident signal in dB. The basis of the value is Rho, and is calculated using the following equation:

$$RL = 20\log(\left|\rho\right|)$$

Where $\rho=$ Rho

Because the reflected signal is lower than the incident signal the RL is always negative. Another way of
thinking about the RL is, the reflected signal is “X” dB down form the input signal.

The following graphs show the Return Loss given the reflection coefficient numbers from Graphs 1&2.

Often RL is referred to as a positive value such as 23dB. This may cause some confusion about why RL (actually a negative value) is referred to as a positive number. This is actually very simple. Because RL is always lower than the input signal, the negative sign is dropped most of the time. Thus –20 dB simply becomes 20 dB, but it is important to remember that the actual number is negative or “X” dB down from the input signal.

There are two types of Return Loss measurements. There is simply Return Loss, and Structural Return loss. There are some important differences between these two methods the need to be discussed.

**RL Measurements:** RL measurements are made using a network analyzer as mentioned earlier. For the RL measurements the analyzer’s ports are calibrated to a known impedance (50 or 75 Ohms). There is no adjustment in the output impedance, which is known as a fixed bridge analyzer.

If the cable under test has a characteristic impedance different than the output impedance of the analyzer, the return loss starts out higher because of this initial impedance mis-match. For example, cable A has a characteristic impedance of 72 ohms, and the network analyzer has an output impedance of 75 ohm. Prior to any measured discontinuities within the cable there is a 3 ohm reflection due to the mismatch of the cable and the analyzer. When the cable is measured on the fixed bridge analyzer the nominal return loss value will be –33.3 dB. The variation from the cable will be centered around –33.3 db. If the impedance within the cable varies ± 10 Ohms the total impedance variation will be from 62 Ohms to 82 Ohms, and the total variation in Return loss will be from the lowest possible to –20 dB. If the same cable had a characteristic impedance of 75 Ohms with ± 10 Ohms variation, the Return loss will be from the lowest possible to –23 dB, or a three dB improvement.

This is the preferred method of measuring cables for the Broadcast market.

**Structural Return Loss:** Structural Return Loss (SRL) is a method of compensating for the initial mis-match in the cable. The network analyzer’s output impedance is adjusted to match the impedance of the cable under test. This type of analyzer is known as a variable bridge analyzer. In the example given in the previous section, this would be equivalent measuring the 72 Ohm cable as if it were a 75 Ohm. This would give a SRL range from the lowest to –23 dB.

There is some concern with this method of measurement. By changing the output impedance of the analyzer to match the cable impedance, the measurement may artificially improve the performance of the cable with respect to the equipment it is attached to. Most equipment manufacturers set the input and/or the output impedance of the equipment at 75 Ohms. When the cable is measured using a Variable bridge analyzer, the expectation of cable performance may be better than the actual results.
SRL is most often used for CATV applications.

**Voltage Standing Wave Ratio:** Another method of interpreting the reflection coefficient is the Voltage Standing Wave Ratio (VSWR). VSWR is a ratio of the power input into the cable versus the power out, and is normally written as 1.2:1 and is said 1.2 to 1. Another way to think about VSWR is it is the amount of input power needed to get an equivalent of 1 power out. In the above example it takes 1.2 power in to get 1 power out.

The bases of VSWR is Rho and is calculated using the following formula:

\[ VSWR = \frac{1 + \rho}{1 - \rho} \]  

(5)

The following graphs show the VSWR of the Reflection Coefficient of Graphs 1 & 2.

Because the standing wave ratio is not always calculated from the voltages, the “V” is sometimes dropped and is referred to as Standing Wave Ratio (SWR). VSWR and SWR are the same number and can be used interchangeably.

**Time Domain Reflectometry:** Time Domain Reflectometry (TDR) is a method of measuring the impedance of a cable. A precision air line, with a known impedance is, is attached to the output of the TDR and is used as a reference. The cable to be tested is attached to the air line and a fast rise time pulse is sent down the cable. The reflection coefficient of the reference air line is measured and averaged over its length. Then the reflection coefficient of the cable is measured and averaged over a length of about six inches. The cables average Rho is then subtracted from the average reflection coefficient of the airline. The resultant Rho is then used in equation 6.

By using equation two and solving for the reflected impedance we come up with the formula for calculating the impedance of the cable under test:

\[ Z_O = Z_L \times \frac{(1 + \rho)}{(1 - \rho)} \]  

(6)

Where \( Z_O \) = Characteristic Impedance, \( Z_L \) = Air Line Reference Impedance, \( \rho \) = Reflection Coefficient.

Because of the short length of cable used to measure Rho on the cable, and because of the typical bandwidth of the TDR, this measurement method is not adequate for measuring RL or VSWR.
Test Lengths: Another important consideration when measuring RL, SRL, or VSWR is the length of the sample to be tested. A rule of thumb is to have the cable length at least five wavelengths long at the lowest frequency to be tested.

For example, using 1505A cable with 83% velocity and a test frequency of 5 - 3000 MHz the wave length of the various frequencies will range from 163.39 ft. (49.8 meters) at 5 MHz to 3.27 Inches (.083 meters) at 3000 MHz. If the RL of a 1000 ft reel of cable is being tested within this range, with a wave length of 163.39 ft at 5 MHz, the number of wave lengths in the cable is 6.12. This meets the desired minimum of 5 wave lengths.

On the other hand, at 3000 MHz there would be 3670 wave lengths, and it can be seen that the lowest frequency is the most critical when determining the length of cable to be tested.

If a length of cable has been installed, and you are trying to determine if it has been damaged. Depending upon the length and the frequency, you man not see any damage in the lower frequencies even though the cable is actually damage.

Example: 200 ft of cable is installed and going to be used for 270 Mbps SDI video. The critical frequency is 135 MHz. Can the RL be measured to determine if there is any damage that will effect the cable performance. At 135 MHz the wave length is 6.05 ft. In the 200 ft of cable there will be 33 wave lengths, and the RL will give you a good indication of cable problems.

On the other hand, if the cable is to be used for 4 Mbps audio the critical frequency is 8 MHz and the wave length is 102.12 ft. In this case the cable is to short for the wave length, and will not give accurate results.

In the same light if there is damage in the cable, the wave length is so long, as compared to the cable length, the cable will not effect the integrity of the signal. Actually, this is the case with analog audio where the impedance of the cable is not critical because the wave length of the signal is so long as compared to the length of the cable run.

Conclusion: Reflection Coefficient is perhaps the least understood parameter of cable testing. Yet, it has more relevance to cable testing than any other single parameter. With Rho the cable can be evaluated for Impedance Return Loss or VSWR. When trying to determining the quality of the cable one cannot overlook this important measurement.

End Notes:
2. For more information on Time Domain Reflectometry Refer to Tektronix article “TDR Impedance Measurements: A Foundation For Signal Integrity” found at www.tektronix.com
3. See “50 Ohm Coaxial Testing” for a discussion on setting up and testing on network analyzers.