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RETURN LOSS

By RON HRANAC

A few months ago, there was a discussion on the SCTE-List about return loss and whether it should be expressed as a positive or negative number. The answer? Positive number. Grab a cup of coffee, your scientific calculator, and read on to see why.

We can model just about any RF transmission line situation with three components: a signal source (the output of an amp, tap, modulator), transmission medium (coaxial cable) and a termination (input to a tap, amp, cable modem, etc.). If the impedances of all three are exactly the same, all power transmitted by the source is absorbed by the termination. The assumption here is that the transmission medium is lossless.

The real world

The impedances of real-world components are rarely, if ever, equal at every frequency, so impedance mismatches exist pretty much everywhere. This is especially true in our cable networks. Every connector, tap, line passive, amplifier—even the cable itself—represents an impedance mismatch of some sort. Return loss is one way to characterize the severity of an impedance mismatch.

An open circuit on a transmission line has infinite impedance. A short circuit has zero impedance. An open circuit, short circuit, or pure reactance terminating a transmission line are incapable of absorbing power from a forward, or incident, wave. Thus, all incident current and voltage are reflected back toward the source. When this condition occurs, the return loss is said to be 0 dB. An open circuit results in the reflected voltage being in phase with the incident voltage; reflected current is opposite polarity of the incident current. With a short circuit, the reflected voltage is out of phase with the incident voltage, and reflected current is of the same polarity as the incident current.

If the transmission line's termination is a purely resistive load that has the same characteristic impedance as the transmission line, all of the incident wave is absorbed by the load. Here, the return loss is said to be infinite. We have a perfect impedance match.

Return loss

So, what the heck is return loss? It's the difference, in decibels, between the amplitude of the incident wave and the reflected wave. Clearly, the higher the return loss number, the better the impedance match and the closer we are to the desired impedance.

Assume that an incident wave's amplitude is +30 dBmV. Because of an impedance mismatch at the termination, there is a reflection whose amplitude is +14 dBmV. Here the return loss is 16 dB (30 dBmV - 14 dBmV = 16 dB), a fairly typical value for passive devices such as taps.

Let's look at a transmission line with an incident wave whose voltage is represented by V+. We'll call the voltage reflected by an impedance mismatch V-. The "+" and "-" as used here simply tell us which direction the waves are traveling. One important parameter in transmission line theory is something called reflection

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coefficient, designated by G (gamma) or p   (rho). Reflection coefficient is the ratio of reflected voltage to incident voltage. Mathematically, G = V-/V+.

Those of you who have swept plant know that when a nasty impedance mismatch exists, the incident and reflected voltages interact to produce standing waves. Voltage standing wave ratio (VSWR) is one way to describe the magnitude of the reflection and is related to reflection coefficient: VSWR = (1 + |G|)/(1 - |G|). Going the other way, |G| = (VSWR - 1)/(VSWR + 1).

Run the numbers

Back to return loss: Mathematically, return loss can be expressed with the following three formulas (there are others, but this is enough for now):

R(dB) = 10log(incident power/reflected power)

R(dB) = 10log(|V+|2/|V-|2)

R(dB) = 20log(1/|G|)

OK, so let's take the previous 16 dB return loss example and plug some numbers in a couple equations. Start with incident and reflected voltages, which can be derived from the +30 dBmV (31.62 mV) incident signal and +14 dBmV (5.01 mV) reflected signal. From these, reflection coefficient is:

G = V-/V+

G = 5.01 mV/31.62 mV

G = 0.1584

Next, let's sort out voltage standing wave ratio:

VSWR = (1 + |G|)/(1 - |G|)

VSWR = (1 + |0.1584|)/(1 - |0.1584|)

VSWR = (1.1584)/(0.8416)

VSWR = 1.38

So far, so good. Reflection coefficient is 0.1584, and VSWR is 1.38:1. While we know, by definition, return loss is the difference in decibels between the incident and reflected signals, let's work through the math to prove it.

R(dB) = 20log(1/|G|)

R(dB) = 20log(1/|0.1584|)

R(dB) = 20 * log(6.31)

R(dB) = 20 * 0.80

R(dB) = 16

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Another formula for return loss is R(dB) = 20log(VSWR - 1)/(VSWR + 1). When you plug in the VSWR from our previous example, the answer is a negative number. It tells us that we are dealing with a "loss" situation, although not necessarily in the typical attenuation sense.

Consider for a moment the decibel: dB = 10log(Pout/Pin). The decibel, by definition, is nothing more than the ratio of two power levels: output power to input power. If we have 200 W present at the input of an unknown device and 100 W at the output, we can compare those two power levels in terms of decibels: 10log(100/200) = -3.01 dB.

A minus sign from the equation tells us that the unknown device attenuated the input signal. We generally describe the situation as 3.01 dB of loss, leaving out the minus sign. Conversely, had the input power been 200 W and the output power 400 W, we would get 10log(400/200) = +3.01 dB. The plus sign in front of 3.01 dB indicates gain. Here, too, the sign can be dropped and the situation described simply as 3.01 dB of gain.

With regard to that last return loss formula, the answer will be the correct positive value if the formula is tweaked slightly: R(dB) = -20log(VSWR - 1)/(VSWR + 1). I've seen the formula both with and without a minus sign in various references, but suspect that the minus sign in front of the 20 was inadvertently left out in some instances.

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