Positioning Leadership

APN-032 December 2, 2004

Application note on Why RF Impedance Matching is Important

Overview

The purpose of this application note is to discuss the importance of impedance matching. This Application Note will not go into the specific engineering formulas involved with designing a complex RF transmission line network.

What is RF Transmission Line Impedance?

A transmission line guides electrical energy from one point to another. In this case it is used to transfer the RF energy from a GPS antenna to a GPS receiver.

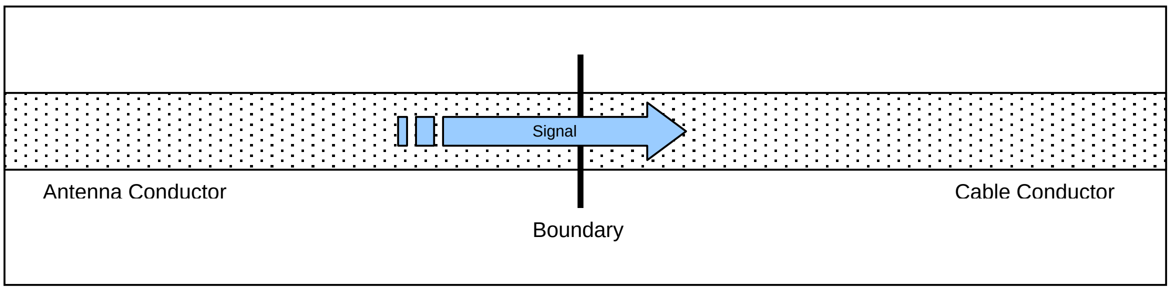
A transmission line can be described in terms of its impedance. The Impedance, Z, is the ratio of voltage to current (E/I). The ratio of voltage to current at the output (E_{out}/I_{out}) end is known as the output impedance (Z_{out}) and conversely, the ratio of voltage to current at the input (E_{in}/I_{in}) end is known as the input impedance (Z_{in}). If an infinitely long transmission line is considered, the ratio of voltage to current at any point on that transmission line would be some particular value of impedance. This impedance is known as the “characteristic impedance” and is the value typically used to describe an RF transmission line.

At RF frequencies, a conductor no longer behaves like a basic DC copper wire connection. The point where things like cable impedance and transmission line theory enter the picture is when the length of the conductor approaches about 1/10 the wavelength of the signal it is carrying. In the case of GPS frequencies, the wavelengths are 19cm for L1 (1575.42 MHz) and 24cm for L2 (1227.60 MHz).

What happens when impedances are matched?

In an ideal situation, all power in the signal is transferred from the transmitter to the receiver via the RF transmission line. Consider the analogy of yelling to another person while the both of you are inside of a small room. That person would be able to hear you perfectly.

This is the same case in the higher frequency domain of RF. As the signal travels across the boundary between the antenna and cable as well as the cable to the receiver, the impedance is the same and no reflections occur. The only significant loss to consider is attenuation due to the length of the cable. The figure below illustrates maximum power transfer between two impedances.

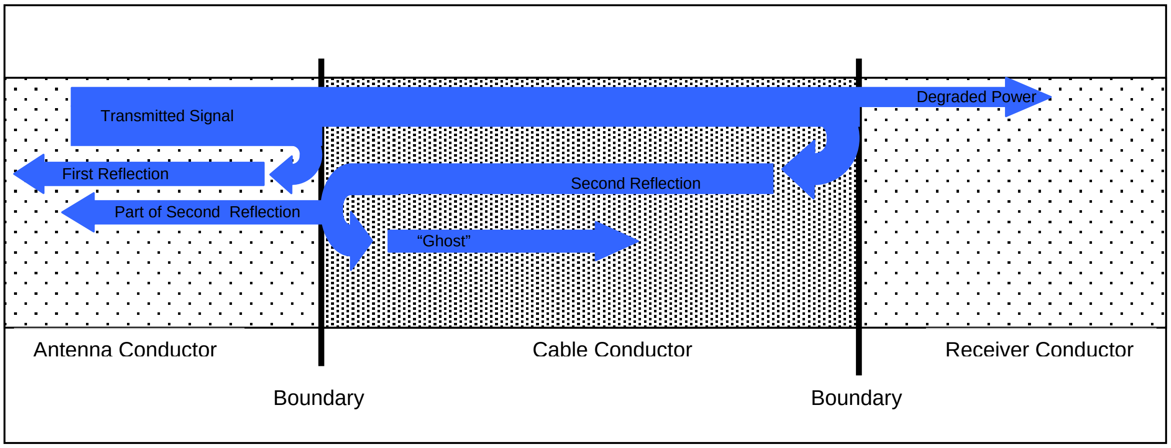


What happens when impedances are not matched?

Consider the analogy of yelling to someone submerged in water. What they hear (if you yell loud enough) is a muffled more quieted down version of what you are yelling. In addition, you might hear your voice getting echoed back to you, which might leave a “ringing sound” in your own ear.

As the wave travels down a cable, from an impedance to another, reflections occur at the boundary (point at which the two different impedances meet), which in turn causes loss. This loss includes part of the wave getting reflected and loss from a standing wave (two wave interacting traveling in opposite directions). The transmitting source (the antenna) begins to take some of the reflected power, which may cause some damage to the transmitting source. “Ghosting” also occurs when power is reflected from the Antenna/cable boundary back down towards the receiver.   The receiver’s overall effective gain is degraded.

The figure below illustrates what happens with mismatched impedances. The potential for standing waves can be seen.



Many times, users will buy "Very Low Loss RG-59" cable because it looks very similar to the RG-58 cable that is supposed to be used. The main difference is that the impedance of RG-59 is 75 ohms and the impedance of RG-58 is 50 ohms. GPS receivers and antennas typically have an impedance of 50 ohms.

Lets go through the calculations to see how much is lost by simply using this 75-ohm cable.

Lets assume that we are using a typical NovAtel receiver and a typical NovAtel Antenna. The antenna input on the NovAtel receiver has an impedance of 50Ω. All NovAtel antennas have an impedance of 50Ω.

Let's first start with the formula for the Reflection Coefficient (Γ) between two different impedances

$$\Gamma = \frac{Z_2 - Z_1}{Z_2 + Z_1}$$

In the ideal case of matched impedances, where $Z_2 = Z_1$, $\Gamma = 0$ and all power is transferred.

In the case where we use a 75Ω cable not all power is transferred.

At the connection between the Antenna and cable and at the connection between cable and receiver the absolute value of the reflection coefficient is 0.2.

When dealing with power, the reflection coefficient is squared. This now means that 4% (0.2 x 0.2) of the power is reflected and lost. 96% of the power is transmitted.

However, in our example there are two boundaries to consider– antenna / cable and the cable / receiver. So at the second boundary, another 4% is lost. This would yield a net 92.16% transfer of power but does not account for other losses.

Some use the Return Loss as a measurement of how good an impedance match is. Return Loss is defined as

$$RL = -20\log|\Gamma|\, dB$$

For both connections (50 ohm to 75 ohm and vice versa) there is a return loss of 13.98dB. The higher this number, the better. For example if a load has a return loss of 10 db, then 1/10 of the incident power is reflected.   In this case, approximately 1/13.98 of the incident power is reflected. The higher the return loss, the less power is actually lost. In most situations a return loss of greater than 30dB is desired.

Let's look at this from another perspective. Using our different impedances we can calculate the SWR (Standing Wave Ratio). A standing wave occurs when two waves traveling in opposite directions interact with each other.

The SWR is defined as

$$SWR = \frac{1+|\Gamma|}{1-|\Gamma|}$$

It is considered a good match when SWR is less than 1.2. With a reflection coefficient of 0.2, SWR equals 1.5, past the point where it is considered not a good match.

In essence the main concern is the total loss if the GPS signal from the antenna to the receiver. The previous example assumed no other losses however in real world application, other losses such as cable attenuation due to lengths, and voltage drop across connections must be taken into account. Taking these additional losses into account, the signal is further degraded and the GPS receiver may not track the satellite.

Is there any way to convert a cable to a different impedance?

The simplest answer is no. The best and easiest solution is to use the right cable the first time. For NovAtel receivers, use 50-ohm RF cables when connecting the GPS Antenna to the RF input of the receiver. One source of low-loss coaxial cables is the Andrew Corporation. Andrew supplies low-loss HELIAX® cables of various sizes, loss values, and flexibility. To find out more about Andrew's products, visit www.andrew.com.

There is a multitude of ways to match impedances. A few techniques used to match impedances include using a quarter wave transformer, single / double stub matching, and lumped elements. However, these are only feasible and available if you have a microwave lab, which includes the equipment to custom-make and test the previously mentioned techniques. With these techniques, people may use micro-strip lines and tune them with, literally, a very sharp blade and a steady hand.

These techniques would not be very practical in the field. If you are interested in such techniques, consult a Microwave Engineering textbook.

Final Points

If you require any further information regarding the topics covered within this application, please contact:

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