Zero dB™ Cable Assemblies

by Dave Slack & Dave Murray, Times Microwave Systems

Picture this, you have an antenna located at the tip of the aircraft's wing. This gives you the best field of view, but makes the cable runs very, very long. The receiver is located forward in the avionics bay where power, cooling air, and maintenance access are all necessities. This means you'll have a very long cable run.

What's the problem?

What are your options now when the available signal at the end of this cable is well below the noise floor? You could try some creative filtering and attempt to pull the signal from the noise, or you could add gain somewhere between the antenna and the receiver. Since gain is usually cheaper, where do you mount that amplifier, and how do you power it...?

Times Microwave has taken this problem on and come up with the solution, Zero dB™. Simply put, we package and locate a low noise amplifier inside the connector that mates to the antenna. This is where the best signal to noise (S:N) ratio is, so this is the obvious place. This requires a package that protects the amplifiers from the vibration environment as well as from the normal liquids that exist on an aircraft. This also requires an amplifier with a low noise figure and good VSWR.

Typical Example - 13 Meter Broadband (4 quadrant) EW runs

The wingtip is typically a very severe vibration and temperature environment. The ideal location for the receiver would be right next to this antenna. However, this just isn't practical. Therefore, it is normal to locate the receiver within the fuselage, or some other relatively benign location, and route the received energy through transmission lines from the sensors to their receivers. (Figure 1 illustrates a typical insertion loss and return loss performance of such an interconnection cable.) The associated insertion loss of this interconnecting path can be directly added to the receiver noise figure, thus reducing the receiver system sensitivity, and decreasing the maximum range at which a particular signal of interest might be detected.

Since we know the best place to locate an amplifier is directly at the antenna, we have incorporated a high reliability package specifically designed for harsh airborne and naval environments. These integrated packages are fully incorporated into cable types that are MIL-T-81490 qualified and that are hermetically sealed to ensure a long life and reliable performance. Figure 2 shows the same run, but now with an equalized broadband low noise amplifier located at the far end.

These devices can be custom tailored for unique applications. If desired, a temperature compensation function can even be incorporated. This provides an unprecedented opportunity for system manufacturers to design systems with standard performance characteristics, regardless of the platform on which the system will ultimately be deployed. Differences in the platform topography (and its associated interconnection cabling) can be normalized by adjusting the gain-frequency slope within the amplifier module. This provides much greater system transportability across a wide range of platform architectures.

In the improbable event that these devices become inoperable (MTBF is calculated to be greater than 100,000 hrs per Mil handbook MIL-HDBK-217), their modular design allows for them to be easily removed and replaced without removing any part of the interconnection cabling.

It should be obvious from these two graphs (Figure 1 and Figure 2) that incorporating an equalized device is the solution, but to be fair, we must take a look at the NF contribution on system sensitivity before making any final decisions.

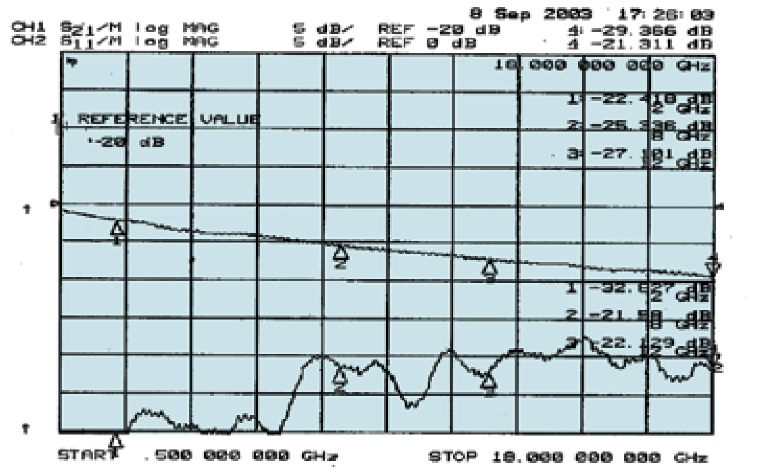

Figure 1: 13 Meter MilTech(340 Cable Assembly Without Pre-Amp

Receiver Sensitivity

Receiver sensitivity is defined as the minimum power level that a receiver may receive and still perform its designed purpose. This power level can be expressed in terms of field strength (uV/M) or, more typically, in terms of power (dBm).

Any received signal level less than the receiver's sensitivity will not be detected. Signal levels above the sensitivity of the receiver will be detected and processed as useful information.

As the distance from a particular emitter increases, the received power from that emitter will decrease. At some point, the received power level will equal the receiver's sensitivity. This is considered to be the maximum range for this emitter to be detected by this receiver.

The power received (P_{rcvd}) is a function of transmitted power (P_{Tx}), transmitter antenna gain (G_{Tx}), transmitter frequency (f), receiver antenna gain (G_{Rx}), the signal attenuation due to spreading of the transmitted beam (A_s) and the signal attenuation due to atmospheric losses (A_a):

$$P_{rcvd} = P_{Tx} + G_{Tx} - A_s - A_a + G_{Rx}$$

The calculation for attenuation due to beam spreading is essentially the ratio of the surface area of the transmitting antenna and the area of the beam at the same distance removed from the antenna. This calculation involves a review of spherical trigonometry and is beyond the scope of this article. The calculation can, however, be summarized as follows:

$$A_s = 32 + 20 \log \text{distance (km)} + 20 \log \text{frequency (MHz)}$$

Where 32 is a unit conversion constant developed when using units of kilometers and megahertz.

Atmospheric losses are nonlinear and are best derived graphically from Figure 3.

The received power can thus be described in the following equation:

$$P_{rcvd} = P_{Tx} + G_{Tx} - 32 - 20 \log \text{distance (km)} - 20 \log \text{frequency (MHz)} - A_a + G_{Rx}$$

By the definition of receiver sensitivity we can state that the maximum range is that range at which received power equals the receiver sensitivity. We can then substitute receiver sensitivity for received power level and algebraically solve for distance:

$$D_{max} = 10\,[1/20\,(GRx + PTx + GTx - Rsens - 32.4 - 20 \log (f) - Aa)]$$

Consider an example of a 100 MHz transmitter, operating at an output power of 500 milliwatts or +27 dBm. The transmitting antenna has a gain of 15 dB and the receiving sensor has a gain of 3 dB.

We will assume, for purposes of this example, that the receiver sensitivity is -75 dBm and that, at 100 MHz, the atmospheric attenuation is zero.

The maximum range equation for this example would be:

D_{max} (kM) = 10 [1/20 (3 + 27 + 15 - (-75) - 32.4 - 20 log(100) - 0)]

D_{max} (kM) = 10 [1/20 (3 + 27 + 15 - (-75) - 32.4 - 40 - 0)]

D_{max} (kM) = 239 kilometers (149 miles)

Receiver Sensitivity vs. Receiver "SYSTEM" Sensitivity

Receiver sensitivity is the values specified by the manufacturer of the receiver.

Receiver **system** sensitivity is defined as the minimum power level, at the sensor, required for the receiver system to adequately perform its designed function. This is a subtle distinction that allows for the fact that interconnection losses between sensors and receivers will most assuredly degrade system performance and maximum range.

Receiver sensitivity is a function of thermal noise, receiver bandwidth, additive noise of the receiver (noise figure) and the required signal to noise ratio required for adequate system operation.

Thermal noise is a function of Boltzmann's constant and temperature. Because noise power increases as a function of measured bandwidth, thermal noise is usually expressed normalized to a 1 MHz bandwidth. The common rule of thumb for thermal noise is:

Thermal Noise = kTB = -114dBm/MHz

For the example range equation above, the receiver parameters are:

- Receiver sensitivity(R_{sens}) = -75dBm
- Thermal noise is -114dBm/MHz
- Receiver bandwidth (BW) = 100MHz (20 dB)
- The noise figure of the receiver (NF) = 5 dB
- Minimum allowable signal to noise ratio (SNR_{min}) = 14 dB

Receiver sensitivity, when expressed in these terms, can be stated as:

R_{sens} = kT + BW + NF + SNR_{min}

S(dBm) = KT + NF + 10LOG (BW) + 10LOG(S/N)

When a lossy transmission line is inserted between sensor and receiver the loss of the interconnection path can be directly added to the NF of the receiver and receiver. The receiver "system" sensitivity is directly reduced by the attenuation of the interconnection cable. It would seem that a 6 dB path loss between sensor and receiver would decrease maximum range by about half.

By co-locating the low noise receiver front end with its associated antenna or sensor this effect can be effectively eliminated. Stated another way, integrating the receiver with the interconnection hardware will significantly increase maximum range.

Adding a high quality pre-amplifier itself introduces noise into the system. Eliminating the cable loss reduces the system noise figure. It is also increased by the additive noise contribution of the amplifier.

The aggregate effect of adding the amplifier is a function of the amplifier noise figure (NF), the amplifier gain, and the cable loss that is between the amplifier and the other receiving system components.

The following three examples serve to effectively illustrate these concepts. The calculation of additive noise, of cascaded components, can be an involved process. The generalized equation is:

$$NF_{cascade} = NF_1 + \frac{NF_2 - 1}{G_1} + \frac{NF_3 - 1}{G_1 G_2} + \frac{NF_n - 1}{G_1 G_2 \ldots G(n-1)}$$

It should be noted that the gains and noise figures are expressed in linear, not logarithmic, terms.

The important issue of note in this equation is that, by inspection, it becomes clear that it is desirable to have a low noise, high gain device early in the received signal path. Having a negative gain (or loss) immediately after the receive antenna is certainly not an optimal situation.

Some graphical methods and simplifying assumptions are made here to keep the discussion within the required scope of this article.

The system noise figure of the system outlined in the block diagram can be estimated by:

System Noise Figure = Pre Amp Noise Figure + Degradation Factor[1]

The degradation factor can be found graphically by the System Degradation Table and is a function of pre-amp NF, pre-amp gain, transmission line attenuation and the receiver NF.

From the original example, the maximum range of the specific emitter was 239 kilometers. This was an ideal case where the receiver was connected directly to the antenna without the detrimental effects of an interconnecting cable.

When a high quality cable is inserted between the receiver and the antenna, the cable attenuation is added to the receiver noise figure, thus increasing the minimum amount of power the system is required to receive before it detects the signal. In other words, the receiver sensitivity has been reduced by 6dB (**-69dBm**) with a corresponding reduction in system maximum range of about 50 %.

The maximum range equation for the system, with the cable installed is now:

D_{max} (kM) = 10 [1/20 (3 + 27 + 15 - (-69) - 32.4 - 20log(100) - 0)]

D_{max} (kM) = 120 kM (74.7 miles)

The next case of interest would be a pre-amplifier with a gain vs. frequency slope such that it perfectly offset the loss vs. frequency slope of the interconnecting cable. This composite of cable and amplifier would have a net gain (or loss) of zero dB across its entire frequency band of operation. It would seem intuitive that this is identical to the case where the receiver was connected directly to the antenna. The cable has been made "transparent" and there should be no system degradation.

It is at this point that the noise problem again reveals itself.

Using the known system parameters and the amplifier gain of 6 dB, the degradation factor derived from the chart is 2.5 dB. This factor is added directly to receiver NF (assume receiver NF to be also 5.0 dB) to obtain a system NF of 7.5 dB. The system sensitivity is now -75 + 2.5 or -72.5dB. The maximum range for this system can now be calculated:

D_{max} (kM) = 10 [1/20 (3 + 27 + 15 - (-72.5) - 32.4 - 20 log(100) - 0]

D_{max} (kM) = 180 kM (112 miles)

Instead of the cable being transparent, it has degraded the maximum range by about 25%. This is still a significant improvement over the performance without the pre-amplifier.

Because the system degradation factor improves furtherwith a higher gain device, system improvements can be made by using an active transmission path as opposed to a "zero loss" transmission path.

Assume a flat gain of +18 dB across the entire frequency band of operation. The system degradation factor now drops to about 0.5 dB. The system noise figure is now 5.5 dB and the overall system sensitivity becomes -74.5 dB. This is only one half dB off from the ideal case, where the receiver was directly adjoining the antenna. The maximum range for this system becomes:

D_{max} (kM) = 10 [1/20 (3 + 27 + 15 - (-74.5) - 32.4 - 20 log(100) - 0]

Dmax (kM) = 226 kM (141 miles)

This is a very small decrease relative to the ideal case. Since the ideal case is not practical (it would require the 6 dB interconnecting cable), the addition of the integrated cable amplifier effectively DOUBLES the maximum range of the receiver system.

Summary

Devices of this nature are available in extremely compact, rugged and lightweight packages.

These devices are completely integrated into the MilTech™ series of aerospace grade microwave cable assemblies.

These devices cover the entire operating range of Radar Warning Receivers operating from 500 MHz to 18 GHz.

The full band noise figure is about 5.5 dB with an available minimum gain of 18 dB. Narrow band systems would have a reduced noise figure.

Typical power output, measured at the 1dB compression point, is a minimum of +10 dBm. These devices are available with a power limiting option that will prevent the device from being damaged when subjected to input power levels of up to +30 dBm (1 watt) of average power as standard. Other power limiters are available.

The active cable assembly is a lightning sensitive device. As such these devices are available with integrated lightning protection devices.

The gain and gain equalization are fully temperature compensated from -55 to +85 C.

Power consumption is quite low at less than 2.5 watts. Primary power consumption is about 3 to 4 times the output microwave power. These devices may be operated from primary aircraft power ranging from +15 to +30 VDC. They can be either powered through an external power pin or through the center conductor of the microwave coaxial cable structure.

When powered through the center conductor of the cable a bias-T network would need to be incorporated to the other end.

The case is completely integrated into the cable and threads on using standard microwave connectors. The physical envelope of the discrete package is 2.5 inches in length and less than 0.65 inches in diameter. The associated cable assemblies are fully qualified per MIL-STD-81490 and hermetically sealed for use in rugged aerospace environments.

They are hermetically sealed and capable of operating at altitudes in excess of 40,000 feet.

These devices can be provided with a flat gain vs. frequency slope or a custom tuned gain profile. This allows the possibility of the system avionics to be identical across a variety of platforms. By changing the gain/loss vs. frequency profile of the interconnecting cable, the system parameters will be identical regardless of platform topography or cable lengths. This provides an excellent opportunity for system designers to provide greater commonality parts and significantly reduce costs.

From a cost and performance perspective there are many advantages to such a device. A device that can withstand the harsh environments often experienced at antenna locations is an absolute requirement. It is precisely this blend of features and capabilities that make these integrated pre-amplifiers such an attractive item.

Power for these devices can either be supplied on the center conductor of the connector at the receiver, or we can add a Bias-t somewhere in the path. We have already designed, and have flying, a Bias-T that accepts normal aircraft power (Mil Spec 28 VDC) and converts it to the pure 12 VDC necessary for the amplifier. This voltage is supplied to the amplifier via the cable assembly's center and outer conductors.

Other options to consider are lightning protection between the amplifier and the antenna, blind mating of the antenna itself, filters to eliminate unwanted signals, and even fault isolation if we also use our "Smart Bias-T's", but that's another article...

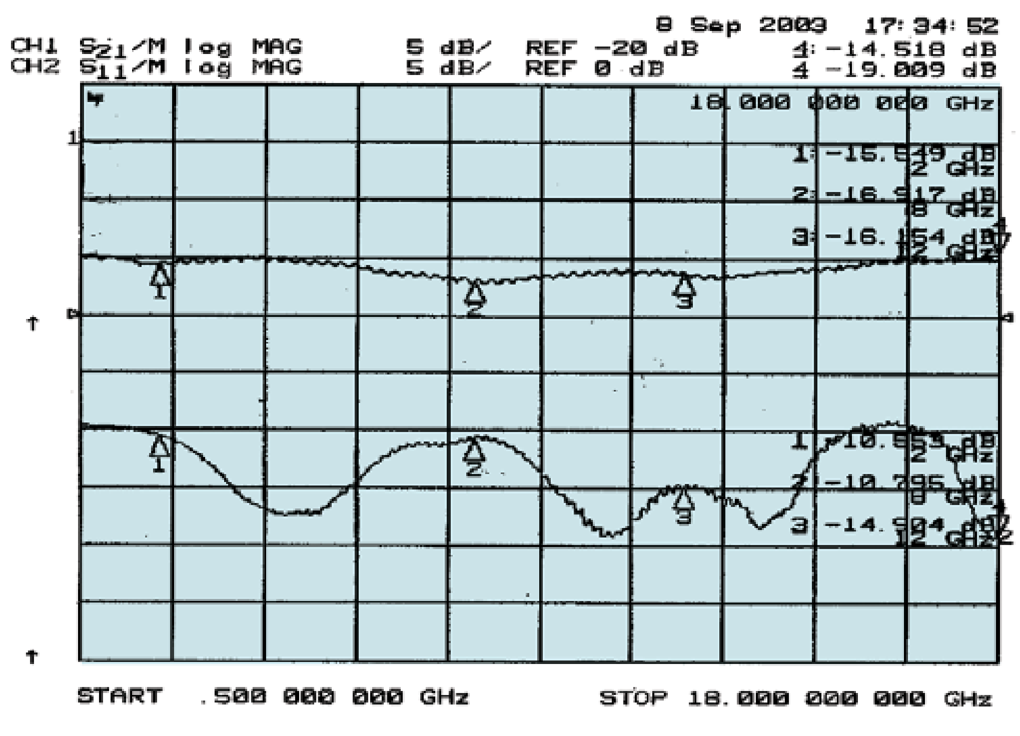

Figure 2: 13 Meter MilTech(340 Cable Assembly With Equalized Low Noise Amp Incorporated

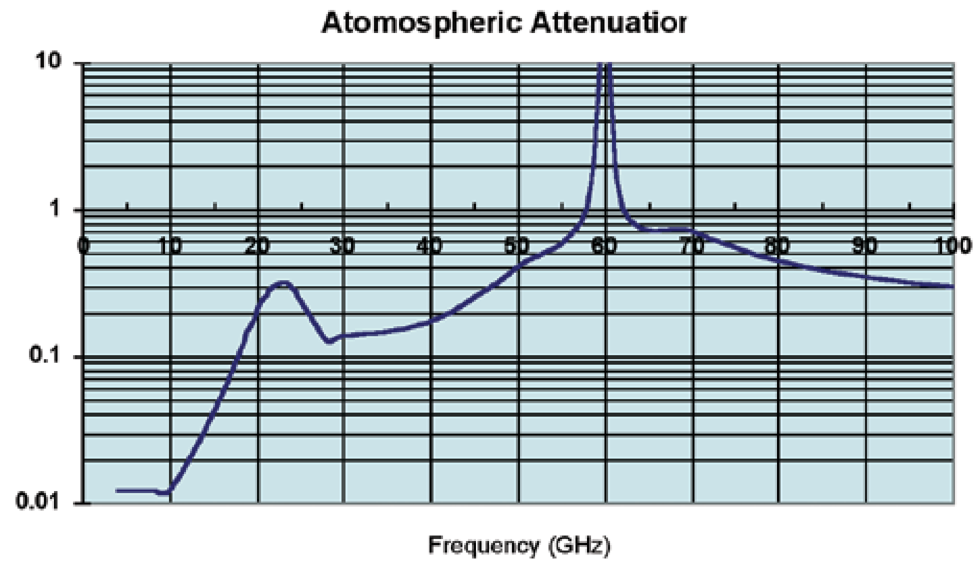

Figure 3: Atmospheric Attenuation as a Function of Frequency

Related devices have also been designed and are in use allowing point to point communications between aircraft in formation. Yes, we have these as well...

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