50 Ohm Magic, UHF Connectors

TO: The Savvy Microwave Group
FROM: Dick, K2RIW.
RE: Coax Impedances, Losses, and the Maligning of UHF Connectors.

Coax Impedances, Losses, and the Maligning of UHF Connectors

by Dick Knadle, K2RIW, 31 May 2001.

Coax Impedance -- Concerning the possible choices of the impedance of a coaxial transmission line, a great reference is "Microwave Transmission Design Data", by Theodore Moreno, Dover Publications, 1948. On pages 64 through 69 he discusses four criteria for choosing a particular impedance. The four choices displayed in the graph on page 64 demonstrates how non-critical (broad ranged) many of these impedances are. Most of the following addresses air dielectric coaxial transmission lines. Here are some interesting "Moreno" facts:

1. The maximum continuous power handling occurs at an impedance of 30 ohms.
2. The maximum breakdown voltage occurs at an impedance of 60 ohms.
3. The minimum insertion loss occurs at 77 ohms.
4. The maximum shorted line, resonant impedance occurs at 133 ohms.
5. Conductor losses (in dB's) are proportional to the square root of frequency.
6. Dielectric loss (in dB) is linearly proportional to frequency. Hence, at higher frequencies the dielectric losses become increasingly important.

Cable Graphs -- We have all seen graphs of the insertion loss of our favorite cables. They are usually displayed on Log-Log paper with the horizontal axis being frequency, and the vertical axis being insertion loss in dB per 100 feet (or 100 meters). The curious thing is that the insertion loss graph appears as a sloping straight line, with some of the cables displaying a slight upward hook at the highest recommended frequency. Here is the explanation.

On Log-Log paper an exponential function appears as a straight line where the slope is proportional to the exponent value. A square root function has a exponent of 1/2. A linear function has an exponent of 1. On most of the cables, only the conductor losses (exponent of 1/2) are significant throughout much of the recommended frequency range. Thus, most of that range is displayed with a slope of 1/2. The hook at the end represents the upper frequency range where the dielectric losses are beginning to kick in. Here the line is beginning to slide into a slope of 1.5, due to the combined effects of the 1/2 slope (conductor losses), plus the 1.0 slope (dielectric losses).

Estimating Trick -- Knowing these facts allows you to make some interesting mental approximations. Let's assume you know that your favorite cable has an insertion loss of 1.0 dB per 100 feet at 144 MHz. If your friend asks you what's the approximate loss at 432, here is what you can do. Since you know that the cable is usable to at least 2 GHz, you assume that conductor losses dominate throughout most of the 144 to 432 frequency region, and conductor loss is proportional to the square root of frequency. 432 MHz versus 144 MHz is a 3:1 frequency ratio. The square root of 3 is 1.73. Multiply the 144 MHz loss (1.0 dB) by the 1.73 factor, and you come up with a predicted approximation of 1.73 dB per 100 feet at 432 MHz. Because there will be a slight contribution due to dielectric losses at this end of the cable's operating range you could round your prediction up to 1.75 dB per 100 feet. Try this procedure on the graphs of your favorite cables and you will be amazed how close the approximation usually is.

Cut-Off Frequency -- As you go beyond the manufacturer's upper recommended frequency, the cable is capable of acting like a round piece of wave guide (WG). The presence of the center conductor adds a little capacitive loading that slightly lowers the WG cut-off frequency. Moreno recommends using this approximate equation for predicting the cut-off wavelength:

Lambda = Pi * (a + b).

a = outer radius of the center conductor. b = inner radius of the outer conductor. Pi = 3.1416 ...

In other words, the limiting wavelength is approximately equal to the circumference at the arithmetic mean diameter.

Coaxial WG -- Now, don't let this limitation always scare you into submission. The cable isn't going to explode if you use it above the recommended frequency, it just gets a little tricky up there. The first wave guide (WG) mode to consider is the TE11 circular mode. That's the one used by the 10 GHz guys who are using 3/4 inch water pipe as a poor man's wave guide -- it turns out to be a very high quality [low loss] wave guide. In the TE11 WG mode the maximum E-field lines flow from the 6 o'clock position to the 12 o'clock position in the pipe (vertical polarization is assumed). If your coax cable doesn't have any significant bends in it, and the inner conductor is centered, it won't launch any E-field (WG mode) at right angles to the center conductor. Your next question is "what's a significant bend?" The microwaver's are going to have to study this, but, my gut feel is that a bend radius of greater than 1 foot is OK.

It is just a matter of time until some smart amateur intentionally launches both propagation modes in a piece of coax in order to lower the over-all insertion loss. It will require some careful tuning of the launching structures at each end of the cable to insure that the two modes end up co-phase at the top of the tower. This is because the phase velocity of the WG mode is faster than the coaxial mode. This technique can only be applied to a narrow band situation, or a set of narrow band situations (like 5 GHz and 10 GHz).

UHF Connector Maligning -- There are many misinformed engineers and amateurs who have been led to believe that a UHF connector is the worst thing ever invented in the RF world -- due to it's lower internal impedance. They believe that each UHF connector causes a 1/2 dB insertion loss and a whole lot of VSWR at 432 MHz. I've heard quite a few amateurs claim that their 432 MHz brick amplifier will now have 1 dB greater gain since they just replaced the two chassis mounted UHF connectors with Type N connectors. This "Old Wive's Tale" has been propagated for decades. Everyone believes it. No one challenges it. Few people have ever make the measurement.

A High Power "Calorimetry" Test -- Here is my observation. I took a 432 MHz Stripline Parallel Kilowatt Amplifier and applied 700 watts through a UHF female and a UHF male connector, and then into my antenna feed line. After 10 minutes of

700 watts throughput power the UHF connectors were mildly warm. If I estimate that "mildly warm" represents a dissipation of 3 watts out of 700 watts, that's an estimated insertion loss of 0.019 dB for the pair of connectors. You're about to ask, "how can this be, the internal dimensions are approximately a 35 ohm impedance, it's got to cause a 1.43:1 VSWR?" Well, it doesn't.

Very Little Total System VSWR -- The mated UHF connector has an internal connector length of less than 0.9 inches. A free space wavelength at 432 MHz is 27.3 inches. The 0.9 inches represents a phase length of 11.9 degrees. If I plot this up on a Smith Chart (or use the mathematical equivalent) I find the following. A 50 ohm antenna with an 11.9 degree long section of 35 ohm line causes an input impedance of (47.9 -j7) ohms. That's an input VSWR of 1.16:1, which gives a worse case reflected-power-caused transmission loss of 0.024 dB. To me that's insignificant. Now, I'll admit that at 10 GHz, where the wavelength is 1.1 inches, that 0.9 inch electrical length connector would be much harder to tolerate.

Power Tolerance -- A Type N connector can tolerate low-duty pulses of over 20 kilowatts without a voltage break down. However, steady state power of more than 1 kW could cause the connector to fail from the RF current overheating the center pin. Most connectors have a very similar failure mechanism when steady state high RF power is applied. The UHF connector has an oversized center pin that can more easily tolerate high steady state RF currents. Moreno said that 30 ohms impedance maximizes the power handling, and the UHF connector has an impedance of about 35 ohms.

Each EME'er who is using those expensive type SC connectors on his kW amplifier could probably use UHF connectors for his indoor cable attachments, if he desired to save money. The UHF connector has a larger center pin than an SC connector, it might actually have a larger power tolerance than the SC -- this will require testing. But, remember that the Fluoroloy-H dielectric on the SC connector is designed to be a good heat sync that cools the center pin.

It's User Friendly Assembly -- There are probably twice as many amateurs who can do a good job of installing a UHF connector on an RF cable, as compared to a Type N connector. The proper installation and WX proofing of a Type N connector requires considerable finesse and experience. It's almost an art form.

UHF Connector Faults -- There are two major faults I can find with a UHF connector when it is being used on 432 and below: (1) the lack of weather proofing; (2) the lack of outer conductor finger contactors. With a proper tape wrapping job, I believe the weather proofing can be accommodated. However, the user must be sure that the internal "teeth" are properly seated, and that the outer nut is kept tight; otherwise the outer conductor can develop a considerable growth in electrical length, with the associated "scratch contacting" noise. For this reason the connector is probably inappropriate for a high vibration environment, unless an auxiliary nut-retaining mechanism is employed.

So, maybe it's time we stop saying such bad things about the poor-orphaned UHF connector. For our purposes, it doesn't deserve all that flack. Properly used by a savvy engineer, who understands the idiosyncracies, it can give you a lot of bang for the dollar. It's been around for 60 years, that's no coincidence.

I welcome alternate opinions on all of the above. Please feel free to correct the mistakes.

73 es Good VHF/UHF/SHF DX,
Dick, k2RIW.
Grid: FN30HT84DC27.

APPLICATION NOTES:

1. UHF Connector VSWR at 432 MHz

A 15 db return loss from a UHF connector that's being used at 432 MHz is quite good in many circumstances. That return loss (a 1.43:1 VSWR) only causes an insertion loss of 0.14 dB (before correction, such as re-tuning the transmitter). On the transmitter side of an EME system, you'll never know it's there.

But, if there was a 15 dB return loss caused by a connector that's in front of a well tuned LNA, that is significant. It could make a considerable difference to the system's Noise Figure, if the operator did not apply VSWR corrective action -- such as tuning the LNA for best Noise Figure performance while it is connected to the real system.

However, I suspect that very few of the currently operation EME antenna systems have a return loss of better than 15 dB -- particularly not during rain and snow. Therefore, that savvy EME operater has had to apply corrective action to the total antenna system, if he wants full performance of his LNA. If the UHF connector is part of that antenna system, it will get lumped together within that corrective procedure. Thus, that connector 15 dB return loss could be very tolerable to a well-informed operator.

2. More 50 Ohm Magic, UHF Connectors

Introduction -- In various responses to my 31 May 2001 treatment of UHF connectors, cogent comments were made that I wish to address, and add to.

Connector Brands -- Since the UHF connector doesn't seem to be protected by a MIL Specification, there is a wide variation in the quality and mechanical performance of the connectors that are available on the world wide market. The buyer must be wary. I hope that a savvy amateur will create a web site list that will inform us of the UHF connector brand names, and sources, that are worthy of our hard-earned money. Lloyd, N5GDB, and Lloyd, NE8I both strongly recommend the silver plated or gold plated versions, particularly with respect to solderability and connection integrity.

Installation -- I probably was too hasty when I stated that twice as many amateurs/engineers can properly install a UHF connector versus a type N connector. An experienced RF maven (one who has a "feel" for the way RF flows) can almost always suggest an improvement in the connector installation procedure -- so that the lowest VSWR, least loss, best mechanical strength, best longevity, and best weather proofing are realized.

Most of my outdoor equipment uses type N connectors, with BNC's most used indoors, and SMA's used within enclosures. For the few UHF connectors that I use, here is my favorite connector installation method.

(1) After properly cutting back the braid and dielectric, I next tin the braid (and

center conductor) with as little solder as possible, that will still coat the strands. Since the end of the cable is completely open to air at this point, the amount of melting of the polyethylene dielectric is minimized.

(2) I slip the nut onto the cable and then screw on the connector body. The tinned braid causes extra resistance, and a strong pair of pliers are definitely required.

(3) Assuming that I've chosen a connector brand that readily accepts solder, the process of tack-soldering through the 4 holes requires very little heating time, when using a large-enough, hot-enough, soldering iron. Thus very little further melting of the polyethylene dielectric takes place, and the complete braid is essentially bonded to the connector body.

(4) Clean off as much solder from the tip of the iron as possible, and heat up the side of the center pin, while applying solder down the front hole. Try to keep solder off the side of the center pin. If need be, wipe off any excess while it is hot. Excess solder left on the outside of connector center pin will interfere with the proper mating with the female connector.

A further benefit of the braid tinning process is that the strands of the braid don't become scattered, spread, and folded back during the process of screwing on the connector body. Thus, full braid strength, and electrical bonding is assured by this process.

I suspect that other experts have further improvements on this process, and I welcome their comments.

Crimp Connectors -- For indoor, non-critical applications I believe that crimp connectors can be very expedient and handy. However, the crimping process has a number of characteristics that bother me:

(A) True UHF Frequency VSWR -- For many crimp connector designs the outer braid is crimped quite far back from the end of the cable. This creates an outer connector choke assembly that makes the outer conductor longer than the center conductor.

(B) Salt Spray Survival -- My previous salt mine (the former AIL System Inc., now EDO-Electronic Systems Group) performed a number of salt spray tests a few years ago on crimp-connected semi-rigid cables. The results were not encouraging. In a number of the cables the UHF or SHF VSWR changed considerably after a few cycles of the salt spray exposure. It is hard to beat the RF bonding that a solder joint creates.

(C) Ultimate Shielding Requirement -- Arguably, the most critical requirement for an indoor connector is that of the jumper cables on a repeater's duplexing filter. In this application you desire the connector to provide 110 dB of shielding integrity (if you can get it). I personally have experienced repeaters that would develop "scratchy interference" and RCVR desensitization as the type N crimp connected jumpers were manually moved. Lloyd, NE8I also mentioned these problems concerning silver plating. On the two occasions that I experienced this, the problem was cured when the jumpers were replaced with well-installed conventional type N connectors. I have been told of desperate repeater owners who used conventional type N connectors, but modified them by soldering the internal collet assembly to the cable braid before assembling the connector, as a way of avoiding any oxidation-caused scratchy braid connections.

(D) Weather Proofing the Crimp -- In a conventional type N connector, the portion that consists of the compression bond of the braid and the internal collet is all contained within the weather-proof portion of the connector. However, in most crimp-type connectors, the crimped portion of the cable's outer conductor is exposed to the weather. This suggests that the crimped joint is subject to corrosion, and a subsequent poor connection. Most of us will tape and shrink-wrap our outdoor type N connectors as a "belt and suspenders" approach to secondary weather proofing. In the case of a crimped connector, our weather proofing of the outer braid is a primary protection requirement.

My (Crimp) Conclusion -- If we do a really good job of installing a connector on an outdoor coaxial cable, we are likely to use that cable for 10 to 15 years. A crimp connector is capable of saving you a considerable amount of time during the initial installation. However, if the crimp connector gives you trouble within the first few years of service (that's what the salt spray tests suggest), than the time saving during the installation of a crimp connector might really be a false economy. I'm willing to spend an extra 10 minutes installing a connector, if it is likely to give me over 10 years of service.

Here is my challenge. Does anyone know of a well documented set of salt spray tests that were performed on various stiles of RF coaxial cable crimp connectors? A salt spray test is a beautiful way of artificially putting 10 years of aging into a cable assembly within a week. Many of us live within a hundred miles of a sea shore, and this characteristic is important to us. I'll admit that the Microwavers who live in the Mojave Desert may not have this particular problem to worry about.

Mismatch -- Leonard, N3NGE spoke of the difficulty of sweeping a cable system that has a high return loss connector at the beginning. Jerry, K0CQ suggested that the problem can be overcome with a Time Domain Reflectometer (TDR), and it will even display the water that is within a section of the cable.

I've spent a few years of my life using TDR's and I love'em. They can make RF measurements that will amaze you. However, they are expensive, rare on the surplus market, and few colleges even mention this wonderful instrument. That's unfortunate. A really good TDR will allow you to inspect the integrity of your transmission line system at possibly every 1/8 inch at a time, and it will "look through" that poor connector that's at the beginning of the cable. There are TDR "De-Embedding Techniques" that will allow you to inspect portions of your cable that are surrounded by some pretty significant mismatches.

There is a solution for us amateurs, it's called the Steinhelfer Technique. If you sweep the cable, and stop at say 1,024 separate frequencies, and measure the amplitude, and phase of the reflected power, you now have a data set that can do magic. Apply this data set to a computer program that performs a type of Fourier Transform, and it will simulate a TDR that is far above the performance of the one that you could afford.

We have all seen those fairly inexpensive hand held VSWR Sweeper-Plotter machines. Add a phase measurement capability, and an RS-232 port to that machine, and you're almost there. That modified hand held device will gather the raw data, and a PC could process the data and make up the TDR plots. A VSWR plotter that sweeps 1 to 1,000 MHz could give you the capability of resolving what's going on in your transmission line system every 6 inches. For most of us, that's good enough to locate a faulty section. Sweep the data gatherer from 1 to 2,000 MHz, and you will resolve every 3 inches, etc. It's about time that somebody offers this as a new RF toy for our pleasure.

I'll admit that the Steinhelfer technique involves some fairly heavy mathematics. But, it can be taken in stages, and you could share the responsibility. Just assemble an RF maven, a mathematician, and a Computer Science major, and point them in the right direction. This would make a fantastic Senior Project for a group of engineering students. Later, it might even make them rich. For those who wish to study this further, see the following references:

(1) HP Application Note 62, "Time Domain Reflectometry", 1964.
(2) HP Application Note 67, "Cable Testing with Time Domain Reflectometry", October 1965.
(3) HP Application Note 75, "Selected Articles on Time Domain Reflectometry Applications", March 1966.
(4) Harry M. Crimson, "TDM: An Alternate Approach to Microwave Measurements", Microwaves, December 1975.
(5) M. Hines and H. Steinhelfer, Time Domain Oscillographic Network Analysis", IEEE MTT March 1974, pp. 276-282.
(6) P.I. Somlo, "The Locating Reflectometer", IEEE MTT, February 1972, pp. 105-112.
(7) H.E. Steinhelfer, Sr., "De-embedding the Capacitance of a Resonant Circuit Using Time Domain Reversal and Subtraction", IEEE MTT Int. Microwave Symp. Digest, 1982, pp. 354-356.
(8) H.E. Steinhelfer, "Discussing the De-Embedding Techniques Using Time Domain Analysis", IEEE Proceedings, January 1986.
(9) D.W. Hess and Victor Farr, "Time Gating of Antenna Measurements", Microwave Journal, January 1989.
(10) D.L. Holloway, "The Comparison Reflectometer", IEEE MTT, April 1967, pp. 250-259.

I'm looking forward to using this new RF Toy, so don't you guys disappoints me now!

I hope this makes you feel a little more comfortable about UHF connectors; they are really not as poor as some think. Please feel free to correct the mistakes.

73 es Good VHF/UHF/SHF DX,
Dick K2RIW.
Grid FN30HT84DC27

[HOME] [NETS] [CALENDAR] [REFLECTOR] [CONTACT US] [REGISTER] [TECH FORUM]
[RELATED SITES] [PROPAGATION] [THE BANDS] [RMG APPLICATION]

go to the top