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Transmission Lines: Setting the Record Straight

Transmission lines is another area of ham radio that abounds with a lot of inaccurate and incomplete information. In this article we are going to dive into this often misunderstood subject in an effort to help you make a well informed decision about which coaxial cable and connector is right for your particular installation be it for HF, VHF, or UHF.

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Introduction

I decided to write this article after listening to a QSO on the local repeater. Through the course of the QSO there was some good information given and some bad information given. It didn't help that I had just finished rereading Joel Hallas book on transmission lines[1]. It's a book I always have with me whenever I go work on someone's antenna even though I have committed most of it to memory. It has all the cutting dimension for installing nearly every connector one is likely to encounter. If you are interesting in learning more I highly recommend his book. Unfortunately not many are interested in reading a 55 page book about such a dry topic.

Who was this article written for? Obviously not everyone that see's this article will read it. But if you're someone who wants to go a bit deeper in understanding the technology, who wants to find ways of maximizing your station capabilities then this article was written just for you.

My intention with this article is to focus specifically on transmission lines and connectors the new ham will encounter and avoid areas that are only tangentially related to transmission lines or that you will rarely encounter or have a need for. I also hope to specifically address some of the myths and often overlooked aspects of transmission lines.

In this article I will at times give my opinion. My intention is help you benefit from what I have learned over the years. My experience not only includes antenna installation I've done but installation I've taken apart or been involved in updating. I have found that by taking down an antenna system or looking at a system that has been up for several years I get to see where the flaws and weaknesses were and where the shortcuts were taken. This is one of the reasons I'm always happy to go help folks with their antennas, not to find fault or throw rocks but rather to learn from others successes and failures.

In the first draft of this paper I started off by trying to first explain what the properties of a transmission line is, I'm referring specifically to all those numbers and charts explaining the physical and electrical properties of the many different kinds of transmissions lines. From there I started going through each kind of transmission line you might see in the typical ham radio catalog. After going back and reading what I wrote I realized what I was doing was giving you information but with no context. As I read other papers and books on transmission lines I realized they all did the same thing to one degree or another. So I decided to take a different approach. I wanted to give you context. To do that I decided to instead start with your station and go through the process of selecting cables based on the specific use in your station.

The way I've organized this paper is I begin by giving you some background on transmission lines. Things that will be helpful when you get to the section where I write about the various properties of a typical transmission line. The goal was to help you understand what all those different numbers mean. Then I go through the typical connectors you will likely use in your

[1] "The Care and Feeding of Transmission Lines", Joel R. Hallas, W1ZE, ARRL Publication

shack and explain their strength and weaknesses. I also include some additional information when you get to the point where you are ready build and install your own transmission line.

After we have given you all of this context we will start thinking about your shack. We will look and what to use for patch cables. We will consider options for the transmission line going out to your antenna. We will consider both HF and VHF/UHF installations. If we have done our job you will be able to make good choices about the right kinds of cable and connectors to use in your station.

In the appendix is where you will find the specifications for several types of cables you will likely choose from as you build your station. Our hope is that as you read the specifications you will understand what the numbers all mean, which will put you in a good position to make the right choices for your unique needs. In ham radio, one size does NOT fit all.

History

I cannot leave the reader with the impression the following section is an original work by me. I found this on the internet. It was one of the best articles on the history of coaxial cable I was able to find and appears to have been used by many as their reference when talking about the history of coaxial transmission line.

Many of the books and articles I've read leave out the history but I felt it was germane to the topic and added value. For that reason I have included it here almost unchanged from the version I found on the Internet. You can find this article on the Internet here:

http://silvercometars.com/docs/History%20of%20coaxial%20cable.pdf

Today about the only transmission line we see is coaxial cable but it wasn't always this way. Prior to its invention the common transmission line was an open-wire balanced feeder made from wire and insulating spacers. This biggest advantage to this type of transmission line is it has very low loss and back in the days when SWR was not an issue it was a good choice. We will discuss SWR and line loss later.

The first known patent granted for coaxial transmission line was a British patent in 1880 to Oliver Heaviside, a self-taught British electrical engineer. Those astute in history will recognize the name as the one due to the Kennelly-Heaviside layer; we now call the ionosphere, which Heaviside in conjunction with Kennelly discovered the reflecting medium high above Earth. Heaviside was the nephew of the British inventor Sir Charles Wheatstone, the co-inventor of the British telegraph system and known for his invention of the Wheatstone Bridge to measure resistance.

Heaviside's coaxial cable was a copper tube, which formed the outer of the line. The inner concentric (coaxial) conductor was a copper wire which was supported by insulating discs to keep the central wire a constant distance from the inner of the copper tube. The major dielectric was air, giving low loss to signals travelling along it.

Heaviside was a prolific experimenter and he coined the names of several items used today. He invented the word impedance, admittance, conductance, permeability, inductance, reactance, reluctance and permittance, which we still use today. (He seemed to like the use of the letters ANCE at the end of the item). He also solved Maxwell's equations and invented differential equations in order to perform this work.


Figure 1: Open Wire transmission line

Heaviside's coaxial transmission lines found many uses; not the least was the transatlantic cables used to carry telegraph and later telephone traffic over vast distances. The first transatlantic telegraph cable was a normal wire cable laid in the late 1800s and was a disaster. The inventor was Lord Kelvin, earlier Sir William Thompson. He however did not know about distributed capacitance, inductance and impedance, the signal loading on this cable was so high it limited the signaling speed to about 5wpm. Unfortunately the cable failed about two weeks after it was laid and was never re-established. It was a financial disaster for the sponsors.

A German patent in 1884 was granted to Ernst Werner von Siemens for a concentric coaxial transmission line similar to Heaviside's design, but little detail is known about this patent or whether the cable was ever put into service.

US Patent for Coaxial Cable

The next known patent for coaxial cable was granted to two American engineers. This patent granted in 1931 was almost the same as Heaviside's original design but had a subtle difference. It was semi-flexible and could be coiled more easily. The patent diagram clearly shows a similar construction to Heaviside's design with an outer copper jacket and inner wire supported by insulating discs.

U.S. Patent No. 1,835,031 for a "concentric conducting system" was awarded to Lloyd Espenschied of Kew Gardens, New York, and Herman A. Affel of Ridgewood, New Jersey, and assigned to the American Telephone & Telegraph Co (today AT&T). This although similar to Heaviside's patent allowed more bending to occur and the cable could be coiled on a large diameter drum for laying at sea. They also showed the use of repeater stations along the line to boost the signal level.

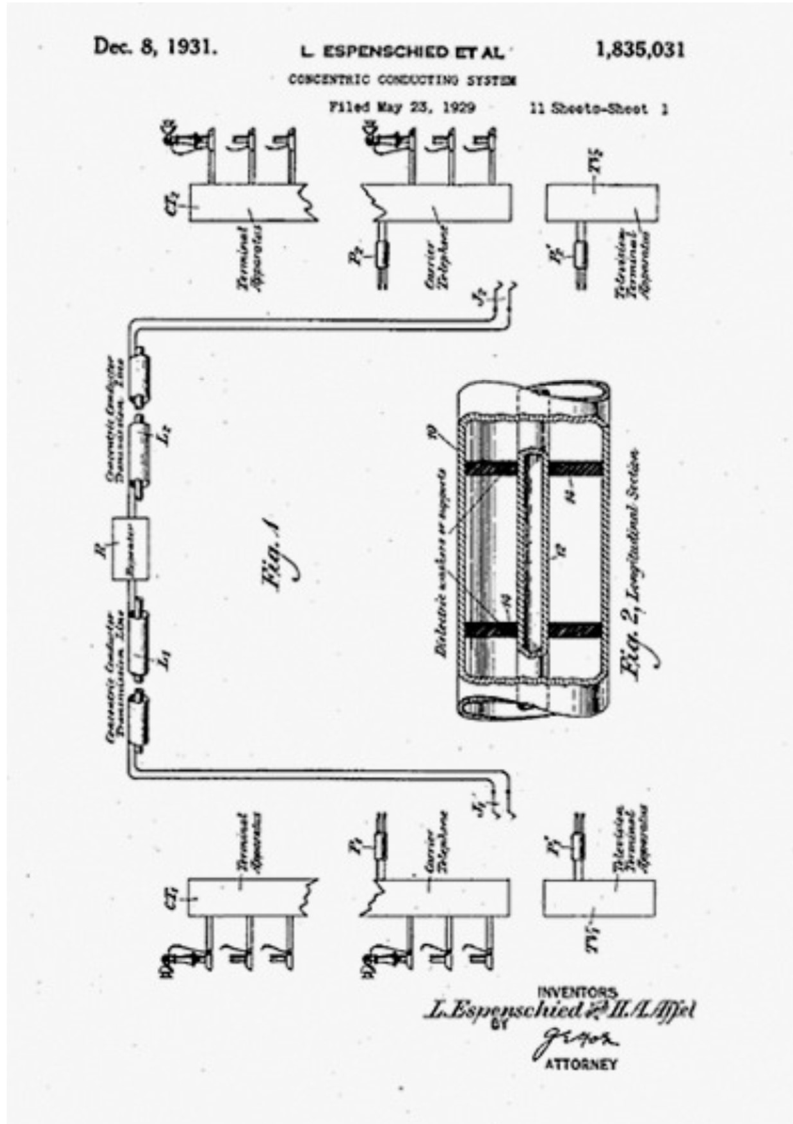

Figure 2: US patent diagram for coaxial line, which clearly shows the outer tube, inner tube and insulating discs as used by Heaviside.

Lloyd Espenschied in 1904 became an amateur radio operator and later a telegraph operator with a maritime station. He also later determined experimentally the optimum impedance to use for high power, high voltage and minimum attenuation at 10GHz in the 1940s, these being 30-ohm, 60-ohm and 77-ohm respectively. Significantly the Germans standardized on 60-ohm before the war.

The next significant use of coaxial cables occurred in 1936. The first experimental carrier telephone system was laid between London and Birmingham with a cable made by Standard Telephones and Cables (STC) which consisted of 4-coaxial cables carrying up to 4-channels per coax. The cable was sheathed in lead as per the normal telephone cables to protect the inner conductors. This revolutionized telephony as many separate telephone channels could be carried on a single cable. The system used SSB suppressed carrier transmissions spaced 15kHz apart.

The second significant event in 1936 was the televising of the Berlin Summer Olympic Games. The transmission was carried by a coaxial cable between Berlin and Leipzig where the main German television transmitter was located. The cable used was very similar to the British Post Office type and laid in sections about 50km in length with repeater stations to boost the signal level, no doubt gleaned from the US patent paper.

The Impedance Battle

As the war in Europe was inevitable the allied scientists and engineers needed to define the common impedance so that coaxial cable could be manufactured in high volume to suit the various users and to introduce some standards. Some factions of this committee favored 75-ohm cable and they demonstrated that this was the ideal impedance to feed half wave dipole antennas and they also showed that 75-ohms had the lowest attenuation per unit length. This committee had many engineers and scientists and the arguments went back and forth as to which was the ideal impedance to adopt. During all this wrangling a Canadian engineer had little to say but finally spoke. He told the committee he had been studying the US copper water pipe tables and proposed that 52-ohm be the preferred impedance, although this hadn't been tabled previously. He showed that 52-ohm impedance could be made in any required diameter as the standard US water pipe tables had all the necessary size tubes. Hence, no extra tooling was needed and so 52-ohm became the standard for a practical reason.[2]

Chain Home Radar

During the run up to WW2 the British realized that a radio direction finding system (later called RADAR) was necessary and embarked on a design called Chain Home in 1935. The transmitter developed very high peak power and the need was to convey this signal from the transmitter to the base of the transmitting tower with minimum loss. On the prototype system ordinary GPO telephone poles and insulators were used with 200-pound per mile copper wire as a balanced feeder arrangement. Although this worked the danger of damage from enemy bombing led to a buried feeder system. A scheme was devised using two copper tubes laid in parallel with central wires and insulating discs, similar to the telephone coaxial cables in Heaviside's original patent. This formed a balanced shielded line that connected to the 600-ohm balanced feeder wires that ran up the tower and fed the multiple antenna arrays. In the final installations the STC telephone coaxial cable was utilized to feed the transmitter and receiver antenna arrays.

Flexible Coaxial Lines

The next saga is the invention of what we know today as "flexible coaxial lines". Edward (Taffy) Bowen was a Welsh engineer working on the Chain Home radar system but left in late 1936 to take up the challenge of developing airborne radar for the allied night fighters. Bowen had been the transmitter designer for Chain Home but friction within the team and the overall supervisor Watson-Watt led Bowen to ask for a transfer to AI work (airborne intercept).

During this development in 1937 he needed a flexible coaxial transmission line. Bowen originally tried balanced wire feeders but this presented problems, the wing mounted dipole arrays were susceptible to damage, as were the feed lines. Where the lines passed through the aircraft skin arcing occurred at high altitude because of the high peak power required. Next Bowen tried rigid coaxial line but this suffered from fatigue fractures under the high vibration experienced in fighter aircraft.

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[2] If you would like to understand in more detail why 50 ohms became the standard and the math behind that decision go to [this link]

Bowen had recently learned of a new insulating material developed by Imperial Chemical Industries (ICI) which was called polyethylene. He asked the scientists at ICI whether it was possible to extrude a tubular layer of polyethylene with a constant diameter onto a stranded wire conductor. They replied it was possible and made a short length for Bowen. He then encased this with a sheath of copper braided wire bound tightly with electrical insulating tape to form a concentric flexible coaxial line. Flexible coax cable was born!

Later in the war the British took to America with the Tizard Mission many secret devices to assist the Americans in making equipment vital to the war effort. Amongst these were the cavity magnetron, Bowen's coaxial cable and others as a bargaining tool in the final "Lend-Lease" agreement between Britain and America.

Connectors for this new type of coaxial cable did not exist and Burndept, a British company, came up with a suitable connector that was widely used on allied equipment. We find this connector on the WS-19, C-11, C-13 and many others. The American company Amphenol in the meantime invented the PL-259 connector which at the time was designated the "UHF connector" as at that time VHF was regarded to start at 30 MHz and UHF was regarded to start at 100 MHz, the connector was rated up to 300 MHz. Although this connector was not "constant impedance" it was used in many 400 MHz radar systems during the war and only later did Paul Neill of Bell Labs invent the "N-type", which is named after him, it being a constant impedance connector rated up to at least 11 GHz. The N-type connector, unlike the PL-259, was inherently waterproof and rapidly became the preferred connector. Even the Russians used the N-type towards the end of the war, although they had a different name for it.

How and Why Did Coaxial Cable Become so Popular?

One of the questions I have often wondered is how and why did coaxial cable become the de facto standard for ham radio?" The answer as near as I have been able to determine from my research was after World War II there were miles of coaxial cable left over from the war. The US military had standardized on coaxial cable for many different reasons. The biggest advantage was the ability of coaxial cable to carry signals without losing much of the signal when passing close to metallic objects. With many other types of feed lines, any metallic object close to the feed line interacts with the signal, essentially shorting out much of the signal. The ability of coaxial cable to minimize interactions with external metallic surfaces was especially valuable in mobile applications including marine, aviation applications. The availability of surplus coaxial cable after the World War II introduced many amateurs to the advantages of coaxial cable.

Myths

In talking and listening to my fellow operators over the years and even looking back over my own ham radio experiences I have come to realize there are some myths and misunderstandings about transmission lines. I've selected a few of the most common ones for consideration.

Myth 1: The length of the transmission line is specific to the frequency the antenna system is design for. In other words the length of the transmission line matters. One manifestation of this myth is many hams are afraid to shorten the coaxial cable that came with their mobile antenna mount. I also believe this is a myth that continues to be perpetuated by the CB radio community even today.

The Truth: The length of the transmission line doesn't matter. With regard to SWR the length of the transmission line does not affect the SWR. If it does then there is another issue. You do however want to keep transmission lines as short as possible especially at VHF and UHF frequencies. This is due entirely to minimizing line loss. The other exception to this rule is in building phasing harnesses and coaxial line transformers. In those situations the length of the transmission line matters.

Myth 2: I don't need the bigger RG-8 type cable runs between my station and my antennas, RG-8x is a good enough. Line loss won't be a big deal.

The Reality: Considering what cable to use should not be just about line loss. Susceptibility to ambient RF (aka: RFI) should also be a consideration. It's true that for most HF base station installations the loss in RG8x will not be a big factor. But there are two things to consider. First if the coaxial cable will be outside make sure to use UV resistant coaxial. This is true for RG-8 or RG-8X. Most bargain RG-8 and RG-8X is not UV resistant. The second and bigger consideration is susceptibility to ambient RF, also known as RFI. Most homes these days have a lot of ambient RF from wall warts, LED lights and a menagerie of other electronics. For that reason you want to use a cable that has the best shielding. Consider that most RG-8x only has a 95% braided shielding. While good RG-8 has a 97% shielding and the top brands of coaxial have both a braided shield and 100% copper shield, M&P HyperFlex and Belden 9913-F are two examples. We should also mention that Heliax that is often used at repeater sites is used due to both its low loss specification and its 100% corrugated copper shielding that is necessary for most mountain top repeater sites such as Mount Ogden.

Myth: RG-58 is good enough for patch cables in the shack even if I'm running an amplifier.

The Reality: Smaller coax cables like RG-58 provide less shielding than larger coax, thanks to the higher resistance of their shields. To minimize inter-station interference, use coax with a beefy copper shield for all cables. It should be noted that although RG-400 is the same size as RG-58 it makes for a very good patch cable due to its double braided shield and its ability to handle high power. It is often used in many commercial and scientific applications as an interconnect cable. It is often referred to as "high isolation" coaxial cable. We will go into more detail on this topic in the section titled *Inside the Shack (HF, VHF, UHF)* on page 40.

Myth 2: LMR-400 is the best coaxial cable to use.

The Reality: Although LMR-400 is very good cable it is not always the best choice. The most important thing to understand about LMR-400 is it has a solid core made of copper-clad aluminum. Which makes it good for installation where there will be no movement in the cable and weight is a consideration. However in installations where the cable will need to flex due to wind or being attached to a steerable antenna, over time the solid core will fatigue and break. Consequently it is not a good choice for rotator loops in beam antenna that can be rotated. If your cable will be susceptible to movement it's better to use a coaxial cable with a stranded wire core rather than a solid wire core.

Myth 3: All coaxial cable is the same, some is just more expensive than others.

The Reality: Nearly all the coaxial cable available from the major vendors that cater to the ham radio community is usually of good quality. The biggest thing is what they advertise is what they sell. So if it says it's Belden then you can count on it being Belden. The same cannot be said for coax bought from vendors like Amazon. The LMR-400 you get from Amazon may actually come from China and not be true LMR-400[3].

Myth 4: All UHF connectors are of equal quality so get the cheapest ones you can find and it's usually at Amazon.

The Reality: I once was involved in an antenna installation of a very expensive beam antenna. What I found baffling was why would one buy a multi thousand dollar antenna and use $2 connectors? Not all connectors are of the same quality. We will talk more about this in the chapter on Connectors (see page 22).

Myth 5: The coaxial cable choice is not that important. What's important is what kind of radio I should buy, Icom xyz, Yaesu abc, Kenwood efg or the Zygote dzx? That's the critical choice? Spend the money on the radio and cut corners on the coax, connectors and antenna.

The Reality: I often hear discussions with new hams about what radio to get. I always find these discussions overlook the most important piece of gear associated with the ham station, the antenna system, which includes the transmission line. I always find it ironic that a new ham will spend hundreds if not thousands of dollars on a new rig and then cheap out the transmission line and connectors and deploy the least effective antenna they could have picked. I want to say it's our fault, the fault of the more experienced hams, we know better. We know the discussion should start with the antenna, not the rig. You can connect a $10,000 or a $400 radio to a crappy antenna and not be able to tell the difference. The reverse is also true, you can connect a $400 radio to an efficient and properly installed antenna system and get better results than the guy with the $10,000 rig and the G5RV in his attic. The antenna and transmission line are the most important elements of any hams station. Without a properly installed antenna "system" that expensive new radio is not going to be any better than the $500 bargain radio from Acme Hardware and Electronics.

Myth 6: Coax degrades with age, causing loss to increase drastically.

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[3] See Dave Kessler's interview with Ray Nelson, N1MPD (#97). In this video they talk specifically about counterfeit LMR-400. https://www.youtube.com/watch?v=4fP94GfqTtk

The Reality: As far as performance on the HF bands is concerned, it's another one of those old wives' tales that, while based on a grain of truth, should not be taken as gospel. What's true is that 1) as copper braid corrodes, its resistance can increase, which increases loss and degrades shielding; and 2) moisture in the dielectric can increase dielectric loss. What causes water to get inside a length of coaxial cable? In my experience I have seen two primary causes for how water can invade coaxial cable. The first is using a cable outside that does not have a UV resistant jacket. Over time the jacket will crack thus allowing water to invade the cable. The second and more common cause is connections that are exposed to weather that have not been properly prepared and sealed. Years ago when I moved into our current home I installed good quality coaxial cable that ran the length of my roof. It had been there for 17 years. Last year I replaced the antenna that it was attached to and inspected the cable and because I had followed a best practice approach when I installed the system I found the fittings looked as good as the day I installed then. I also ran a test to measure cable loss, I wanted to see if any water had seeped into the coaxial. Its measured loss was well within the manufactures specification indicating the cable was as good as the day I installed it. A good quality cable properly installed can last decades.

Why Does It Matter

Have you heard the old saying, "a chain is only as strong as its weakest link." That saying also applies to antenna systems[4]. A station is only as good as its weakest link. The best radio you can buy will not be much better than an inexpensive radio if that $2 UHF connector has let water into the coax or the transmission line has developed a crack or a wear spot. It also matters if half the signal is converted to heat due to attenuation in the transmission line. So it does matter, it matters a lot. Your goal should be to make sure every watt of power being sent to the antenna gets to the antenna and every microvolt coming from the antenna gets to the radio. There are a lot of factors that can impact that.

- If the cable is installed outside is the jacket UV resistant?
- If the cable is to be buried is it rated for direct burial?
- Is the center conductor prone to break?
- Is the transmission line too small for the power you will be running?
- Are you using the right kind of transmission line for the application?
- Are you using cheap connectors that are prone to let water in and RF leak out?
- Are the connectors made of low quality materials that are prone to melt while soldering or that solder does not adhere to very well?
- Are the connectors prone to rust and corrosion?
- Does the transmission line have high loss specifications for the frequency range it will be used for? Or if you measure the attenuation across a length of transmission line are the measured losses on par with the cables technical specifications?

[4] Throughout this paper we will use the term antenna system. An antenna system consists of the antenna tuner, transmission line, RF connectors, baluns, ununs, chokes, and the antenna.

These are many of the factors to consider. In the section on "*Types of Transmission Lines*", see page 10, we will talk about the applications for each type of transmission line.

Types of Transmission Lines

Transmission line comes in all sorts of configurations and looking at any list of transmission lines such as the one found in the ARRL Antenna Book[5] can leave one scratching their head. In this paper I'm not going to go through several different transmission lines in an effort to help you select the right cable for your specific needs. I'll highlight the kind of cable or transmission line that works best for each specific purpose. I'll try to give you a good, better, best perspective so you can make up your own mind which will be best for your particular needs tempered by your constraints.

Flexible Coaxial Cable Family

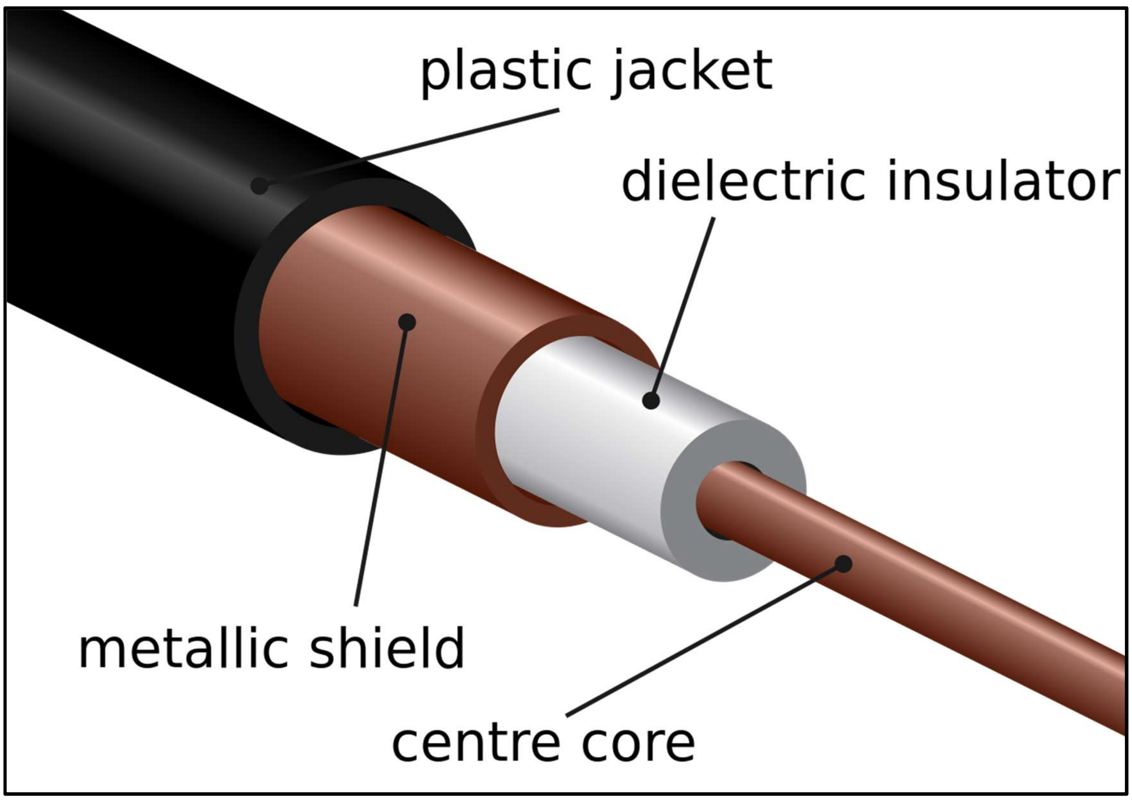

Figure 3: Typical coaxial Cable

[5] See: "*ARRL Antenna Book*" Volume 24, table 23.1 on page 23.24. You will find this table in practically every volume of the ARRL antenna book ever published, although I'll admit I've not seen them all. I specifically referenced the 24th Edition because it's the one that sits on my desk.

I have estimated there are not less than 100 different offerings in this category and I'm sure I've underestimated it by a fair amount. Their construction is all basically the same, you have a metallic center conductor, usually copper, then a dielectric material separating the inner conductor from some type of a braided shield and then a PVC jacket. There are many variations on this design. Some use a solid wire for the center conductor of varying size, others use a center conductor made up of various sizes and number of stranded wire. The dielectric materials also vary. Some use a solid dielectric others and others a foam dielectric. The shields are also diverse. They are typically made up of some kind of braided conductor. The percentage of coverage can vary as well as the makeup of the wires used in the braid. There can sometime be more than one braided shield and they may also include some kind of a metal foil wrapping between the dielectric and the braided shield. And the jacket material can also vary. It can be formulated for different kinds of environments such has high heat, used outdoors or directly buried and so on. Each of these variables can be altered to enhance specific properties of the cable. This is what makes it all so confusing. Before we start designing your station let's look at one more aspect of Coaxial Cable.

Where Does the RG Designation Come From?

Late in the 1930s the U.S. Army and Navy began to classify different cables based on their constructions. Since the purpose of these different cables was to carry radio wave the designation "RG" was used rather than the words "radio guide." At that time there was no correlation between the number assigned and any construction property of the cable. Thus an RG-8 came after an RG-7 and before an RG-9, but these seemingly similar designations could be completely different and unrelated in their specification. The RG numbers were assigned to a particular cable simply because of the page number in the cable specification manual.

The whole point of all the complex technicalities were to ensure the buyer got a specific cable design with predictable and repeatable characteristics for specific military applications. As cable designs changed with new materials and manufacturing techniques variations on the original RG designs began to be manufactured. Some of these were targeted improvements, like a special jacket on an existing design or an improved dielectric. These variations are generally noted by an additional letter on the designation, thus RG-58A, RG-58B and RG-58C were all variations of the basic RG-58 cable type.

The real challenge for the manufactures of these cables is the testing and certification process to gain the MIL spec certification. The process is time intensive, complex and requires specialized equipment. Consequently the process is extremely expensive. What makes matters worse is the buyers are usually looking for the lowest cost bidder. Both manufactures and customers wanted a non-certified lower cost alternative given their applications were not being used in life or death situations. In the free market of the US and elsewhere the manufacturers began to make cables that were identical to the original RG specification but that were not subjected to the rigorous testing and certification process the military required. These cables were designated as "utility grade" and a slash plus the letter U was placed at the end, for example: RG-58C/U. This is the utility version of RG-58C, which is identical in construction but has not been tested or certified for military use and consequently does not carry the MIL Spec designator.

In reviewing the market it is clear that most manufactures are leaving off the /U designation. If you read the fine print they will often say, "This cable is MIL Spec equivalent to M17-*fill in the blank*". But the cable designation in the catalog does not include the /U. Unfortunately you have no real way of knowing if it really does comply with a given MIL Spec. At that point you need to decide if the vendor is one you trust or not. Vendors like HRO, DX Engineering, and GigaParts are going to care that they are selling what they claim they are selling. Vendors like Amazon don't care. I say this based on the number of counterfeit items I have bought from them over the years.

Often the word "*Type*" is included in the RG designation. This indicates that the cable under consideration is based on one of the earlier military standards but differs from the original design in some significant way. At this point, all the designation is inferring is the cable falls into a family or type of cables, RG-8 for example. It might indicate the size of the center conductor, the impedance, and some other aspects of construction. The key takeaway is that the cable varies in some undefined ways from the military specification for that cable type. This is where a lot of confusion comes in and also why what I'll call "knockoff" coaxial cable can be legally sold in the market place. This is the primary reason I do not recommend buying coaxial cable from companies like Amazon or other big box retailers. You never know what you are getting[6], so buyer beware!

I did find it interesting that during my research I came across a vendor's web site that had this notice as a footnote on its web page of specifications for its coaxial cable products: "Dimensions and specifications may be changed without prior notice. (RM01)". Are you kidding me!

By the time the RG system approached the RG-500 specification, whole blocks of numbers had been abandoned mainly because they were replaced and/or superseded by improved designs. The system became unwieldy and confusing. Consequently the military abandoned it in the 1970s and instituted what is today known as the MIL-C-17 (Army) and JAN C-17 (Navy) designations.

In shopping around on the Internet it became fairly clear that almost none of the cable out there carries the MIL spec certification. I called a couple of different vendors and asked them if their cable was MIL spec certified and all of them said that it wasn't but were quick to add they were made to a specific MIL spec specification. They also inferred that the MIL Spec standard was fairly obsolete and practically no cable on the market today carried a MIL Spec certification. In going through my own inventory of used coaxial I noted that some of the older coaxial cable I had was actually stamped with the MIL spec number.

I placed a call to MPD Digital and put the question to them, "is the MIL Spec standard still relevant today?" Their answer was "Yes, absolutely, however…..". He indicated that they often

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[6] See Dave Kessler's interview with Ray Nelson, N1MPD (#97). In this video they talk specifically about counterfeit LMR-400. https://www.youtube.com/watch?v=4fP94GfqTtk

get requests for cable assemblies calling for a certain MIL Spec certification but did indicate that it was fairly rare and that the MIL Spec certification is still relevant. He also indicated that the cost goes up by nearly three times when MIL Spec certified cable is specified. He also warned me there are a lot of companies, especially in China selling coaxial cable claiming to be in compliance with a given MIL Spec standard but actually aren't. Again repeating the old adage, buyer beware.

So what conclusion should we draw from this rather confusing situation. First let me say that for our needs we do not need a MIL Spec certified cable. However, I'd like to know if what I'm buying is actually built to a specific MIL Spec standard even though it's not certified. I'll go back to an old saying, "you get what you pay for." And another old saying, "If it sounds too good to be true, it probable isn't." So I'll leave it up to you to decide.

The popularity of RG cables continues to grow, there's no question it's the most popular cable in use today. They are used in applications and industries ranging from audio & video, cable and satellite, cell phone systems, medical equipment and even in our special niche, ham radio. RG cables are in use everywhere across the globe and even in space.

Parallel Conductor Transmission Line

This group includes twin lead, window line, and ladder line. This group is characterized by having two parallel conductors running side by side that are separate some consistent distance apart using some type of spacing material. This is the kind of transmission lines that were in common use before WW2.

Back then most hams built their own rigs and solid state equipment was still years away. The commonality to these old tube rigs is they had circuitry in them for tuning the radio, in effect they had an antenna tuner of sorts built into their circuitry. Also, back then the idea of SWR was not well understood so often antennas would have a high SWR but the equipment could handle it. Which brings be to one of the strength of the parallel conductor transmission line, it has extremely low loss. For example if we look at 100' of 600 ohm open wire line, its loss at 10 MHz is only .06 dB! As compared to the best RG-8 coaxial cable which has a loss of .4 dB.

Of course there is also a down side to the parallel conductor transmission line, it should not be placed near any metallic objects like metal vents, pipes, aluminum siding, windows seals and so on. It also should not come in contact with the ground or be coiled up. This is one of the key reasons the military standardized on coaxial cable in WW2. It also is not shielded so it has a tendency to not only radiate but also pickup ambient RF.

The parallel conductor transmission line is considered a balanced feed line, unlike coaxial cable which is an unbalanced feed line.

For some applications it's a good choice, in the G5RV for example. The original designer specified the use of a parallel line transmission line. In the ARRL Antenna Book they specifically call for feeding the G5RV with 450 ohm window line.

Parallel line is a good choice for any antenna that will have a high impedance at its feed point. But remember it's also necessary to include a balun where the parallel line is connected to a coaxial cable. The reason for this is you need to convert from an unbalanced transmission line, the coax, to a balanced transmission line.

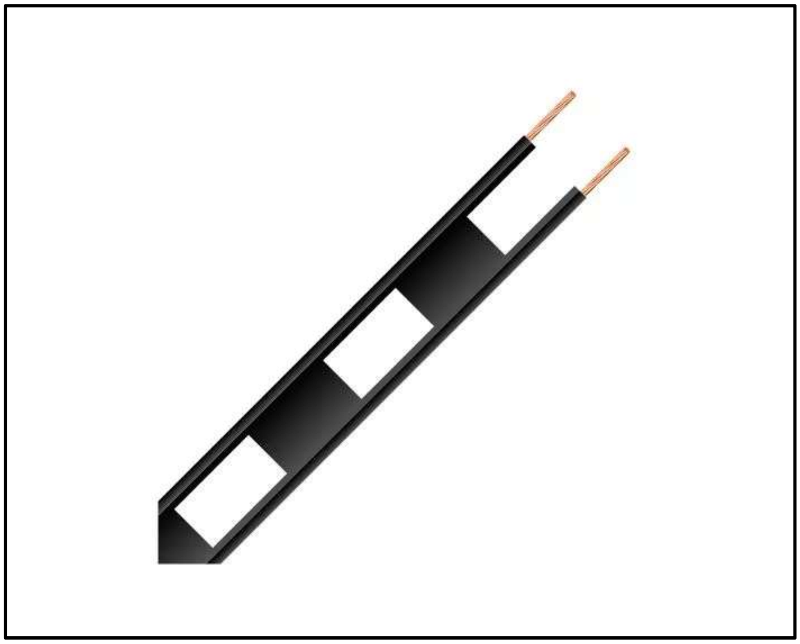

Figure 4: Window Line

Hard Line/Heliax

This group includes Heliax[7] and hardline. This group is characterized as having a center conductor running inside some type of full metal tube. This group is usually fairly rigid. The metal tube is sometimes made of corrugated copper or smooth aluminum. The dielectric material can range from air using intermittent spacers to a full foam dielectric as illustrated in Figure 5.

Figure 5: Heliax

[7] Heliax is actually a brand name specific called Andrew Heliax. Commscope purchased Andrews. Due to its wide spread use it's generically referred to as just Heliax.

Figure 6: Typical Hardline used by the cable companies

Within the industry these three families are also broken down further based on a manifold of criterial which can include but is not limited to their specific application, size, or impedance. By no means is every cable type included in this paper. For example there is twinaxial that has two center conductors and triaxial that has two separate shields. And there are a host of other coaxial cable types that include not only the traditional coaxial cable as pictured in Figure 3 but also includes one or more twisted pairs of wires. We are also going to leave out fiber optic cable in this paper, which technically can also be used as a transmission line. But it is unlikely anyone reading this paper will ever use it as a transmission line for their radio station with the possible exception of using it as a networking cable for their computers. As I said, we are going to try to keep it simple and only focus on the type of transmission lines you and I are likely to use throughout the course of our ham radio hobby.

Earlier in this section I mentioned that many of the variables in a transmission line can be altered by the manufacturer to enhance certain characteristics of a transmission line. We are going to look at the specification we see in the data sheets so we can understand what they mean. We are going to define things like attenuation, impedance and other measurable properties that are common to all transmission line. This will help us to understand the difference between different transmission lines in such a way that we will be smarter about what we choose to put in our station rather than relying on anecdotal recommendations that are not always the best source of information.

Properties of Transmission Lines

In this section we will look at a number of common cable specifications and explain what each one means. It's important that the knowledgeable amateur understand what those specification actually mean.

Attenuation aka: Matched Line Loss

Let's begin with the actual definition of the word. *Attenuation: the reduction of the force, effect, or value of something. The reduction of the amplitude of a signal, electric current, or other oscillation.* In short it means loss in the signal as it traverses the transmission line. Attenuation is measured in decibels, aka: dB. In the US the dB values are the amount of loss across 100' of the line being tested. In Europe the unit of measure is usually across 100 meters (328 feet) of the line being tested .

What is a dB or Decibel[8]? I'm not going to go into a lot of depth here but it's important to understand what a dB is at a high level. First a dB is always a comparison of two or more things, two or more quantities if you will. A dB is the proportional difference between the items being measured. In the case of a transmission line it's a comparison of the amount of power going in as compared to the amount of power coming out. If 10 watts is put into the cable and 5 watts is measured at the other end of a 100' transmission line, the line is said to have a loss of 3dB or -3 dB. The second point is every 3 dB is equal to one half of the power or a doubling of power, likewise -3 dB would be halving the amount of power coming out of the transmission line. If you want to learn more about dB may I recommend the following six minute YouTube video:

https://www.youtube.com/watch?v=G8DpvfEwyGs

In the case of transmission lines the thing to understand is that every transmission line has some amount of loss regardless of its construction. The lossless transmission line does not exist in the real world, it's only a mathematical construct like the isotropic antenna. The other thing to know is that loss increases with both frequency and the overall length of the transmission line. To put this into context RG-59 has more loss than RG-8X, which has more loss than RG-8, which has more loss than half inch Heliax. This means that attenuation is an important consideration when selecting a transmission line.

Another important point to make is regarding the concept of "*matched line loss*." When manufactures measure loss in a length of coax they always use a load at the far end equal to the impedance of the transmission line. So when measuring loss in a 50 ohm coax they put a 50 ohm load at the far end. That is what is meant by "matched line loss." In the real world it is rarely the case that at the end of the transmission line will the load, the antenna, be perfectly matched to the transmission line. There is almost always some amount of mismatch. The amount of mismatch is referred to as the Standing Wave Ratio, aka: SWR.

[8] See: https://en.wikipedia.org/wiki/Decibel

The thing to know is the greater the mismatch the greater the loss in the transmission line. If you were to measure the loss with a 50 ohm dummy load in place of an antenna and then replace the dummy load with an antenna with a 10:1 SWR you would measure considerably more loss. I explain this in much greater detail in another paper I wrote, see: "*Setting the Record Straight: SWR.*" You can find it on the OARC web site here:

http://ogdenarc.org/downloads/Setting%20the%20Record%20Straight%20-%20SWR.pdf

At HF frequencies for runs under 100' line loss will not be an important factor assuming the system has a reasonable SWR of under 3:1. However there are other factors that should be considered, such as screening, power handling and jacket material.

Impedance

Impedance is a much more complicated concept. I'll try to explain without invoking paragraphs of strange mathematical formulas. For our needs, which are specific to transmission lines the key thing to understand is that for the average ham, impedance is 50 ohms. All the radios on the market today regardless if it's for HF, VHF, or UHF are designed for 50 ohm transmission line. That's really the key takeaway. But let's explain what impedance is without using a lot of math or deep diving into ohm's law. To state it as simply as I can it's the measure of resistance in a transmission line to alternating current, AC[9]. RF current is alternating current. The AC current that comes out of your wall outlet is usually around 60 Hz, the AC that comes out of your radio on 20 meters is 14,000,000 Hz or 14 MHz. One is simply wiggling back and forth, going from positive to negative a lot faster than the other.

If this very high level description of impedance has left you unsatisfied let me recommend the following YouTube video by one of my favorite YouTuber's. Jim W6LG:

https://www.youtube.com/watch?v=kxUE46kjf14

Yes there are transmission lines that have different impedance values. For example RG-11, RG-59, and RG-6, all are 75 ohm coax. There are cases where using 75 ohm cable is necessary, for example when building phasing harnesses. In addition, 75 Ohm coaxial cable is the standard in the cable TV industry and for most video applications.

Another kind of transmission line we see is twin lead, window line and ladder line. These types of transmission lines come in several different impedance values; twin lead is usually around 300 ohm, window line usually around 450 ohms and ladder line can be anywhere from 600 to 1200 ohms. One example of where windows line is used is in the G5RV which uses 450 ohm window line. It's generally understood that an impedance transformer should be used when going from a high impedance transmission line such as windows line to a 50 ohm coaxial able.

But for 95% of us 50 ohm coaxial cable is what we all use and in 99.99% of the cases what our radios expect to be connected to. One of the questions that usually comes up at this point is, "can I use 75 Ohm coaxial cable for my installation?" The answer is of course "yes". However

[9] See: https://en.wikipedia.org/wiki/Electrical_impedance

my recommendation is unless you know what you're doing, don't. Follow the manufactures recommendation and use 50 ohm coaxial cable. Your radio will be glad you did.

Velocity Factor

Velocity Factor is a pretty simple concept with an extremely simple associated formula. Velocity Factory is the ratio of the speed at which the electrons flow in a medium as compared to their speed in a vacuum. For example electrons flowing through a length of insulated 12 gauge copper wire is around 98% the speed of light in a vacuum, yes the insulation makes a difference. In some coaxial cable the velocity factor can be as low as 66% as in the case of most RG-8 using a solid polyethylene dielectric. In RG-8 type cable using a foam dielectric the velocity factor can be anywhere from 78% to as high as 91%. Generally speaking the more air there is in the dielectric the higher the velocity factor. However it is important to note that the velocity factor of the cable has nothing to do with the quality of the cable.

In cheap (junk) cable the velocity factor of the cable may not be consistent through the entire length of the cable. This can be tested using an antenna analyzer. To measure the velocity factor you will need to know the physical length of the cable. If you measure the velocity factor and find that it is within the manufactures specifications that is good. But if it differs by more than 5% then chances are you have either a bad length of cable or it's what we often refer to as junk cable.

Shield Properties (aka: Screening Efficiency)

The shield is the braided covering you will find just under the outer jacket of the coax. It's is often measure in % of coverage. Unfortunately shielding is one factors often over looked when considering patch cables and the coaxial run to the antenna. This is the reason I do not recommend the use of RG-58. Although RG-8X makes an acceptable patch cable I would suggest a better option might be a flexible RG-8 type coaxial with a foil and braided shield. M&P Hyperflex is a good example. It's very flexible and has both a copper foil shield and a braided copper shield. However my favorite coaxial for patch cables is RG-400 also known as high isolation coaxial cable. RG-400 is the same size as RG-58 and has two braided shields. It also has a high current rating.

Why is shielding important? The shielding keeps ambient RF out of the cable and the RF traveling in the cable inside the cable. By using a quality PL-259 connector and a coaxial cable with a high % of shield you will minimize RFI from getting inside the cable, and you will keep the RF you are sending to the antenna in the cable. So the selection of the right cable is about more than just the attenuation, you should also consider the shielding properties of the coax.

It should be noted that twin lead, window line and ladder line does not have a shield, which is one of the biggest reasons it should not be placed close to any metallic objects such as rain gutters, metal vents, or electrical wiring. This is the reason it should never be used in attic installations given that it provides no shielding to ambient RFI and also acts as a part of the antenna system in that it both radiates and picks up RF.

The shielding provided by coax depends primarily on two factors. First, the resistance of the shield – the lower the resistance, the better the shielding, this is why copper makes for a better shield than aluminum. Second, the density and homogeneity of the shield – that is, a very dense shield that is uniform provides better shielding when compared to coax with less dense and inconsistent shielding. This is where quality of manufacture comes into play – open a cheap piece of coax and you'll find a relatively thin copper or aluminum braid that is not tightly woven so that the white dielectric is plainly visible. For the best shielding, look for coax that combines a heavy copper braid with a dense layer of copper foil. Messi & Paoloni uses both a copper braid as well as a copper foil on their coaxial products. See Figure 7.

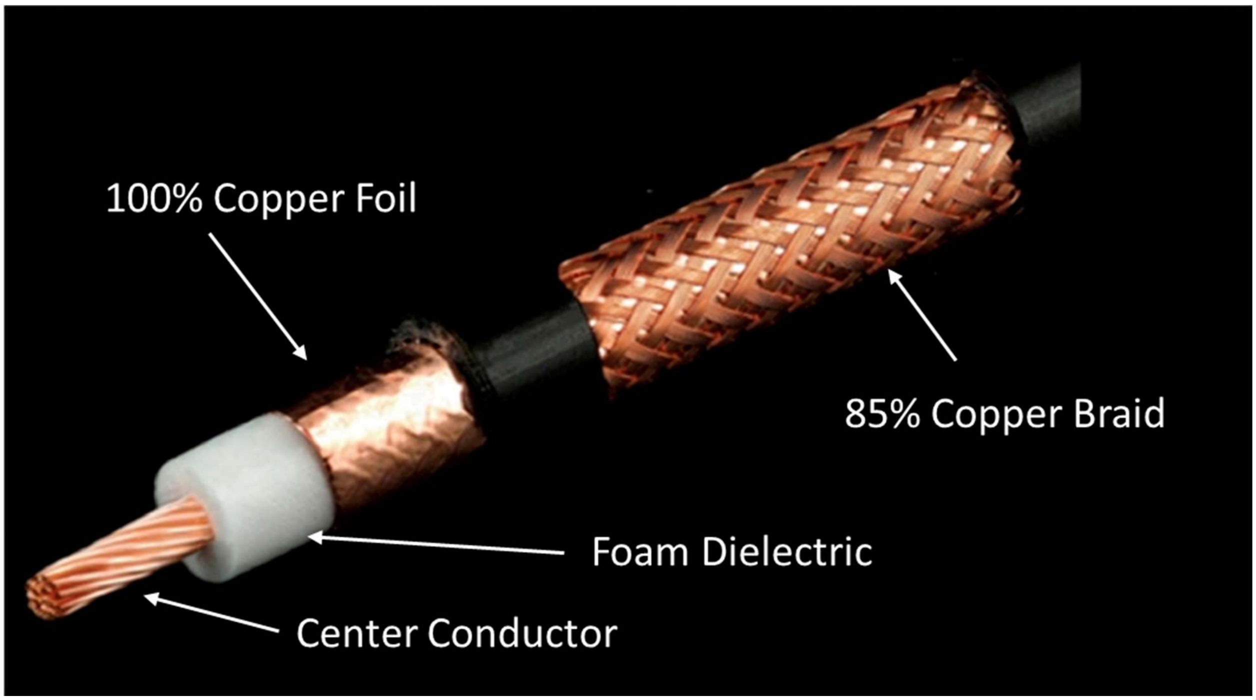

Figure 7: M&P HyperFlex 10

For most UHF and VHF installations at most repeater sites you will often find Heliax as the transmission line of choice, see Figure 8. There are two key reasons, very low attenuation properties and a solid copper shield. It should also be noted that many of the big contest stations use Heliax even for transmission lines to their large HF antennas. As one ham told me, “I don’t want to give up even 1 dB to signal attenuation.” He was referring to the signals going both out and in from the antenna. Are the builders of these big contest stations a little excessive, yes maybe, but when you have invested several $100 of thousands of dollars on an antenna array you want to maximize every penny of the investment.

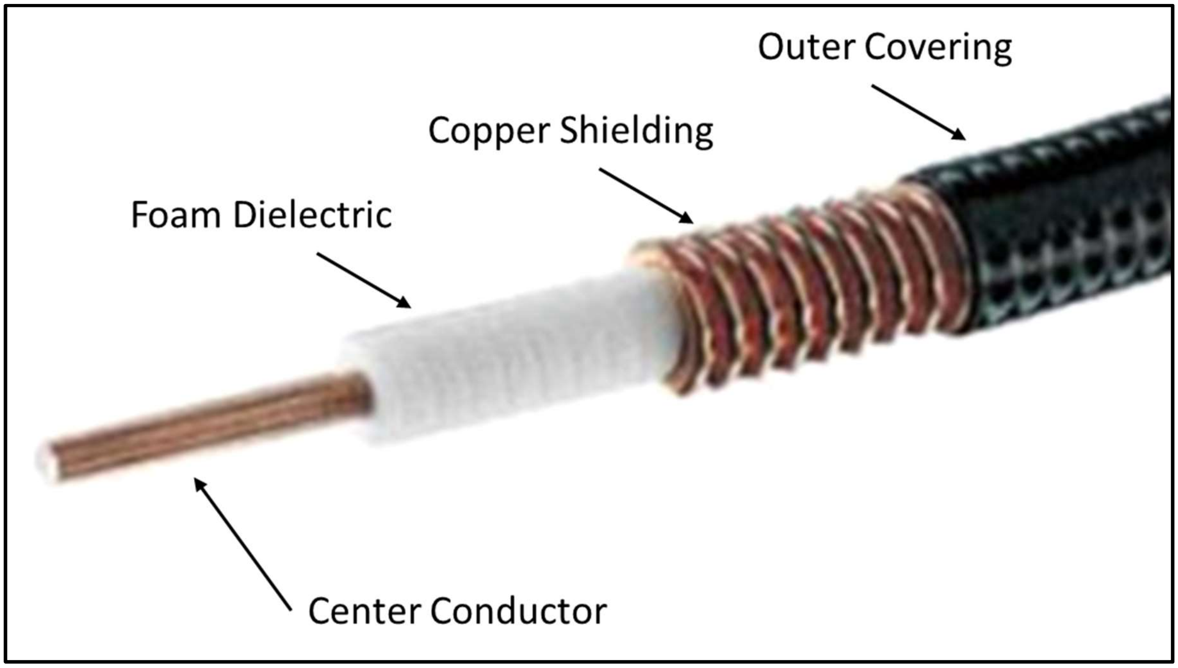

Figure 8: Andrews Heliax FSJ4-50B

Dielectric Properties

The dielectric material is one of the most important considerations when selecting transmission line. The primary reason for this is that it has perhaps the biggest impact on attenuation in a transmission line. For example ladder line uses air as its dielectric and consequently has the lowest attenuation of practically all transmission lines. Contrast that with coaxial cable that uses a solid Polyethylene dielectric which has the highest attenuation of practically all coaxial cable. Also note that coaxial cable that uses solid Polyethylene dielectric has the lowest velocity factor, 66% as compared to 91% for Foam Polystyrene.

A transmission line using a solid Polyethylene dielectric can be used for most HF frequencies, but it should be avoided for all VHF and UHF applications.

When shopping for coaxial cable take note of the dielectric material. The key giveaway when looking at cable specs is attenuation. What you will notice is the coaxial cable that uses a foam dielectric will have lower attenuation values than a cable that uses a solid dielectric. You will also notice that the velocity factor will be fairly high with a foam dielectric, >86%.

There are a lot of different dielectric materials in use today. At a fairly generic level they include:

- Solid Polyethylene
- Foamed Polyethylene
- Air
- Fluorinated Ethylene Propylene

- Foamed Fluorinated Ethylene Propylene

The key thing for you to consider is selecting the right coaxial cable for your specific needs. For example I would never recommend the use of a coaxial cable that uses a solid polyethylene dielectric for VHF or UHF transmission lines. Instead I would select a coaxial cable that uses some kind of a foam dielectric such as foamed polyethylene. If you're not sure ask the vendor. I know in the case of HRO and DX Engineering they have hams on their staff that are knowledgeable and can recommend the right transmission line for your specific needs.

I've avoided the really icky technical details of coaxial cable impedance as I don't think it necessary for the average ham. But if you're really interested consider the following formula which is the formula for Characteristic Impedance[10]: Now that I've warned you if you want to dig deeper start by reviewing the material referenced in footnote 10.

$$Z = \sqrt{\frac{R + sL}{G + sC}}$$

The Outer Jacket

Another important consideration for any coaxial cable is the outer jacket. For coaxial cables that will be indoors the outer jacket material is not a big consideration in most cases. The exception is coaxial cable that may run through some kind of air duct. In those cases you want to avoid any coaxial cable with a PVC jacket. For cables that will be exposed to extreme heat or cold there are cables made specifically for those installations as well[11].

For outdoor installations in our area there are two factors to consider. It must be UV resistant and if you are going to bury the cable without using a conduit it must also be rated for direct burial.

Although there are many different types of jacket materials used in the electrical field the one we find most prevalent in amateur market are all made of PVC. However not all PVC jackets are the same, some can be direct buried, some have UV resistant properties and some have neither. So when considering coaxial cable be aware of these properties and select the correct one for your particular application.

Power Handling

The final technical specification we will talk about is power handling. This is the specification that denotes the amount of current the transmission line is capable of handling. This is usually stated in **Max Volts (RMS)**. For example most RG-8X cable can handle up to 300 volts.

[10] See: https://en.wikipedia.org/wiki/Characteristic_impedance

[11] Messi & Paoloni manufacture a line of coaxial cables made for use in extremely hot countries called the Sahara Series. See: https://messi.it/en/catalogue/50-ohm-coaxial-cables/white-jacket--hot-countries-sahara-series.htm

For most of us the power handling capability of the transmission line is not a big consideration primarily because most of us don't use big amplifiers capable of putting out full legal limit. However if your station is capable of putting several 100 watts then it should be a consideration. For example I use an RM Italy amplifier which is capable of generating around 250 watts. For me it was a consideration, let me explain why. I go into this in much more detail in another paper I wrote about antenna tuners[12] but I'll explain the basic concept here.

What is going on is in antenna systems where there is a high SWR on the transmission line the voltage can actually be greater than the specified output of the amplifier. For example if you put 200 watts into a transmission line with a 3:1 SWR, 25% of the 200 watts will be reflected back and at certain points along the transmission line, where the waves are in phase, the forward and reflect voltages will combine, 200+50=250 volts. That's coming very close to the maximum power rating for RG-8X. At higher power levels and/or higher SWR values that voltage will be even greater. It's important to understand that using an antenna tuner does not change the SWR on the transmission line, it only changes the SWR between the tuner and the amplifier or the tuner and the radio if there is no amplifier in line.

The key takeaway, SWR can increase the amount of voltage on the transmission line, this is especially so when you are using antennas that exhibited a high SWR regardless if you are using an antenna tuner or not.

Now that we have looked at the various physical elements inherent to coaxial cable let's now look at the various kinds of connectors. In the next section we will go through several different connectors so when we start to build your station you will have a good idea of which connectors is best for your station.

Connectors

Now that we have looked at different transmission lines we should next look at the connectors that serve as the interface between the transmission line and the equipment you are connecting to. Let me start off by saying that not all connectors are built the same. Even within a certain class of connectors, you will find a wide range of variability in the quality of the connector. This is especially true in the case of PL-259's which is the most common connector we find in amateur radio. Let's take a look at each of the connectors we will often find in amateur radio.

The PL-259 Connector

This is by far the most common connector we will find in ham radio. You will often find its counterpart, the SO239 on the back of nearly all our radios regardless of frequency. Yes there are some exceptions. Often in radios that have a separate antenna port for the UHF antenna you will often find an N-Type connector. We will get to N-Type connectors later.

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[12] See: Antenna Tuners: "*Setting the Record Straight*", E Morgan WB7RLX, page 32. http://ogdenarc.org/downloads/Antenna%20Tuners%20-%20Setting%20the%20Record%20Straight.pdf

The PL-259 is also referred to as a UHF connector. And its counterpart is called the SO-239. Why is the PL-259 referred to as a "UHF" connector even though it is not recommended for use at UHF frequencies? The reason for that is when the PL-259 was first invented, sometime in the 1930's, the UHF spectrum started at 56 MHz and went up. Since then the frequency spectrum has been reclassified and now UHF, Ultra High frequency, is defined by the ITU as frequencies between 300 megahertz (MHz) and 3 gigahertz (GHz). For these frequencies the PL-259 is never recommended, yet it still retains its designation as a UHF connector, even though in this day and age it is not recommended for use in the UHF range.

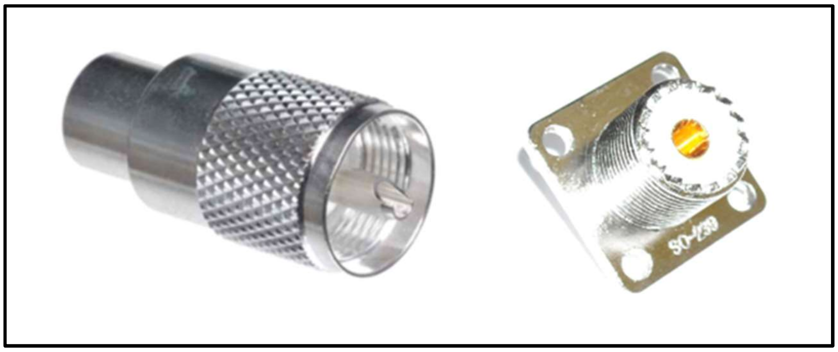

Figure 9: Typical PL-259 (Left) and SO-239 (Right)

The UHF connector is ideally suited for use in the HF spectrum and below. The SO-239 is the connector you nearly always find on the back of any piece of equipment designed for use at HF frequencies. It is also often found on radios in the VHF frequency range.

There is a lot of misunderstanding about the UHF connector, that it's a poor connector due to its inherent insertion loss, claimed to be as high as a .5 dB. It also been suggested it introduces an impedance bump in the transmission line which is the reason for the claims of high insertion loss. Here's what I believe to be true based on both my experience and my research. Yes I will be expressing an opinion as well as presenting some facts.

I have found that so often the biggest problem with the UHF connector is not so much the connector but the installation of the connector. It is often installed incorrectly and often by inexperience amateurs and more often by amateurs who are trying to save a buck.

I've never understood why many amateurs spend so much time dwelling on which radio to buy or which antenna to install but don't place as much attention to the transmission line and connectors. They will often cut corners by buying poor quality connectors and budget transmission line but go all out for a radio and/or antenna? I was once involved in an antenna installation where no expense was spared on the antenna, radio, tower and rotor. The total expense was several thousands of dollars, but they used $2 connectors from Amazon and bargain basement coax. Remember, your station is only as good as its weakest link.

The biggest complaints I hear are:

- It can’t handle high power, (FALSE). It’s claimed that 1 kW can cause the PL-259 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. However the UHF connector has an oversized center pin that can tolerate high steady state RF currents. When compared to other connectors such as the N-Type connectors the PL-259 pin is quite large. If the failure occurs at the UHF connector it’s almost always due to a flawed installation such as a poor solder joint or moisture penetrating into the cable or connector or a loose connector.

- It has a high insertion loss (TRUE & FALSE). This is partially true. At HF frequencies the amount of loss is hardly measurable. The guy on the other end of your QSO, even if it’s low signal type communication such as in the case of FT8, the station at the far end of your signal would not be able to tell the difference if you had two PL-259 connectors between you and your antenna or ten. However at UHF frequencies and above insertion loss can have a measurable impact. This is why the use of a UHF connector at UHF and above is never recommend.

- The UHF connection does not have the same impedance as 50 ohm cable. (TRUE, but) The typical UHF connector has a 30 to 40 ohm impedance for the length of the connector which is around one inch. At HF frequencies this is a non-issue. This does start to become an issue as frequency goes up and becomes a significant issue at frequencies above 1 GHz. This is another reason that the UHF connector is never recommended for UHF and above and at VHF not necessarily the best choice if doing weak signal work such as EME.

- The PL-259 is not water proof. (TRUE). This is true and one of the biggest issues I have with the PL-259. However this can be overcome following a best practices approach to sealing out the elements. See the section on *Weather Sealing the PL-259* on page 32.

- Lack of a way to secure the collar (TRUE). In other words the metal collar can come loose because there is no way to secure it. I have seen this at several installations where the PL-259 had come loose, so loose it was practically falling out of the SO-239. One case in particular was at a local repeater site. We knew there was an issue, which was the reason for our visit to the site initially. While in the process of replacing the transmission line we discovered the loose PL-259 connector at the junction of the antenna and the transmission line. We still replaced the transmission line anyway. See *Weather Sealing the PL-259* on page 32.

- The quality of PL-259 connectors can vary greatly. (TRUE). This is absolutely true, so much so the next section talks specifically about that issue.

Not All PL-259 Connectors Are Equal

The UHF connector is actually a very good connector if one uses a high quality connector that is installed correctly and properly sealed from the weather.   There are significant differences in the quality of PL-259's on the market today. Below are three examples starting with a low quality (junk) connector, a better connector, and what many feel is the best PL-259 on the market.

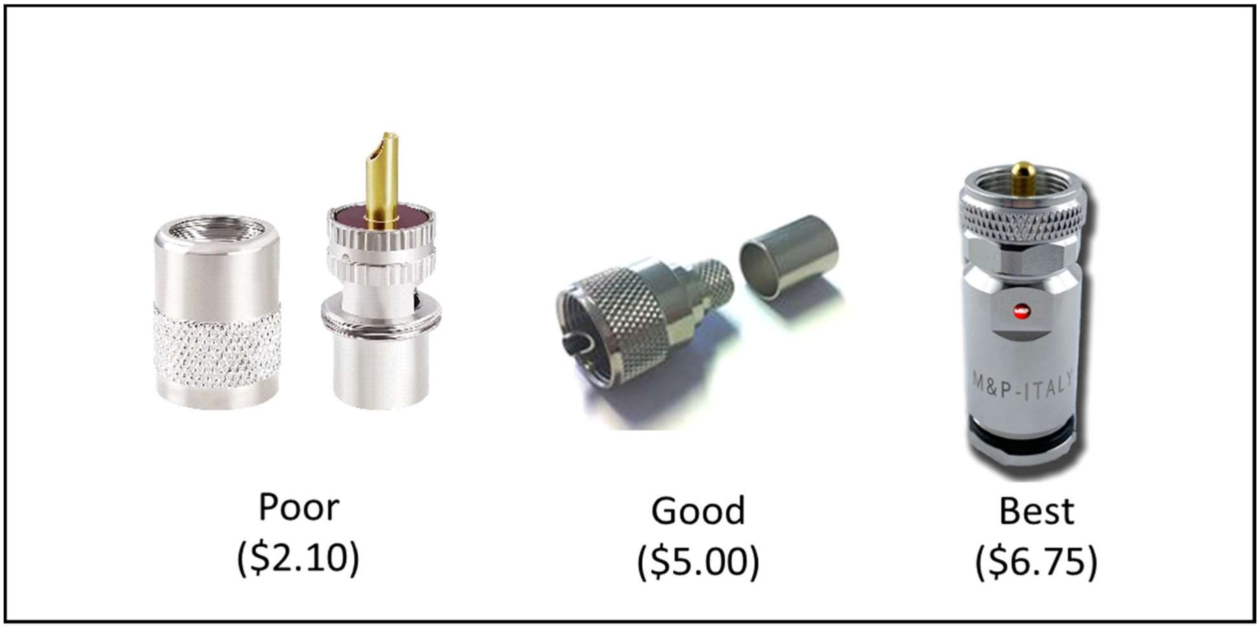

Figure 10: Three Grades of PL-259 Connectors. Prices are as of October 2022.

Poor: This is the typical connector you get from Amazon. There are several issues with this connector. The first is the poor quality of the machining. If you have ever held one of these in your hand you will notice right away the loose fitting collar. It may also have improperly sized parts such as the center pin, which might be too big or too small. The second issue is the Bakelite insulator. In other cases they may use a plastic insulator that has a low melting point. The other issue are the large rectangular windows where the solder is applied to the braided shield.   With this connector it can be difficult to get a consistent connection between the braided shield and the connector. What I often see are big globs of solder with cold solder joints. This connector also allows more heat to get to the dielectric when soldering the braid to the connector due to the high heat necessary to get a good joint coupled with a lack of heat absorbing metal. Another issue with this connector is the use of cheap plating. This becomes very apparent if you have ever seen one of these connectors after prolonged exposure to weather. I've seen more issues with this connector than any other PL-259 I've worked with. I never recommend these cheap Chinese made PL-259 that so often come from Amazon. Unfortunately many new amateurs and even a few experience ones buy these connectors because they think there is little difference in PL-259's and consequently are driven solely by differences in price.

Good: The next connector I consider to be a very good connector that I recommend for the amateur on a budget. The connector pictured in Figure 10 comes from HRO (*LP UHF-03T-TSS*). The machining is excellent. The connector uses Teflon insulation between the center pin and the outside of the connector. The pin and body are silver plated which provides excellent conductivity and a very good surface for soldering. The other thing to note is this connector is a crimp on connector, meaning the center conductor is soldered to the center conductor of coaxial cable but the braided shield is crimped to the connector. This results in a consistent connection between the braid and the connector that will last for years provided that it is properly sealed from the weather. That consistent connection between the braided shield and the connector is the reason why this connector shows little loss in testing as compared to the poorer quality connector. The other factor is the dielectric will not be compromised due to the high heat when soldering the connector simply because the braid is not soldered. I also take extra precautions to protect the dielectric from heat by using a small clip-on heat sink at the base of center pin when soldering this type of connector.

Best: By far the best PL-259 on the market today is the Messi & Paoloni PL-259. Its construction is very similar to Heliax connectors. This connector is weather sealed and clamps tightly around the outer jacket and the coaxial braid. The way the center pin is soldered on is exactly the same as for N-Type connectors where the solder is applied through a small hole at the base of the center pin. This makes for a consistent solder fill with no air gaps between the center conductor and the center pin. This connector is as close as you can get to a connector that has the same characteristics as the N-Type connectors. I hate to sound like a commercial for this connector but it really is the best PL-259 on the market. Messi & Paoloni will be only too happy to share their impressive test results. The only downside to this connector is the cost. This is the connector I would recommend for the amateur that wants the ultimate connector to minimize insertion loss, minimize ambient RF noise leakage and maximizes power handling and weather protection. I would highly recommend this connector for your 70 cm UHF antenna system rather than the PL-259/SO-239 connectors.

Other UHF Accessories

Along with the PL-259 and SO-239 there are number of other items that often come in handy. They include 90° adapter, various length of barrel connectors and a number of adapters that allow for adapting the PL-259 to other connectors such as N-Type, BNC, and SMA. I would note that the 90° PL-259 adapter has the highest loss of all the PL-259 associated adapters at around .21 dB. For comparison a typical barrel connector has an insertion loss of .12 dB[13].

[13] See: https://www.clooms.com/rf-cable-loss-calculators/#:~:text=CLF%20is%20the%20connector%20loss%20factor%20which%20is,of%20resistive%20loss%2C%20dielectric%20loss%2C%20and%20connector%20loss.

Here again you need to be aware that not all these adapters are equal. Of particular note is the 90° connectors. I have on several occasions tracked down transmission line issue to a faulty 90° connector. In every case they were connectors that came from Amazon. So again, buyer beware.

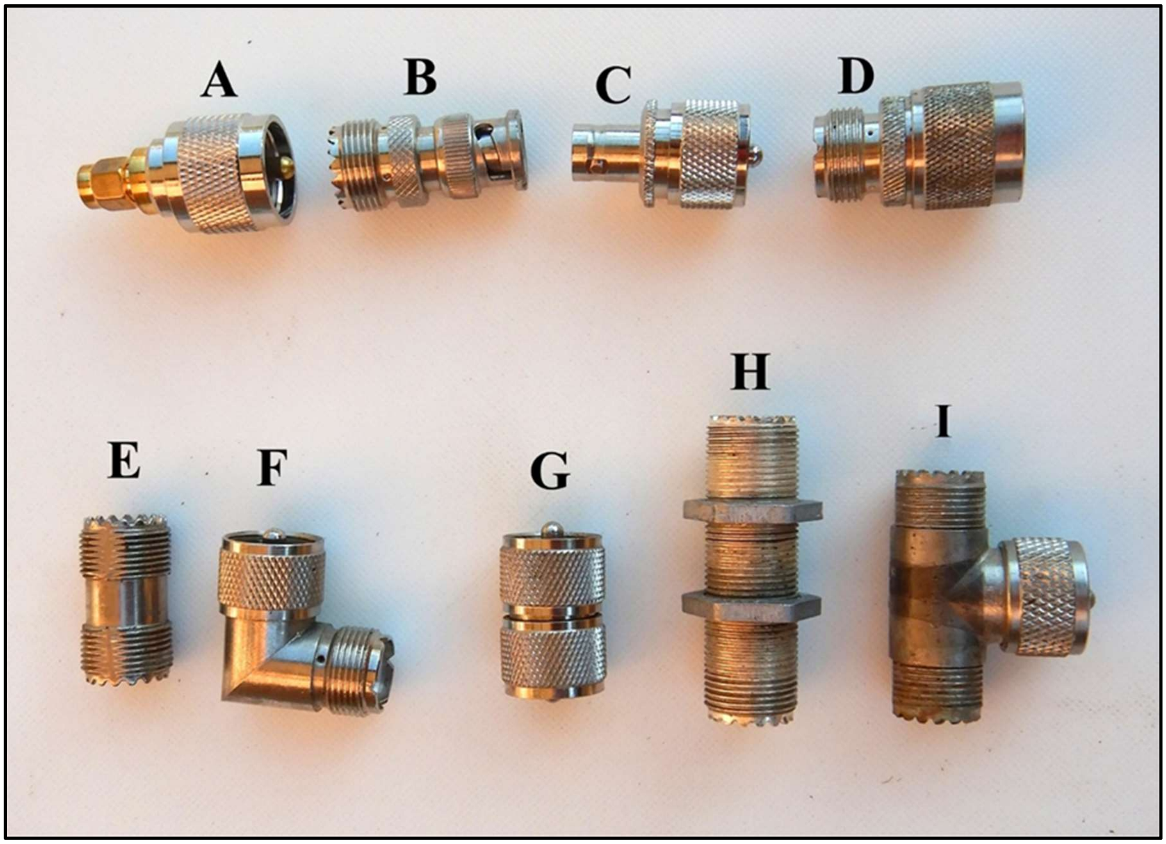

Figure 11: Various UHF Fittings and Adaptors

A: SMA to UHF	B, C: BNC to UHF	D: N-Type to UHF
E: Barrel Connector	F: 90° Connector	G: Male to Male
H: Extended Barrel	I: T Connector (aka: splitter)	

Solder or Crimp?

This is an often debated question. After years of building cables I came to the conclusion that I much preferred crimping over soldering. To be clear I'm not talking about crimping the center pin, those I always solder. What I'm referring to is attaching the braided shield to the connector. After tearing apart more connectors than I can remember and troubleshooting intermittent antenna issues over the years I have become a believer in crimping.

There are several disadvantages to soldering. The soldering process generates heat in the coaxial cable. The center pin is usually not the issue and can be easily mitigated by using a heat sink. But soldering the braided shield to the connector is where problem is most often seen. In so many cases I've seen either too much heat which ends up melting the dielectric or not enough heat which results in a cold solder joint and in nearly all cases the soldering is inconsistent.

The heat has the potential to cause problems, especially when the temperature rises above the operational limits of the dielectric in both the coaxial cable and the insulator material inside the PL-259.

"Cold" solder joints can result if the solder does not completely melt. This creates a rough, uneven, or lumpy surface, resulting in an unreliable bond which can be difficult to spot. The issue is that trouble may not appear initially but over time problems can arise such as intermittent high SWR with a change of weather. In addition cracks may develop over time and cause additional intermittent issues. Also but less often seen soldered connections are more sensitive to both corrosion and vibration, which can be especially problematic for connectors used outdoors or in harsh conditions such is often encountered in automobile and marine applications.

The final issue is the soldering process is also more time-consuming than the crimping method. And as mentioned above soldering can create problems with both quality and reliability of the connection if not performed correctly. And a final potential issue is if a low quality solder material is used the soldered connection may degrade over time and can cause the connection to ultimately fail.

The only down side I see to crimping is the crimping tool itself can be rather expensive. Other than that the tools are exactly the same regardless if you're soldering or crimping.

Mounting a PL-259 Connector

There are lot of good videos about installing PL-259 connectors. In this section I'm going to reference a particular YouTube video but I'm going to augment it with some comments. At this point I'm going to ask you to watch Dave Kessler's video on mounting PL-259 but I want you to pause at three different points in the video. Here's the link to his video:

https://www.youtube.com/watch?v=IbKMiteF0_o

You will note in this video he is installing a PL-259 on a piece of RG-8X. Regardless if it's RG-8X or an RG-8 type the process is for the most part exactly the same.

At 2:40 stop the video: At this point slide a 3 inch length of the appropriate diameter marine grade heat-shrink over the end of the cable. For RG-8 type coaxial use 1/2 inch heat-shrink, for RG-8X use 3/8 diameter heat-shrink. Next slide the threaded collar over the end of the cable.

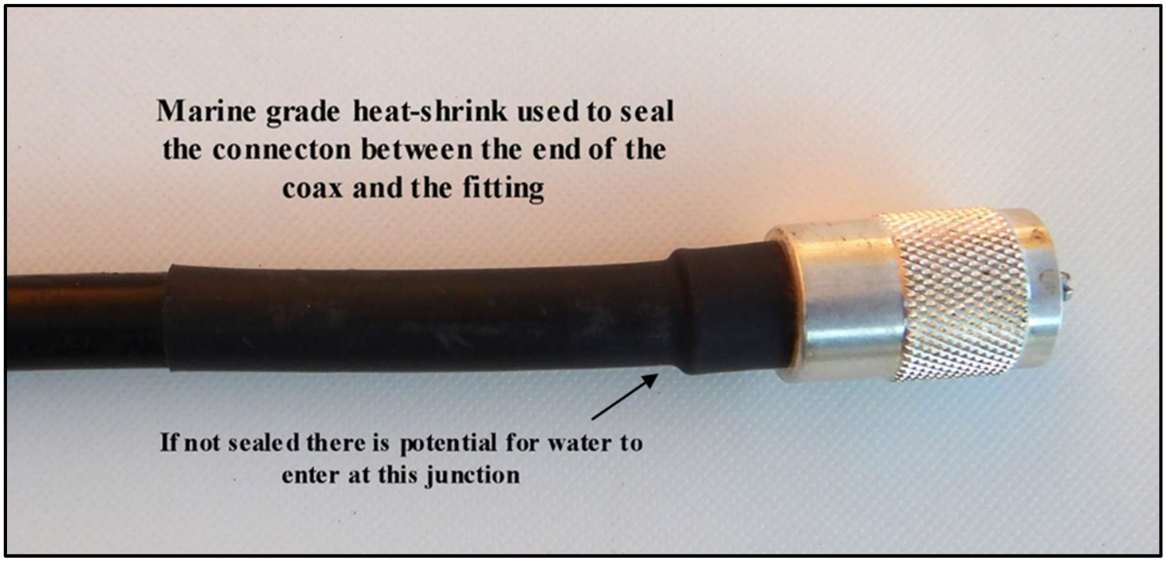

Figure 12: Install heat-shrink to seal the connection between the jacket and the fitting

At 3:50 stop the video: At this point I use a can of air to blow away any loose metal such as small bits of wires from the braid and if using coax with a foil shield any loose bits of the foil. Quite often if you inspect the end of the dielectric after cutting and trimming you will see small bits of loose metal left over from the cutting and trimming process. Using a can of air blow away any bits of metal or other debris. You want an absolutely clean uncontaminated dielectric end. Always inspect the end closely to ensure the dielectric is clean. You will note in Figure 13 a small bit of the shield is visible at the end of the dielectric. If I had not clear this before soldering on the connector the assembly may have failed in testing.

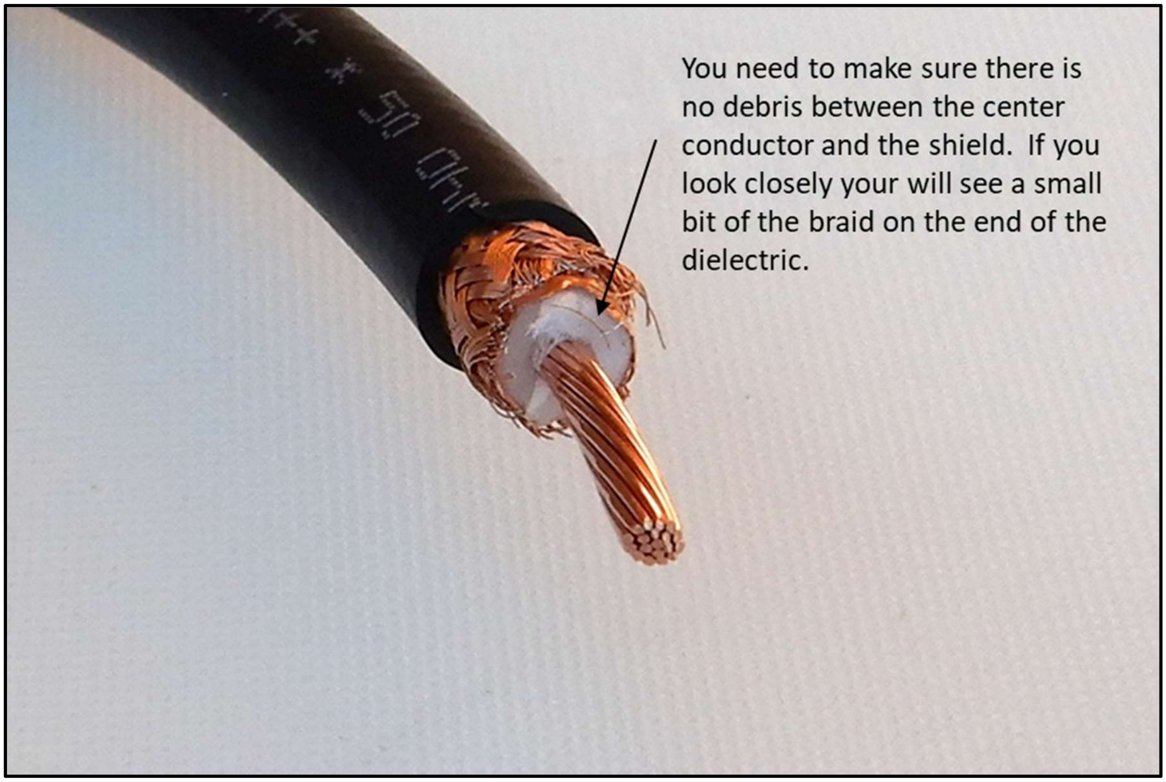

Figure 13: Be sure to clear the end of the dielectric of any metal debris

At 7:30 stop the video: This is the point where he is getting ready to solder the center conductor to the center pin. At this point I attach a clip-on heat sink at the base of the center pin.

This will help to keep the heat from reaching the dielectric while at the same time allowing for a good soldering of the pin and center conductor together.

Figure 14: Clip-on Heat Sink[14]

Some other notes about doing your own connectors: There are several tools that are critical to doing it right. In Dave's video he uses a very nice tool set that comes in a kit from DX Engineering. I was able to get everything I needed locally except the soldering iron.

- A really good pair of scissors. I use a pair made by Klein and have a second pair from Messi & Paoloni.
- A small very sharp razor knife with replaceable blades.
- A sharp pointed tool for combing the shield when called for and for removing small bits of the braid from the dielectric.
- A can of air or a small paint brush
- A pair of sharp coaxial cable cutters. I use two sizes, one for RG-400 and RG-8X and a larger pair for larger RG-8 type coaxial. I got mine at Harbor Freight. Do Not use side cut pliers, also known as dykes. For Heliax I use a small hacksaw.
- A good soldering station that can get up to 900 degrees.
- A clamp-on heat sink see Figure 14
- A coaxial crimping tool that has dies sized for the coaxial cable you are using.
- A small file. This is used for cleaning up any loose solder or sharp wires that may be protruding from the center pin beyond the solder.
- 2 Pairs of pliers for tightening adapter inserts
- Electrical crimping/wire stripping pliers.
- Optional: A pair of 3X or stronger reading classes.

[14] There are many places where you can purchase this item. Just search for "Clip-on heat sink for soldering." The entire clip is a little over two inches long.

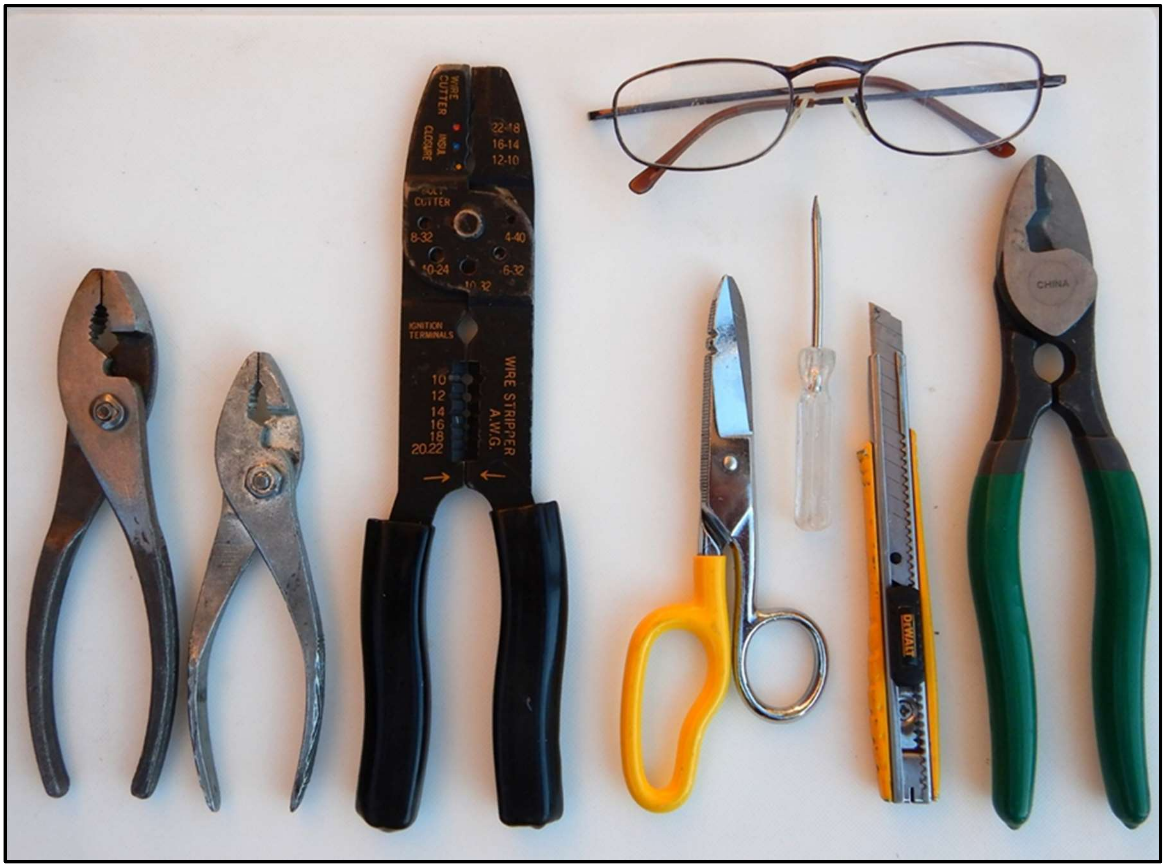

Figure 15: This is my tool tray when mounting connectors. Not shown is a small vice, a file, larger cable cutters, crimping tool, soldering station, clip-on small heat sink for soldering.

Weather Sealing the PL-259

There are lot of good videos on installing PL-259 connectors. However I've not found any that describe how to prepare the connector once the soldering is done and you're ready to connect it to the antenna. The extra step I do is when using a connector such as the one I refer to as the "better" connector is I seal the junction of the coaxial cable to the connector with a good grade of heat shrink 3 to 4 inches long. The intention is to minimize the ability for moisture to enter the coaxial cable between the end of the jacket and the connector (see Figure 12). However if you are going to do this you have to decide in advance because you need to slide the heat-shrink over the coaxial cable before you start the soldering process.

To seal the connector against weather I first fill the end of the PL-259 with small amount of dielectric grease. Use enough to fill any air gaps but not so much that it oozes out as you tighten the collar. Next I snug up the connector with a pair of pliers. Note that I said snug up. What I have seen is over time the constant expansion and contraction due to changes in air temperature will cause the connector to come loose. The connection needs to be slightly tighter than finger tight but not so tight that it distorts the shape of the screw on collar or worse yet, strips the threads. I then wipe down the area to be taped over with denatured alcohol or a favorite of high school kids, EverClear (200 proof straight grain alcohol). This will clean off any extra dielectric grease or other oils and contaminates. This will help the tape to better stick to the coaxial cable and metal connector.

Next I cover the entire area with two layers of a good quality self-vulcanizing electrical tape. After I've applied two layers of this tape I stretch it until it breaks in order to get a tight self-sealing fit. A good example of this type of tape is Scotch 2242 rubber splicing tape. You can usually get this at building centers such as Lowes and Home Depot.

Over the self-vulcanizing tape I wrap two layers of a top quality vinyl electrical tape such as Scotch Super 88. The reason for this second layer is to protect from UV and any possible abrasion or wear. I like the super 88 due to its extra thickness. I do not recommend the tape one often finds at places like Harbor Freight.

One final note, NEVER break the vinyl tape by stretching it to its breaking point. When done wrapping the connection cut the tape cleanly with a razor knife or sharp scissors leaving about two inches. Complete the final wraps by just pressing the remaining loose end of the tape into place around the joint and laying it on top of the existing layer of tape. Do not wrap it over the PVC cover. What will happen if you stretch the tape is over a short period of time the portion of the tape that was stretch will unravel and you will have an inch or two of tape flapping in the wind.

The N-Type Connector

Now that we have looked at the most common connector we use let's turn our attention to the second most common connector in use in amateur radio, the N-Type connector.

The N-Type connector was developed in the 1940 by Paul Neill of Bell Laboratories. It's from Pauls' last name that we get the name of this connector, simply the "N" type connector. Mr. Neill was involved in developing many of the RF connectors in use today, he contributed to the development of the BNC and the TNC connectors as well as the N-Type connector.

As the United States entered the war the UHF connector was the primary connector used on practically all coaxial cable. But the development of radar require a better connector due to the higher frequencies that were typical of radar. Originally, the connector was designed to carry signals at frequencies up to 1 GHz in military applications, but today's common N connector easily handles frequencies up to 11 GHz. More recent enhancements to the design by Julius Botka at Hewlett Packard have pushed this to 18 GHz.

There are two types of N connectors, the 50 ohm version which is used exclusively for RF applications and the other a 75 ohm version used in the video industry. At first glance they appear to be interchangeable but in fact they are not. Consequently when buying N-Type connectors make sure you are getting the 50 ohm version. The differences is in the size of the pin and socket of the two connectors. The 75 ohm version has a thinner pin, so it will fit into the 50 ohm version but the connection may be intermittent. The 50 ohm version will slip into the 75 ohm connector but it will stretch the socket making it unreliable if a 75 ohm version is ever plugged into the stretch socket.

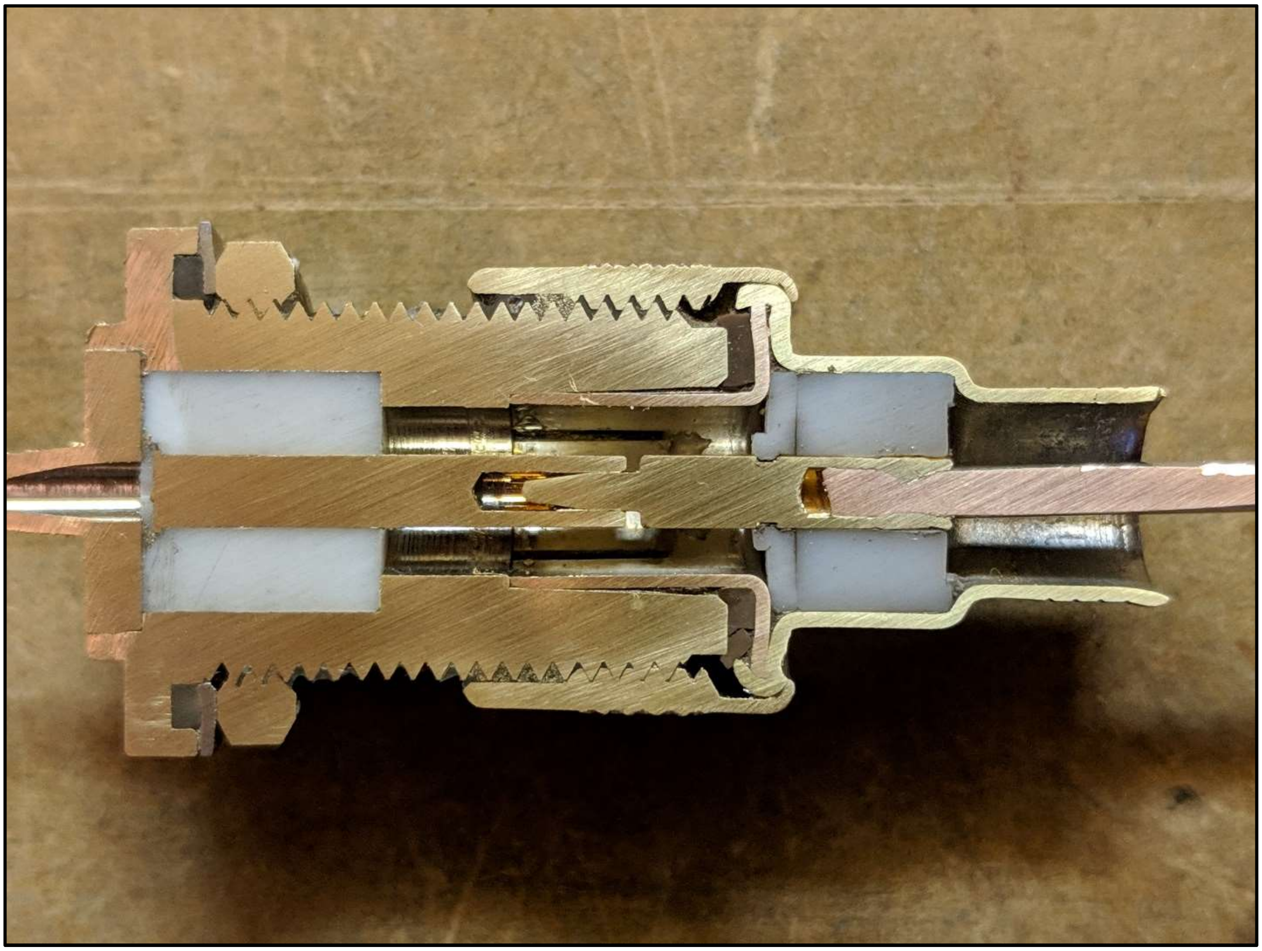

Figure 16: Cross section of the N Connector

There are several advantages to the N-Type connector which make it idea for use in the UHF band and above. It is considered a constant impedance connector unlike the UHF connector. At HF the impedance bump in the HF connector is not a concern but as frequencies increase into the UHF range it does become a concern. That is why you will almost always see an N-Type connector on equipment that will be used exclusively for UHF and above.

Many of our radios today are designed for the VHF and UHF band and consequently the manufactures install SO-239 sockets on the back of our radios, the FTM-400 being just one of many examples. For 2 meters the UHF socket works fine, for 70 cm and above it's not the best choice. Some manufactures offer a choice between a UHF or N-Type connector. Given the superiority of the N-Type connector I would recommend you consider specifying the N-type connector when it's an option. Some of you may be thinking that if you have to install an adapter then what's the point? Don't install an adapter. On the radio end of the cable you install the appropriate connector and at the antenna end install the N-Type fitting. N-Type fittings are not that difficult to install and in fact I find the N-type easier to mount than the typical PL-259, but we will talk more about that later.

The other advantages of the N-Type fitting is they are water proof when done properly and due to the compression design the threaded collar will not come loose over time.

Different Type of N-Type fittings

There are many different types of N-Type fitting available. There are three that I use:

1. Fitting design to use a sleeve adapter. I like this kind for building patch cables. I usually make patch cables using either RG-400 or RG-8X. By using an adapter sleeve I can order the just one fitting that will work regardless if I'm using RG-400 or RG-8X. All I need to do is make sure I have adapters for both on hand. The downside is this fitting is its not weather proof, consequently I never use it for anything but patch cables that will be used inside the shack or repeater shelter.

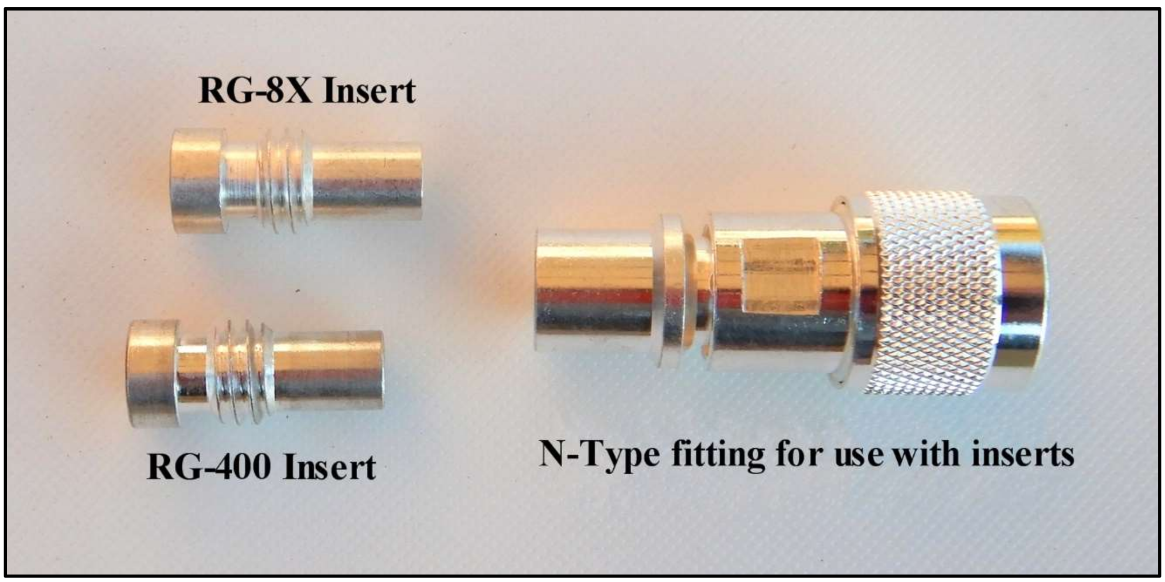

Figure 17: N-Type using adapter sleeves

2. Crimp-on N-Type. This is like any other crimp type fitting. The only down side is the fitting is not weather proof so it's necessary to seal the joint between the jacket and the metal fitting using marine grade heat-shrink.

Figure 18: N-Type Crimp Type Fitting

3. Compression fitting. This is by far the best fitting due to the use of compression for sealing the connection between the jacket and the fitting and it uses compression to secure the braided shield. This fitting is very much like the fittings we use on Heliax.

Figure 19: Compression N-Type Fitting

Like the popular UHF connector there are a host of other N-Type fittings available including adapters for UHF and BNC fittings. There are also barrel connectors, male to male, female to female connectors and of course 90° connectors. One final point I want to bring up is the quality of these connectors. As a rule I have found the N-Type connectors to be fairly consistent in both quality and price. They do run a few dollars more than UHF connectors with the compression fitting being the most expensive.

Mounting the N-Type Fitting

When it comes to mounting the N-Type fitting I have found it to be no more difficult or time consuming than mounting UHF fittings. The process is exactly the same for all three mounting types: sleeve, crimp, and compression. The only real difference is the cutting dimensions and even then they don't vary that much from the PL-259. At first the N-Type may seem intimidating but I assure you they are no harder than the PL-259.

I'll not go deeper into how to mount the N-Type connector given the number of good and a few not so good videos on YouTube. However I would give the same cautions as I gave for mounting PL-259's:

- Use marine grade heat-shrink to cover the joint between the coaxial jacket and the metal fitting. See Figure 12
- Make sure you clean away any metal debris that may be on the end of the coax between the braid and the center conductor. See Figure 13
- Here's the exception. I do not use a heat-sink at the base of the pin. Usually the amount of heat that is transferred to the dielectric is minimal due to the nature of the joint. You are applying focused heat for a very short duration. Only enough heat to see the solder sucked into the small hole at the base of the pin. This usually only requires a second or two of heat on the pin. If it takes longer your iron is not hot enough.

A Brief Look at a Few Other Connectors

There are a number of other connectors you may hear mentioned but it's unlikely you will use any of them in your ham station. The only exceptions I can think of are some of the audio and power connectors but because they are not associated with RF we will not touch on them here. There are however a few more RF connectors we should include. They are rarely used in the typical ham shack but you may hear them mentioned from time to time.

SMA Connector

The SMA connector is a very small connector typically use on small devices such and micro VNA's and micro spectrum analyzers. There are also a few SDR devices that use the SMA connector. Perhaps the most common use is on handheld radios. It's the fitting of choice for many of today's small hand held radios such as the BaoFeng, Yaesu and several other brands of radios. Like virtually all the other connectors the SMA comes in two types, male and female. If you order an aftermarket antenna for your hand held make sure you order the correct gender. For example the BaoFeng uses a female gender antenna and the Yaesu the male gender antenna.

Figure 20: SMA Connector: The upper connector is male, the lower female.

The BNC Connector

You almost don't see the BNC connector used much anymore. It is a close relative to the N-Type connectors which is no surprise because both the N-Type and BNC were designed by Paul Neill. The BNC, like the N-Type is also considered a constant impedance connector. It is a very good connector. The biggest drawback to this connector is it's not weather proof so it is almost never used outdoors. Some say the BNC connector can't handle a lot of power. When compared to the N-Type fitting. In fairness the BNC it is more than adequate for all but the most extreme ham radio applications. The other positive feature is the positive lock built into the male BNC connector which locks around the ears on the female connector. The BNC connector will never accidently come undone. Where you often see the BNC connector use is on interconnect cables (patch cables) between a repeater and the duplexer cavities. You will also sometimes see it used between the radio and RF amplifier and preamplifier and some type of measuring equipment. However, outside of repeater installations you will rarely see the BNC connector use in ham radio, however it is widely used in the commercial sector.

As far as mounting the BNC connector it too is a fairly easy connector to work with. I personally prefer the Amphenol RF 31-202 version of this connector because it uses a compression design like many of the N-Type connectors but it is also available in a crimp on style.

One interesting side note about the BNC connector. Back in the early days of 10Base5 Ethernet it ran on 50 ohm coaxial cable and used BNC connectors. During that time BNC connectors was in wide spread use. It was available in a solderless screw on version that could be installed in less than a minute. As the Ethernet standard was improved coaxial cable was replaced by twisted pair cable using the RJ45 connectors.

Figure 21: BNC Connector. Top is male and the bottom female

The F Connector

I have never seen the F connector used in ham radio. However it is extensively used in the cable TV and Satellite TV industry. The Internet connection to your home is most likely also using F type connectors. And your TV most likely has an F Type connector on the back. I'm not going to say much more about this connector simply because we don't use it in amateur radio. However because it's so popular outside of ham radio I felt it worth mentioning. And no, you should not use this connector to connect to any antennas that you intend to transmit on.

Figure 22: F Connector

Building for Your Station – Making Good Decisions

Now that we have spent some time educating ourselves about coaxial cable and connectors we are now in a good position to make informed decisions as to patch cables and transmission lines for our stations. If we have learned nothing we should at least understand how important the selection of the type of coaxial cable is to setting up a good station.

Almost all of us are constrained in the selection of equipment we decide to include in our station. These decisions are often tempered by budget, space, and needs of our families, neighbors and a number of other factors. For that reason we will offer up several different options.

Inside the Shack (HF, VHF, UHF)

If you have the need to interconnect equipment such as connecting from your radio to an antenna tuner, an antenna switch or other equipment the use of smaller coaxial cable is often more than adequate. For most installation I recommend either a good quality RG-8X or RG-400 with RG-400 being the far better choice.

RG-400 has a dual braided shield made of silver coated copper and is referred to as high-isolation coaxial cable. It keeps the RF that is flowing inside the coaxial inside the cable and the ambient RF outside of the cable. The only down side is the cost. When last checked in October 2022 it was about $5.50 a foot where a good quality RG-8X was running about 48¢ a foot. Note that RG-400 is rated at 2.75 KW at 30 MHz and 670 watts at 450 MHz, which is more than enough power handling capability for amateur radio applications. Note that RG-400 has a power handling capability that is even higher than most RG-8 cables. For example typical RG-8 is rated at 2 KW at 30 MHz. DXE-400 Max is rated at slightly more than RG-400 at 2.8 KW at 30 MHz.

Figure 23: RG-400 patch cable fitted with PL-259 ends

Losses with RG-400 and RG-8X will be higher than with most RG-8 type cables but given the overall short lengths of patch cables typically used the losses are not worth mentioning at HF or even UHF for that matter.

Regarding connectors that is nearly always dictated by the connectors on the station equipment. In amateur radio that almost always means the use of UHF style connectors, PL-259s. The rare exception is equipment that has a dedicated UHF antenna port. In those cases that is almost always an N-Type connector. Wherever possible stick with N-Type connectors. It is by far the better connector at UHF frequencies and above. Don't be tempted to put UHF adapters on them simply because you don't have any patch cables with N-Type connectors. As mentioned previously they are not that hard to build.

What about other options for patch cables you may be wondering? Yes you can use RG-58 or even RG-8. However I would never suggest the use of RG-58. It is intended for use in the CB radio market so let it stay in that realm. Why? Most RG-58 is built for the CB folks and consequently most of it is junk. My biggest complaint is the shielding, which tends to not provide the same coverage as a good quality RG-8X which usually has a 95% to 97% coverage.

What about RG-8? You can also use RG-8 for patch cables however it tends to be fairly stiff and for the most part would be overkill. If it's a good quality cable with a 96%-98% coverage, RG-8 makes a very good patch cable.

If I were to use an RG-8 type cable M&P HyperFlex would be my second choice. It has very good shielding and very low attenuation. My third choice would be RG-214, which is a double shielded RG-8 style cable but has slightly more loss than the M&P, but less loss than RG-400. However, it is very expensive at nearly $8 per foot and is also fairly stiff.

If shielding and isolation is your higher priority I would recommend RG-400. If low loss is your higher priority I would recommend the M&P HyperFlex.

From the Shack to the Antenna (HF)

If you are connecting to an HF antenna I recommend that you only use an RG-8 type transmission line. Some examples include RG-8/U foam coaxial cable from Davis, Times, or Belden. DX Engineering also offers DXE-400 Max which is a high quality RG-8 foam type cable. All of these cables are moderately priced at around $1.15 - $1.20 per foot. For HF installation up to about 150’ any of these cables is a good choice. If you have a long run of over 100’ you might consider M&P HyperFlex 10 or M&P UltraFlex 10. This cable is almost double the price of RG-8/U or DXE-400 MAX but it does offer slightly lower loss at 30 MHz and has better shielding.

Also make sure that the coaxial cable is UV resistant. If you are going to bury any part of it make sure that it’s rated for direct bury.

I do not recommend anything smaller than .400 diameter cable (RG-8 type) and would not recommend RG-8X except for very short runs that are not going to be exposed to the weather or in situations with a lot of ambient RF, attics for example.

I would also stay away from any bargain basement cable or any cable that is manufactured in China unless the vendor will certify that it is what it says it is. With vendors like Amazon you can never be sure what you’re getting, this is especially so with LMR-400. I recommend that you only buy cable from vendors who cater to the amateur market or the RF related industry.

There is always a lot of discussion about LMR-400 and is considered by many to be the best RG-8 type coaxial cable on the market today. After doing some comparisons it appears that LMR-400 is fairly average when it comes to specifications yet is higher in price that most other RG-8 type cables, only the M&P cable seems to be more expensive, but the M&P cable also has better numbers than the LMR-400. Due to its popularity and “mystic” it is often counterfeited.

The other issue with LMR-400 is that true LMR-400 has a solid copper clad center conductor just slightly bigger than 10 gauge wire. Generally speaking any cable with a solid center wire is going to be fairly stiff and is prone to breaking due to wire fatigue if exposed to repeated bending and flexing. LMR-400 should only be used in installations where the cable will be fixed in position such as when run inside conduit. It is expressly NOT recommended in installations where some degree of flexibility is necessary. Examples can include steerable antennas, installation between two fixed buildings where there is some degree of movement between the buildings or between a tower that can move in the wind and solid fixture.

From the Shack to the Antenna (VHF/UHF)

As we move up in frequency the selection of your transmission line becomes even more important. The reason for that is due almost entirely to attenuation in the transmission line or to put it another way, loss in the transmission line. Let me offer some examples.

At 448.6 MHz, which is the output frequency of one of our local repeaters the loss across a 100'[15] length of RG-8X is around 8.6 DB. Remember that every 3 DB equals a doubling or halving of power. So at 8.6 DB with 50 watts leaving the radio only 12.5 watts makes it to the antenna. The rest is lost as heat in the cable. On the receive side it's just as bad. Whatever signal the antenna received only 25% of that signal makes it to the receiver. And if there is any kind of mismatch (high SWR) between the antenna and the transmission line, the problem is made even worse.

By selecting a good quality RG-8 type cable with a foam dielectric the loss at 450 MHz will be around 4.5 dB, with DXE-400 Max around 3.3 dB and with M&P HyperFlex 10, it's reduced to 2.8 dB. And with ½ Heliax the loss will be 1.45 dB. That's a considerable improvement over 8.6 DB loss for RG-8X.

Of course with each improvement in loss there comes a cost. For example RG-8X runs about 48¢ a foot. Typical RG-8/U about $1.13, DXE-400 Max $1.18, HyperFlex 10 about $2, and Andrews ½ Heliax averages about $3.00[16] per foot. I should note the connectors for Heliax are fairly expensive at about $25 per connector. Although you don't need a special tool to mount these connectors it is strongly recommended. The tool runs around $300[17].

Another consideration when considering your transmission line for use in the higher frequencies ranges is the shielding. One of the reasons we see Heliax used in repeater sites, besides its low loss specifications, is the shielding it provides. Heliax has a thick solid corrugated copper shield that provides a maximum amount of shielding. In repeater sites this is important for several reasons. First, at the typical mountain top repeater site, such as Mt. Ogden, there is a lot of equipment and nearly all of it intended to radiate RF. By properly grounding the equipment and the shield you minimize the amount of RF that can get into the transmission line from external sources. This helps to protect us from them and it protects them from us. Second, for reasons that are out of scope of this paper when a transmission line is carrying both the received and transmitted signals at the same time there can be some undesired interaction. Of course in our home stations that's not an issue, we are never receiving and transmitting at the same time. Regardless shielding should be an important consideration. Let's look again at our four different cable options.

Standard RG-8/U typically has a single braided shield covering the dielectric. The typical coverage is between 95% to 97%. DXE 400 Max has an aluminum foil shield surrounding the dielectric and is covered with a tinned copper braid with a 95% to 96% covering. HyperFlex 10 has copper foil surrounding the dielectric that is then covered with a copper braided shield rated at 85% coverage. Both the DXE-400 Max and HypeFlex provide 100% shielding. The difference is DXE-400 Max uses an aluminum covering and HyperFlex uses all copper shielding. Note that copper is a slightly better conductor (lower loss) than aluminum. Aluminum has 61%

[15] You can calculate loss for a particular length of cable by multiplying the DB by the length by the percentage of 100' your length. For example for 50' length of RG-8xe multiply the attenuation by 50%. So a 50' length of RG-8X at 450 MHz would have a loss of .5 x 8.6 = 4.3 DB
[16] All prices noted are as of October 2022.
[17] We do have people in the club that can do these ends for you and will only charge you for the connectors.

less conductivity than copper[18]. Heliax as mentioned has a thick corrugated copper tube surrounding the foam dielectric. This corrugated construction maximizes the surface area of the shielding that in turn provides the maximum amount of shielding possible.

Summary

In selecting your transmission line consider the length of the cable run and your budget and make the right choice for you. Of course at frequencies about 60 MHz I would always recommend ½ Heliax for runs over 50' or so. I also recognize that not everyone can afford Heliax or has the expertise and tools to mount the connectors so the obvious next best choice would be HyperFlex 10. But even that may be a bit steep for most people's pocketbooks. As I said, make the best choice for you based on your unique constraints.

One other big consideration, be wary where you buy your coaxial cable. Coaxial cable has become one of the most heavily counterfeited products on the market today. Given my experience with Amazon I would never buy coaxial cable from Amazon, simply because there is no guarantee of what you are getting. It may be sold as LMR-400 but the chance that it really is, especially, if it's has a bargain basement price is most likely not LMR-400.

What about the cable you might buy at a ham fest or swam meet? Again I would say buyer beware. You never know what you are getting. It could be a length of coax that has been outside for years and when you open it up and look inside you will see the shield has turned green with corrosion. Or worse yet if it's LMR-400 the center conductor could be broken somewhere. I would only buy it if the seller guarantees it. And the first thing I would do when I got home is I would put it on a VNA and measure the attenuation and compare it to the manufacturer's specifications.

My strong recommendation is you only buy coaxial cable from a vendor you know and trust and only vendors that specialize in the radio industry or ham radio community like HRO, DX Engineering, GigaParts, and a hand full of others. The key message is only buy coaxial cable from vendors you trust, who will stand by their products and who specialize in the RF market. I would never buy coaxial cable from Amazon. I would also never buy coaxial cable from a company that does not disclose the specifications for their cable.

In doing research for this article I went out to several web sites looking for prices and what information they disclosed about their product. On Amazon they were pushing an LMR-400 clone made by Wilson Amplifiers. Nowhere in the product information did they list ANY specification of the product they were selling. One might ask why, is it because they do not want to tell you for legal reasons or is it they think you are too ill-informed to understand? Either way I would not buy a product simply because they provide no information about the product. Even after visiting the Wilson web site there was only minimal information disclosed. However to their credit they did provide the shielding specification which is something few vendors do.

[18] See: https://en.wikipedia.org/wiki/Electrical_resistivity_and_conductivity

As to connectors, again this choice will be driven by your equipment which in most cases will be a UHF type connector such as the PL-259 connector. But if you have the option to go with and N-Type connection I would encourage you to do so. I have built many cables with N-Type connectors on one end for connecting to the antenna and a PL-259 on the other end for connecting to the radio or other equipment. If possible avoid using adapters.

Conclusion

I know this was a long paper and there was a lot of information provided. My hope is that you got something out of it and that you understand there's a lot more to the simple patch cable and transmission line going to your antenna.   They are important choices that can make a difference. I would also ask that you don't always believe what other hams tell you especially when it's based on anecdotal testimony. Ask questions, ask for references, look at the specifications and don't let price be your final arbitrator. You could end up wasting a lot of time looking for that faulty connector or bad bit of coax. In the end you may find that the money you saved you will pay for in frustration, poor results, and lost operating time. Remember, ham radio is supposed to be fun, dang it, so go have fun!

73,

Gene

(WB7RLX)

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Appendix

RG-400

RG-400 is a high-isolation 50-ohm coaxial cable that is ideal for critical, very low signal level, low noise applications as well as high power capabilities. Its high isolation property is what makes it a popular cable for interconnection (patch) cables for industrial and scientific applications. It is considered an "aerospace" grade when built to the MIL17/128-RG400 specification, which I suspect is one of the reasons for its high cost. Currently RG-400 sells for around $5.49 a foot as of this writing at DX Engineering. On Amazon I was able to find three different prices: $1.48, $2.20, and $4.19 per foot. My question, is the cable you get from Amazon, any of it, made to the MIL17/128-RG400 specification? We have no way of really knowing.

Figure 24: RG-400

RG-400 is the same size as RG-58 and is compatible with N-Type and PL-259 solder type connectors when used with UG-175S reducer. RG-400's distinguishing feature is its double shield and its distinctive semitransparent orange brown color.

It is the perfect cable for interconnecting equipment in the shack. It is capable of handling up 1900 volts. It can be used for HF, VHF, and UHF applications. I highly recommend if for patch cables. However, it's not suitable for long cable runs at VHF and UHF frequencies due to its high loss values of 5.18 dB @ 150 MHz and 9.1 dB @ 450 MHz across 100' length.

Cable Type:	RG-400
Jacket Outside Diameter:	0.195 in.
Jacket Material:	FEP
Center Conductor Gauge:	20 AWG
Center Conductor Material:	Silver plated copper
Center Conductor Construction:	19 strands of 32 AWG

Dielectric Material:	Poly-tetra-fluoro-ethylene (PTFE)[19]
Dielectric Outside Diameter:	0.116 in.
Shield 1 Construction:	Silver plated copper
Shield 2 Construction:	Silver plated copper
Loss Per 100 ft. at 30 MHz:	2.2 dB
Loss Per 100 ft. at 450 MHz:	8.7 dB
Power Rating:	2.75 kW @ 30 MHz
Velocity Factor Percentage:	.695 (69.5%)
UV-Resistant:	Yes
Direct Bury:	No
Price as of Oct 2022:	$5.49 (DX Engineering)

Figure 25: RG-400 Specifications

RG-58

RG-58 is perhaps the first coaxial cable many of us used. It is very popular with the CB crowed and it is perfect for mobile CB applications. Stop by any CB store or roadside truck stop and you will see roles of it for sale. In ham radio we often see it used in mobile installations and as patch cables in the shack. I do question the use of RG-58 due largely to the low quality of the braided shield and the outer jacket which often seems to not do well with long term exposure to UV and road salt. There is good quality RG-58 cable available on the market and I suspect is fine for some ham radio applications. I would never use it as a transmission line running from the shack to an outdoor or even attic antenna even at HF frequencies. I would ask, why use it when something like RG-8X is only a few cents more and would be better choice.

The primary place where we see RG-58 cable used is with mobile antenna mounts. It often comes as a part of the antenna mount. I have installed several of these mounts and have found the coaxial cable to be adequate, however I'm not able to speak to their long term use. I have noted that some manufactures of mobile antenna mounts are now offering RG-8X in place of RG-58. If you have a choice I would encourage you consider the offering that uses RG-8X.

For industrial and scientific applications I have rarely seen RG-58 cable used. Because of its PVC jacket it should not be placed inside of air ducts and ventilation system. For those application you need a cable with a plenum type jacket. It is my opinion that RG-58 is acceptable for use as patch cables but would suggest there are better options for only a few dimes more. For most mobile applications I think its fine to use. But again if you have an option of using a good quality UV resistant RG-8X, I would choose that over RG-58. Also note that some RG-58 has a solid copper center. I would never use a cable with a solid center in applications where there will be a lot of movement in the cable.

[19] Polytetrafluoroethylene (PTFE) is a synthetic fluoropolymer of tetrafluoroethylene that has numerous applications. The commonly known brand name of PTFE-based compositions is Teflon (Trade Mark) by Chemours, a spin-off from DuPont, which originally discovered the compound in 1938.

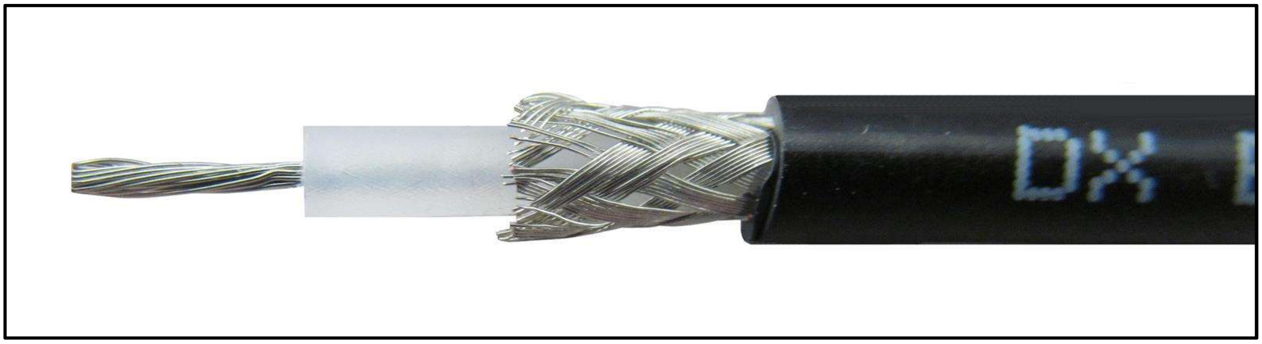

Figure 26: RG-58A/U

Cable Type:	RG-58A/U
Jacket Outside Diameter:	0.195 in.
Jacket Material:	PVC, Type I[20]
Center Conductor Gauge:	20 AWG
Center Conductor Material:	Tinned copper
Center Conductor Construction:	19 strands of 33 AWG
Dielectric Material:	Low density polyethylene[21]
Dielectric Outside Diameter:	0.116 in.
Shield 1 Construction:	Braided, Tinned copper
Shield 1 Percent Coverage:	95-97
Loss Per 100 ft. at 30 MHz:	2.8 dB
Loss Per 100 ft. at 450 MHz:	13.5 dB
Power Rating:	350W @ 30 MHz
Velocity Factor Percentage:	.66 (66%)
UV-Resistant:	Yes
Direct Bury:	No
Price as of Oct 2022:	.49 (DX Engineering)

Figure 27: RG-58A/U. Please note because this cable carries a /U designation the cables specification can vary from manufacture to manufacture.

RG-8

This is by far the largest coaxial type. Typically it's .400 inches (about 3/8") in diameter and made up of the traditional center conductor, and separated from a braided shielding by some type of dielectric and covered with a PVC type jacket. The diversity of construction is mind boggling. Let's start with the center conductor.

Center Conductor: The center conductor can be made of copper or copper clad aluminum. The center conductor can be made up of several stranded wires all twisted together or from a single

[20] Polyvinyl chloride (PVC) is a flexible or rigid material that is chemically nonreactive. PVC offers excellent corrosion and weather resistance. It has a high strength-to-weight ratio and is a good electrical and thermal insulator.
[21] See: https://en.wikipedia.org/wiki/Low-density_polyethylene

solid wire. Even the diameter of the center conductor can vary from #9.5 to slightly larger that #10 wire.

Dielectric: The dielectric material can be just as varied: Polyethylene, Teflon, Air Spaced Polyethylene. The dielectric can also be solid, generally made of polyethylene, or a foam type cable. The foam dielectric has lower loss and a higher velocity factor. The foam dielectric is ideally suited for long runs in HF antenna systems and good for VHF and UHF installations where cable runs are going to be less than about 80 – 90 feet. These are just three types of dielectric material listed in the ARRL Antenna Book for RG-8. There are many more.

Shield: The braids are extremely diverse. There are cables with one braided shield, others that have a foil cover over the dielectric with a braided shield over that. There are other cables that could also be included in the RG-8 category due to their size alone but aren't due to their construction. Belden 8268 (RG-214) has a double braided shield and is not considered to be in the RG-8 family even though it's .425 inches in diameter. Do you see how totally confusing this can be?

Jacket: In the ARRL Antenna book they list the following jacket types for RG-8: Polyethylene and Polyvinyl chloride, Class 1. They also list Polyvinyl chloride, Class 2 and a Polyvinyl chloride, Class 2 N. The class 2 identifies it as having excellent impact, corrosion, and chemical resistance. I'm not sure what advantages it offers over class 1 other than its chemical resistance. The N identifies it's as non-contaminating jacket.

The key thing one should look for if you will be running this cable outside is to make sure that it specifically says that it's UV resistant. Otherwise over time it will develop cracks and allow water to contaminate the shield. The other important consideration, if you are going to bury it without a conduit is to make sure it specifically says that it's rated for direct bury. Not all cables are.

Figure 28: Typical RG-8

Cable Type:	RG-8/U
Jacket Outside Diameter:	0.405 in.
Jacket Material:	PVC, Type I[22]

[22] Polyvinyl chloride (PVC) is a flexible or rigid material that is chemically nonreactive. PVC offers excellent corrosion and weather resistance. It has a high strength-to-weight ratio and is a good electrical and thermal insulator.

Center Conductor Gauge:	11 AWG
Center Conductor Material:	bare copper
Center Conductor Construction:	7 strands of 21 AWG
Dielectric Material:	Gas injected foam polyethylene
Dielectric Outside Diameter:	0.285 in.
Shield 1 Construction:	Braided, bare copper
Shield 1 Percent Coverage:	95-97
Loss Per 100 ft. at 30 MHz:	.9 dB
Loss Per 100 ft. at 450 MHz:	4.6 dB
Power Rating:	2 kW @ 30 MHz
Velocity Factor Percentage:	.81 (81%)
UV-Resistant:	Yes
Direct Bury:	No
Price as of Oct 2022:	$1.13 (DX Engineering)

The specification listed above are for type RG-8 cable. There are many variations of this type of cable that have much lower loss values. For example DXE-400 Max has a loss of .8 dB. Messi & Paoloni HyperFlex 10 and HyperFlex 10 offers an RG-8 equivalent that claims a loss of only.6 dB. I've personally used this cable and found it to be some of the best coaxial cable on the market today. We currently are using a 90' length of HyperFlex for the receive antenna for the 146.90 repeater at the Mount Ogden repeater site.

DXE-400 MAX

This is perhaps DX Engineering most popular cable. It has slightly better numbers than standard RG-8/U and is only a few cents more. I have personally used a lot of this cable and have been pleased with the results.

Cable Type:	**DXE-400 MAX**
Jacket Outside Diameter:	0.405 in.
Jacket Material:	PE, Type III
Center Conductor Gauge:	10 AWG
Center Conductor Material:	bare copper
Center Conductor Construction:	19 strand - 0.0210 in
Dielectric Material:	Gas injected foam polyethylene
Dielectric Outside Diameter:	0.285 in.
Shield 1 Construction:	Aluminum
Shield 1 Percent Coverage:	100%
Loss Per 100 ft. at 30 MHz:	.8 dB
Loss Per 100 ft. at 450 MHz:	3.3 dB

Shield 2 Construction:	Braided tinned copper
Shield 2 Percent Coverage:	95-96%
Power Rating:	2.8 kW @ 30 MHz
Velocity Factor Percentage:	.84 (84%)
UV-Resistant:	Yes
Direct Bury:	Yes
Price as of Oct 2022:	$1.18 (DX Engineering)

Figure 29: DXE 400 MAX

One of the things to note about this cable is that it is NOT recommended for use in a rotator loop. My solution to that is to run the cable to the top of the tower and then use a short length of UV resistant RG-8X for the rotator loop.

M&P Hyperflex 10

This is perhaps the best RG-8 type cable on the market today. It is made in Italy by Messi & Paoloni. There are several things I like about this cable. The first of course is the construction. It uses a stranded copper center surrounded by a high pressure injection foamed polyethylene dielectric, then a copper foil shield and that is covered by a copper braided shield resulting in a flexible cable with some of the best specifications I've seen for coaxial RG-8 type cable. This is the cable I would recommend for VHF and UHF installations.

Cable Type:	**M&P Hyper Flex 10**
Jacket Outside Diameter:	0.405 in.
Jacket Material:	PVC
Center Conductor Gauge:	10 AWG
Center Conductor Material:	bare copper
Center Conductor Construction:	19x59mm wire
Dielectric Material:	Triple layer high pressure injection foamed polyethylene

Dielectric Outside Diameter:	0.287 in.
Shield 1 Construction:	Copper foil with pe-layer
Shield 1 Percent Coverage:	100%
Shield 2 Construction:	192 wires of braided copper
Shield 2 Percent Coverage:	85%
Power Rating:	3.35 kW @ 30 MHz
Loss Per 100 ft. at 30 MHz:	.6 dB
Loss Per 100 ft. at 450 MHz:	2.63 dB
Velocity Factor Percentage:	.83 (83%)
UV-Resistant:	Yes
Direct Bury:	No
Price as of Oct 2022:	$1.78 (100' roll with connectors – GigaParts)

This cable is available directly from Messi & Paoloni or can be ordered from GigaParts or Buy2WayRadios here in the US.

Figure 30: M&P Hyperflex 10

LMR-400

This has been for a long time considered the gold standard of coaxial cable. It's not clear why because its specifications don't set it apart from other RG-8 type coaxial cables as you can see from its specifications, it's fairly average with a .7 DB loss at 30 MHz. By comparison Hyper Flex 10 has better numbers but is more expensive. DXE-400 Max is equal in terms of loss and shielding and costs less than LMR-400. However LMR-400 is good quality coaxial cable for the right application and should not be over looked.

Cable Type:	LMR-400
Jacket Outside Diameter:	0.405 in.
Jacket Material:	PE, Type III
Center Conductor Gauge:	10 AWG
Center Conductor Material:	bare copper
Center Conductor Construction:	Solid Copper-clad aluminum
Dielectric Material:	Gas injected foam polyethylene
Dielectric Outside Diameter:	0.285 in.
Shield 1 Construction:	Aluminum bonded Mylar foil
Shield 1 Percent Coverage:	100%
Shield 2 Construction:	Braided tinned copper
Shield 2 Percent Coverage:	95-96%
Power Rating:	3.33 kW @ 30 MHz
Loss Per 100 ft. at 30 MHz:	.7 dB
Loss Per 100 ft. at 450 MHz:	3.3 dB
Velocity Factor Percentage:	.85 (85%)
UV-Resistant:	Yes
Direct Bury:	Yes
Price as of Oct 2022:	$1.50

Because LMR-400 has a solid core made from copper clad aluminum it is not recommend for applications where there will be any movement such as rotator loops. The center conductor can fatigue and break over time due to repeated movement. Warning: Due to the popularity of LMR-400 it is perhaps the most counterfeited cable sold. I would not recommend you purchase LMR-400 from anyone other than a reputable company that specializes in the ham radio or the commercial radio business. I refer you again to Dave Kessler's interview with Ray Nelson of USACoax - MPDigital[23].

[23] See: https://www.youtube.com/watch?v=4fP94GfqTtk

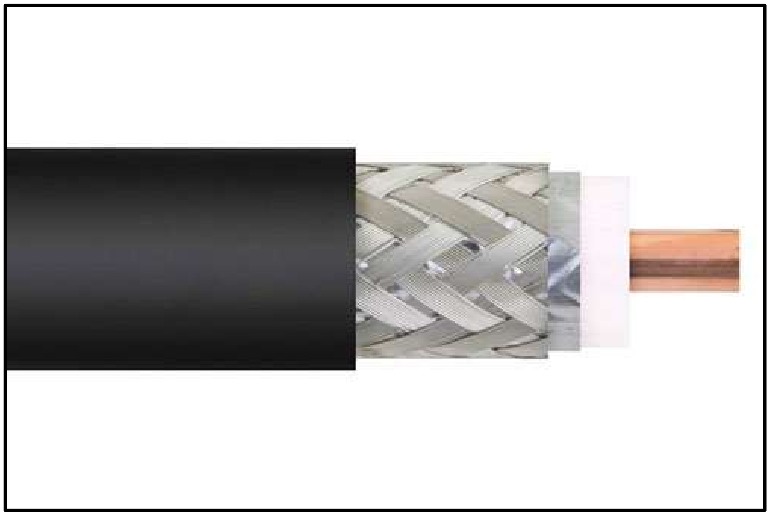

Figure 31: LMR-400

Andrews-Commscope 1/2 Heliax (FSJ4-50B)

For most hams they will never use Heliax. For most amateur application it would be consider overkill due to its expense and special tools and connectors. However in situations where there is a long run from the shack to the UHF antenna it is a very good choice due to both its low loss numbers and superior shielding.

Cable Type:	½ Heliax FSJ4-50B
Jacket Outside Diameter:	.5 in.
Jacket Material:	PE
Center Conductor Gauge:	.14” (About 7 gauge)
Center Conductor Material:	Copper-clad aluminum wire
Center Conductor Construction:	Solid
Dielectric Material:	Gas injected foam polyethylene
Dielectric Outside Diameter:	.350”
Shield 1 Construction:	Corrugated copper tubing
Shield 1 Percent Coverage:	100%
Loss Per 100 ft. at 30 MHz:	.557 dB
Loss Per 100 ft. at 450 MHz:	2.314 dB
Power Rating:	15.6 kW @ 30 MHz
Velocity Factor Percentage:	.81 (81%)
UV-Resistant:	Yes
Direct Bury:	Yes
Price as of Oct 2022:	$3.91 (RF Parts Company)

Figure 32: 1/2 Heliax

Figure 32 shows a picture of the end of a piece of Heliax that has been prepared to accept a Heliax compression fitting. The preparation is very specific. Note how the end of the center conductor has been chamfered. That allows for a perfect fit of the center pin over the center conductor to maximize contact and minimize any air space. Also note that the shielding is cut off at the maximum radius of the corrugated shield. That provides enough surface area for the compression fitting to securely clamp on to the shield. This is why the use of a Heliax prep tool is strongly advised. The ½ prep tool runs around $250. One of the other reasons that Heliax is rarely used in the typical ham station is due to the cost of the connector. For example a typical N-Type compression fitting for ½" Heliax will cost on average around $30. The nice thing is that if you mess up you can reuse the connector because nothing is soldered.

Figure 33: Typical Heliax fitting from HRO that sells for about $27

RG-214

RG-214 is double shielded version of RG-8 and would be used in applications where shielding would be important. The RG-214 coax cable is a favored type of coax cable used for high-frequency signal transmissions. The cable's shielding prevents electrical interference giving the cable an excellent and consistent current. We don't see much of it used in amateur radio I suspect due largely to its high cost. For most applications in amateur radio it would be overkill with no real benefit to justify its high cost.

Cable Type:	RG-214
Jacket Outside Diameter:	0.425 in.
Jacket Material:	PVC, Non-contaminating, Type II-A
Center Conductor Gauge:	12 AWG
Center Conductor Material:	Silver plated copper
Center Conductor Construction:	7 strands of 21 AWG
Dielectric Material:	Polyethylene
Dielectric Outside Diameter:	0.285 in.
Shield 1 Construction:	Braided silver plated copper
Shield 1 Percent Coverage:	96%
Shield 2 Construction:	Braided Silver plated copper
Shield 2 Percent Coverage:	97%
Power Rating:	2 kW @ 30 MHz
Loss Per 100 ft. at 30 MHz:	1 dB
Loss Per 100 ft. at 450 MHz:	5.7 dB
Velocity Factor Percentage:	.85 (85%)
UV-Resistant:	Yes
Direct Bury:	Yes
Price as of Oct 2022:	$7.87 (DX Engineering)

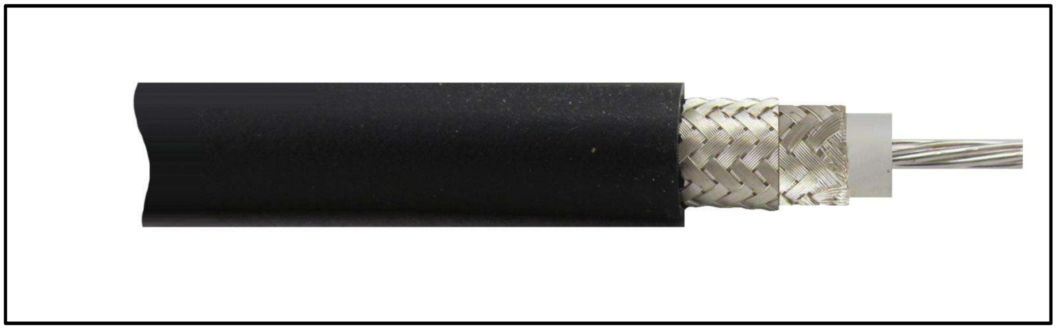

Figure 34: RG-214

There are many more coaxial cable options than I could ever hope to include in this short appendix. I chose to only include the cable that you will most likely come in contact with even though there are many more to choose from. The coaxial cable that I have presented here should cover 99% of the needs most amateurs will ever encounter. Hopefully with the information you have learned from this paper you will better understand the many differences between cable types so you will be able to make an informed decision when it comes to selecting cable for your station.

Name	@ 10 MHz	@ 30 MHz	@ 50 MHz	@ 150 MHz	@ 450 MHz	VF	Price	UV	Direct Bury	Notes
LMR-600		0.4	0.5	1	1.7	85%	$ 2.83	Yes*	Yes*	Connectors are expensive - PL-259 Crimp on runs around $60 each.
M&P Airborne 10	0.3	0.5	0.7	1.2	2.3	87%	$ 1.60	Yes	Yes	Solid Core
1/2 Andrews Heliax	0.318	0.557	0.724	1.285	2.314	81%	$ 4.91	Yes	Yes	Connectors run about $35 each
M&P ExtraFlex Bury 10	0.4	0.6	0.8	1.4	2.6	87%	$ 1.10	Yes	Yes	Appears to not be available from US Vendor
M&P HyperFlex 10	0.4	0.8	0.8	1.4	2.6	87%	$ 1.82	Yes	No	Appears to not be available from US Vendor
M&P-UltraFlex 10	0.41	0.61	0.82	1.44	2.65	83%	$ 1.79	Yes	No	Not available by the foot. Can be ordered in specific precut lengths up to 500'. Rolls include either PL-259 or N-Type connectors.
3/8 Andrews Heliax	0.372	0.649	0.842	1.482	2.641	83%	$ 3.10	Yes	Yes	Connectors run about $25 each
LMR-400		0.7	0.9	1.5	2.7	84%	$ 1.89	Yes*	Yes*	Coaxial Cable, LMR-400, 50 Ohm, Low Loss, CCA Solid Center, Black UV Resistant Polyethylene Jacket
DXE-400 Max	0.5	0.8	1.1	1.8	3.3	84%	$ 1.18	Yes	Yes	Coaxial Cable, 400MAX, Low-Loss Gas Foam, 10 AWG Stranded Copper, Dual Shield, Waterproof PE Jacket,
Davis RF BURY-FLEX	0.6		1.1			82%	$ 1.29	Yes	Yes	
Belden RG-8/U (8214)	0.5		1.2			78%	$1.89	Yes	Yes	RG-8/U type, 11 AWG stranded (7x19) .108" bare copper conductor, foam polyethylene insulation, bare copper braid shield (97% coverage), PVC jacket.
1/4 Andrews Heliax	0.559	0.973	1.261	2.21	3.906	84%	$ 2.15	Yes	Yes	Connectors run about $25 each
DXE-8U	0.6	1	1.3	2.2		81%	$ 1.13	No	No	Coaxial Cable, RG-8/U, 11 AWG, 7 Strand Bare Copper Center Conductor, Type I PVC Jacket
DXE-213U MIL-Spec	0.6	1	1.3	2.4		66%	$ 1.09	Yes	Yes	Coaxial Cable, RG-213/U, 12.5 AWG, Bare Copper Center, Non-Contaminating Type II-A PVC Jacket
DXE-214	0.6	1	1.3	1.9		66%	$ 7.87	Yes	Yes	Coax Cable, RG214, 12 AWG Silver Plated Stranded Copper Center, Double Braid Silver Plated Copper Shield, PTFE Dielectric, Non-Contaminating Type II-A
DXE-8X	0.9	1.4	2	3.8		0.78	$ 0.48	Yes*	Yes*	Coaxial Cable, RG-8X, 16 AWG, 19 Strand Bare Copper Center, Type II-A Non-Contaminating PVC Jacket,
DXE-RG400-CTL	0.9	2.2	2.9	5.1		69.50%	$ 5.49	Yes	No	High Isolation Coax Cable for special applications. Not to be confused with LMR-400. Cable is made of 20 AWG Silver Plated Stranded Copper Center, Double Braid Silver-Copper Shield, PTFE Dielectric, FEP Jacket
DXE-RG58AU	1.5	2.8	3	4		66%	$ 0.44	No	No	Coaxial Cable, RG-58A/U, 20 AWG Strand Copper, Type I PVC Jacket

Figure 35: Side by side comparison of various coaxial cables