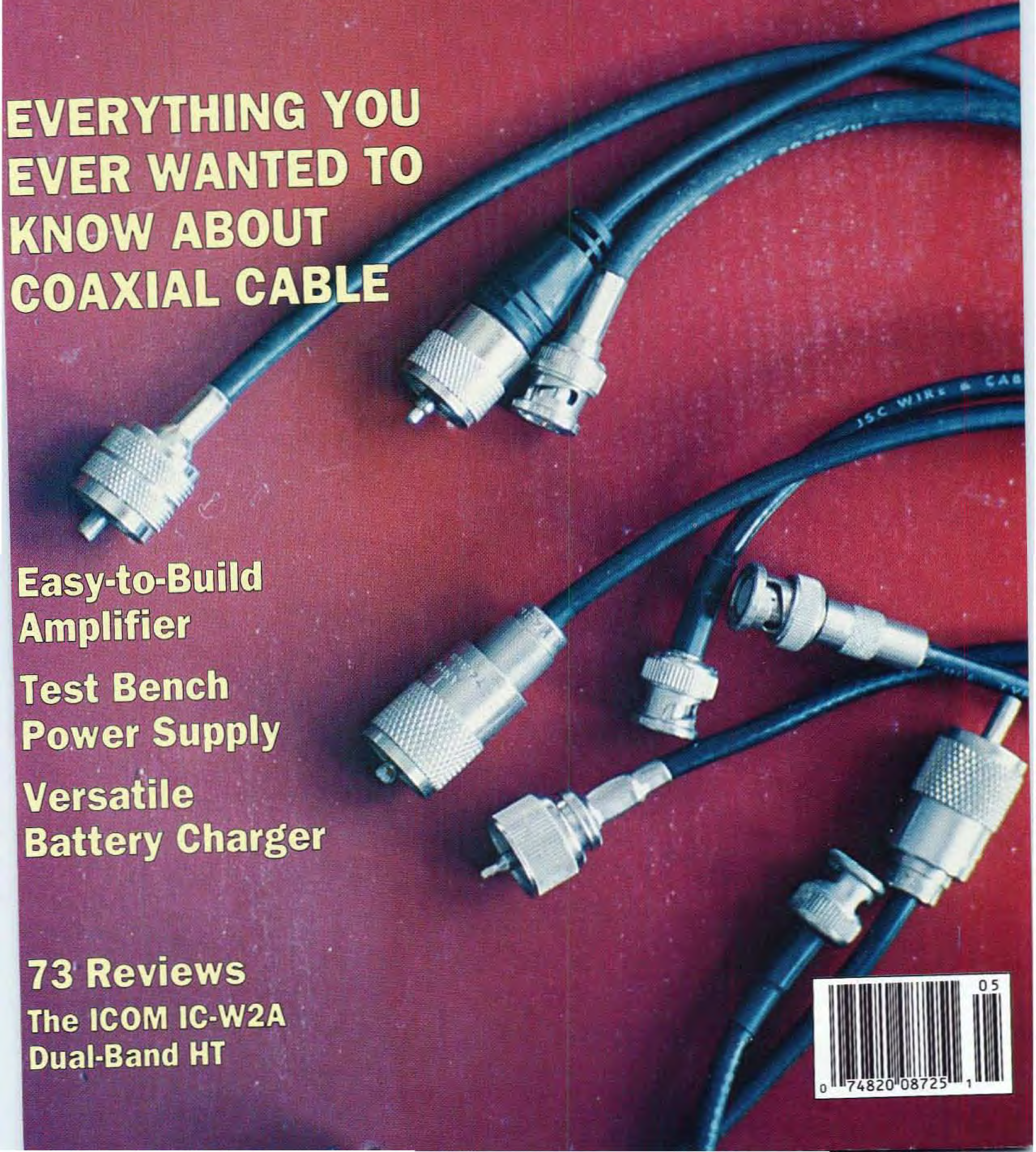
73 Amateur Radio Today

MAY 1993
ISSUE #392
USA $2.95
CAN $3.95
A WGI Publication
International Edition



EVERYTHING YOU EVER WANTED TO KNOW ABOUT COAXIAL CABLE

Easy-to-Build Amplifier

Test Bench Power Supply

Versatile Battery Charger

73 Reviews

The ICOM IC-W2A Dual-Band HT

05
0 74820 08725 1

The Hows and Whys of Coaxial Cable

How to select the most appropriate kind for your need.

by Steve Katz WB2WIK/6

Hams have used coaxial cable for transmission lines almost since its invention nearly 50 years ago, but many don't know why or how this trend started. Although much has been written on the subject, I'm frequently startled to hear so much misinformation chatted about on the ham bands, even by old-timers who should know better. Perhaps this article will help newcomers and old-timers alike clear up misconceptions and make more educated decisions regarding this important piece of station apparatus.

Why Coax?

Why do we use coax, and why is most of it 50 ohms nominal impedance?

This is the best question anyone can ask. Before there was coaxial cable, amateurs and professionals alike used primarily open-wire transmission lines, typically in the 300 to 600 ohm nominal impedance range. Sometimes they used no transmission line at all—they just directly fed antennas with a single piece of wire. In the latter arrangement, the connection wire became part of the antenna system itself, and radiated along with the antenna. The drawback to this scheme was that the connecting wire's orientation would play a critical role in antenna performance, and often a high-voltage point would appear right at the antenna connection to the transmitter, creating both RF interference and even possibly fire hazards when the wire would come in proximity to combustible materials.

Open-wire "balanced feeders" helped solve some of these problems. Because the currents in the feeder wires were balanced (assuming a well-balanced load, or antenna), feedline radiation was minimized and the RF field contained to a very small area around the wires. By orienting the feeders perpendicular to the intended antenna field, antenna radiation pattern distortion would also be minimized and antennas could be better optimized. Open-wire "balanced feeders" were also a natural for connecting vacuum-tube push-pull amplifier circuits to balanced antennas without the need for complex matching networks. Tube amplifiers are normally high-impedance devices whose output impedance is roughly equivalent to the plate voltage divided by the plate current of the output stage. Thus, a tube amplifier with 1,000 volts on the anode, drawing 500 mA anode current (this is a 500 watt stage), would have a plate load impedance of about 2,000 ohms. Matching 2,000 ohms to a 600 ohm open-wire feeder connected to a 600 ohm balanced antenna required only a transformation ratio of 2000:600, or 3.33:1, which was easily achieved by a very simple, low-loss "link output" circuit.

The problem with open-wire lines, and

> ***"Coaxial cable solves a great number of problems and that is why it is used so universally in amateur as well as non-amateur communications systems."***

"twin-lead," which is identical to open-wire except that the dielectric (spacer insulation) is a continuous strip of material (such as polyethylene), is that they are adversely affected by conducting objects in close proximity to them. They cannot be taped or otherwise directly attached to metal towers, masts or antenna booms, and even water, snow or ice laying on them dramatically increases their losses. Twin-lead and open-wire feedlines must be carefully insulated and spaced from all surrounding objects and cannot be directly buried beneath the earth. Besides all this, they still radiate to some degree, especially if terminated in any kind of unbalanced load. And, although the current in high-impedance feedline is lower than it would be in lower-impedance (coaxial) cable, making IR (ohmic) losses lower, voltages are much higher, to the point where exposure to living organisms (like people!) can be deadly hazardous. For example, if someone were running the amateur legal-limit power level of 1,500 watts PEP output and using a 600 ohm antenna and feedline, the voltage across the feedline would be 948.68 volts (calculated by the formula: $E = \sqrt{P \times R}$

This is quite a lot of voltage and is considered by all authorities to be extremely hazardous.

Coaxial cable to the rescue! Coaxial cable is self-shielding and, if well-made, does not radiate at all when properly terminated in a matched load. Since the outer conductor (shield) normally operates at ground potential, coax can be secured to all sorts of objects, including tower legs, metal masts and booms, and almost anything else that comes to mind, making its installation extremely uncritical. If the coax has the proper outer jacket material, it may be buried beneath the earth for many years without degradation. Coax is unaffected by the presence of water, snow or ice. Although the nominal impedance of coax is lower than open wire line and it therefore has higher IR (ohmic) loss, its lower impedance allows direct power transfer to low-impedance antennas (a half-wave dipole in free space, for example, looks like 70 ohms) and keeps the voltage across the feedline and antenna connection points to a safer level. A 1,500 watt PEP output transmitter connected to a 50 ohm antenna will have only 273.86 volts across the feedline—still a somewhat hazardous level, but about one-fourth that obtained using a 600 ohm system. Because coaxial cable's working voltage is quite low, its insulating dielectric material may be optimized for minimal loss, rather than maximum insulation resistance.

Why 50 Ohms?

Clearly, coaxial cable solves a great number of problems and that is why it is used so universally in amateur as well as non-amateur communications systems.

"Why is most coaxial cable 50 ohms nominal impedance?"

This can best be answered in two parts: (a) Coax isn't all 50 ohms, but commonly runs from 30 ohms to 90 ohms, and sometimes even a bit higher when called for. Impedance selection is very application-dependent. (b) 50 ohms represents an excellent compromise between the lowest possible transmission loss, which occurs at 70 ohms nominal, and the highest possible power handling capability, which occurs at 30 ohms nominal. Because of these factors, 50 ohms was settled on as the best all-around impedance for the widest variety of applications. To this day, 70 ohm cable is used almost exclusively in receive-only applications where no power transmission is required (such as cable TV systems).

Cable Specs

If 50 ohm coax is the best thing to use, I guess I should buy a big roll of RG58/U and use it everywhere. Isn't that right?

Yes and no. RG58/U might be great stuff, but again, most choices in life are application-driven and one needs to consider the specific use before making an intelligent cable selection.

First of all, what do the "RG" numbers mean? Well, these indicate that the cable is *registered* (simply a matter of someone spending the money and filling out a few forms). Cables which are truly RG-XX-/U are also "mil-qualified," which means they are certified for lot compliance with MIL-C-17D, the general military specification for wire and cable, and manufactured in a qualified facility. The two- or three-digit number after the "RG" prefix means absolutely nothing by itself: You need to refer to MIL-C-17D to see exactly what the cable designator means. The numbers are arbitrarily assigned in numerical order, from 1 to infinity, and only tend to indicate the age of the product's registration. For example, RG8/U is a much older product than RG213/U, which is essentially identical except that RG213/U is a *QPL* (MIL-C-17D qualified) product, while the older RG8/U no longer is, having been replaced by the newer part number. Many amateur coaxial products are not mil-qualified at all, but might still be imprinted and sold as "RG" products. Usually, if these are identical to mil-spec cables but are simply not qualified, they will be labeled with the word "TYPE" after the part number: For example, Belden 9913 is "RG8 TYPE" cable but is not RG8/U. Other non-qualified products might simply leave off the "/U" suffix, such as "RG8X" or "RG8M" mini-8 cable. Admittedly, it's all a bit confusing.

How to Choose

Since most of us will be using 50 ohm cables in our stations, the most important parameters to consider in making product choices include: (a) transmission loss; (b) power handling capability; (c) flexibility; (d) availability of standard and reasonably-priced connectors; and (e) resistance to weathering and ultraviolet (UV) exposure. These parameters vary in importance and not necessarily in the order I've listed. Again, the selection is and should be application-dependent. Oh, yes—I've almost forgotten the most important parameter for many hams: COST!

In general (but not always), the larger diameter the cable is, the lower its loss will be at any given frequency. This is because the leading contributor to transmission loss is the ohmic resistance of the conductors, which are usually copper, and the larger the cross-section the conductors have, the lower their resistance will be. But if loss were based on conductor size and ohmic (DC) resistance alone, coaxial cable would have the same loss for a given length at all operating frequencies, from DC to microwaves. That is *not* the case.

There are two other factors that enter into the RF loss equation (and they do not apply to DC circuits). One is a property called "skin effect," which assumes that AC (and RF) currents will flow only in the outermost surface of any conductor and therefore conductors could be hollow (with no center core at all) and be just as effective as solid conductors for any given diameter. The other is dielectric (the spacing insulation between the center and outer conductor) loss, which increases directly with operating frequency for most commonly used dielectric materials. The "skin depth" of a conductor becomes more and more shallow as the RF frequency is increased, meaning that a more and more shallow region of the conductor is used as we work our way up the spectrum. This means that a given conductor will have loss that increases with frequency, as less and less of the conductor is actually used.

"It pays to select coaxial cable which has commonly-available, reasonably-priced connectors that will fit."

There is a third factor that applies mostly to *flexible* coaxial cables (the most-used kinds in ham stations), and that is radiation loss, which also increases directly with frequency as the outer conductor, which is made of braided materials to add flexibility, becomes a less effective shield for containment of RF energy. Solid outer-conductor cables (semi-rigid, rigid, "hardline," etc.) typically don't suffer radiation losses.

The bigger the cable is in diameter, the more power it can usually handle, since the conductors will have less loss and thus dissipate less power (generating less heat) and the insulating materials tend to be thicker, too, sustaining higher operating voltages. An exception to this general rule are the Teflon dielectric cables, which have great power handling ability even when small in overall diameter. This is because Teflon can withstand much greater heating than normally-used insulating materials, like polyethylene, and it has a higher dielectric withstanding voltage for a given thickness. This is *not* to say that Teflon cables are superior to standard polyethylene ones—they are not, except as regarding power handling for a given diameter. In general, Teflon cables are actually *inferior* to standard polyethylene-insulated coax in almost all other respects because Teflon has a high dielectric constant, creating the need for smaller center conductor size (for a given nominal impedance) and increasing dielectric losses. An example of Teflon coax is RG400/U, which is about the same size as RG58/U but will withstand more than 10 times the power; however, RG400/U actually has *more* transmission loss than standard RG58/U and costs about 10 times as much!

Throughout the HF spectrum, hams use "UHF" or "PL259" type connectors almost exclusively because commercially-made gear is already fitted with their mating receptacles (SO239) and they are good, high-power, inexpensive fittings that are very useful through 144 MHz or so. However, on 220 MHz and above, the connector of choice is the Type "N," which has a variety of military designators, mostly UG21D/U. The Type "N" connector surely costs more than the "UHF" PL259 type, but is actually easier to install and is a far superior connector throughout the VHF/UHF/SHF spectrum. In fact, some Type "N" fittings work well through 12 GHz (12,000 MHz)! For smaller cables, both PL259's with appropriate "reducers" (type UG175/U and UG176/U for RG58/U and RG8X types), Type "N" and "BNCs" are commonly used. BNCs are very good fittings through the UHF and SHF spectrum and, when properly installed, have no measurable loss at 1 GHz. However, because of their mechanical frailty they are best used with small-diameter cables like RG58/U, RG174/U and so forth.

In any case, it pays to select coaxial cable which has commonly-available, reasonably-priced connectors that will fit, or you may find yourself with $5 worth of cable that will require $200 worth of connectors to attach to anything. The "standard" ham coaxial lines (RG58, RG8, RG213, even RG217 and RG17 for those with the budget and need for giant-sized cables) all have readily-available and reasonably-priced fittings. Probably the only caveats in the market are "surplus" cables which cannot be readily identified and "hardline" cables, which do require special connectors that can sometimes cost a small fortune.

Beware of double-shielded coaxial cables! These are often found on the surplus market and, while they might be wonderful in many respects, they can be difficult to use, to flex, and to find connectors which fit. For example, the double-shielded version of RG213/U is RG214/U. These two cables have exactly the same electrical properties, the same transmission loss, and so forth, but the double-shielded type will *not* fit a conventional connector which is intended for single-shielded cable. Why would anyone want double-shielded cable? For very specific and demanding applications, where a few dB of additional shielding is very important. Connections within full-duplex repeater systems come to mind as a good application. If you don't own a repeater, there's no reason I can think of to use double-shielded cable. It's generally more trouble than it's worth.

Specific Questions

After contemplating all of this confusing information, what in the world should I use to feed my 40 meter dipole?

Great question! That's getting down to specifics. Unless you intend to run the legal power limit (1500 watts PEP output), I'd usually recommend RG58C/U (for runs up to 50' long and power levels below 400 watts PEP) or RG8X (for runs up to 150' long and power levels below 1000 watts PEP). These are both very flexible, lightweight cables which will exhibit very low loss on 40 meters in the lengths I've specified, and their only restriction will be power handling. For legal-limit power, I'd recommend RG213/U, which is heavier and less flexible, but will withstand 1,500 watts all day long.

What about feeding my 2 meter beam?

Another great, specific question. The only question I'd ask in reply is, "How long will your feedline need to be?"

For lengths less than 50 feet, RG8X is a good, general-purpose cable for 2 meter use. A 50-foot run will have about 2 dB loss, which is not too much for most applications (like working FM repeaters and such), but might be excessive for demanding applications like SSB/CW weak-signal work where every dB counts. For lengths up to about 100 feet, RG213/U is a great choice. It will lose about 2.4 dB or so in a 100' run. For lengths beyond 100 feet, or for more demanding applications, I'd recommend Belden 9913, which is the same o.d. (outside diameter) as RG213/U but has somewhat lower loss, about 1.3 dB per 100 feet at 144 MHz. The drawback to the 9913 is that it is far less flexible than RG213/U and does not fit a standard Type "N" connector; however, special connectors for 9913 are available and don't cost much more than the standard ones. For very long runs, or highly demanding applications like EME (moonbounce, where every tenth of a dB starts to count) or full-duplex repeater installations, 1/2" or larger "hardline" or Heliax is most commonly used.

I'd like to use a single feedline to connect my 146, 222 and 440 MHz FM antennas at home, using a "duplexer" at each end of the line to separate the signals. Any problems with that? What should I use?

There's no problem doing this, as long as you use high-quality "duplexers" (I'd prefer to call them signal-splitters, which is what they really are) on both ends, and remember to make the topside one, which will be exposed to weather, very waterproof. There are some multiband signal-splitters on the market which have almost immeasurably low loss (less than 0.5 dB) and will handle 150 watts or so. Since you intend to use the coax on 440 MHz, where losses will be the highest, I'd recommend RG213/U for short runs up to 50 feet or so, then Belden 9913 up to 100 feet, then commercial "hardline" or Heliax for runs longer than 100 feet. Bear in mind that the "hardline" types cannot take repeated flexing, are quite inflexible to begin with, and require specialized, costly connectors. But properly used, it's great stuff.

I have a 10-15-20 meter triband beam on a 70-foot tower located 150 feet behind my house. What do you recommend for coax to feed this system?

I'd probably recommend RG217/U or RG17/U in this case, and I'd bury it underground to get to the base of the tower. It will have minimal loss and is very high quality cable. Connectors are readily available (although they have a larger back end than connectors for RG8-sized cables and are not interchangeable), at least for Type N, and adapters can be used to mate with UHF fittings if necessary. Of course, you could save a lot of money by using standard RG213/U, but since you'll need nearly 250 feet of it, this stuff will begin to get lossy at 28 MHz. It's a matter of balancing your appetite for performance against your budget and trying to make the most educated decision possible.

"Properly-installed coaxial connectors have losses too low to measure if they are used in the spectrum for which they were intended.

I've heard that coax connectors all have loss, and every time you use one, you're giving up a dB or so. Is this true?

Not at all! Where in the world did you hear this gibberish? While everything has *some* loss in this imperfect world, properly-installed coaxial connectors have losses too low to measure, even with the world's most sophisticated laboratory equipment, if they are used in the spectrum for which they were intended.

A "UHF" connector, say type PL259ST, which implies a silver-plated connector with a Teflon dielectric (the best kind to use because they solder so easily and resist soldering heat so well), used at 28 MHz will have less than 0.01 dB insertion loss when mated to an equivalent receptacle. Similarly, a UG21D/U Type "N" connector, properly installed and mated to its equivalent receptacle, will exhibit less than 0.05 dB loss at *500 MHz!* This a whale of a lot less than 1 dB loss. The problem is, many amateurs don't know how to install connectors properly, and probably do end up with more loss than there should be. But 1 dB is an awful lot to lose, especially at the lower frequencies, where simply twisting the coax conductors together in a "mid-air" splice and using no connectors at all will usually result in far less than 1 dB loss.

Probably the worst misapplication of RF connectors is when hams try to use "UHF" PL259 types at 440 MHz. Most of them don't work very well at this frequency, and losses may be as high as 0.5 dB per connector or so if you're not careful. At 440 MHz and above stick with the time-proven, constant-impedance Type N fittings.

My 220 MHz "mag mount" whip antenna came with RG174/U coax installed, about 10 feet of it. Is this lossy? Should I replace it?

At 222 MHz, 10 feet or RG174/U will lose about 1.3 dB or so. Replacing it with an identical length of RG8X will only lose 0.5 dB, so you'd pick up about 0.8 dB by making the change.

What about the coax sold by Radio Shack and similar retail outlets? Is it any good?

It can be, but it might not be. I don't mean to disparage Radio Shack or anyone else, but the problem with commercial, non-military cables is the lack of *consistent* quality. Since their cables are manufactured in non-qualified facilities and each lot does not undergo the rigors of considerable Quality Conformance Inspections, many times these products are less than desirable, especially for long-term installations. I'd not hesitate to use their stuff for patch cables around the shack, or for mobile installations and other non-critical applications where the cable can easily be replaced. But for more demanding applications or installations where replacement might be very difficult, I'd stick with the real mil-spec products, or at least try to find the highest quality commercial products available. Shop around a bit, looking not only at the price, but also at the product itself. Is the braid coverage very good (at least 95% of the dielectric should be covered by the braid, with no visible "holes" between the strands)? Is the outer jacket "UV stabilized" (that is, will it withstand continued ultraviolet radiation from the sun without contaminating the cable)? Is the run you intend to use free of splices under the jacket (usually visible as a small bump in the cable diameter)? If everything looks great, use it! If not, look elsewhere.

What about "foam" cables versus "non-foam?" What's the difference?

"Foam" cables use this term to refer to the dielectric material; it is cellular polyethylene, which looks a bit like foam rubber, and is softer and spongier than solid-dielectrics. The "foam" stuff is usually very white in color (although it needn't be) and you can permanently indent it with your fingernail. Foam cables tend to be a bit more flexible than those with solid dielectrics, and their transmission losses will be slightly lower for a given cable type and diameter. However, there are drawbacks. The cellular foam melts easily at a relatively low temperature, and once melted, it is permanently damaged. Because of this, foam cables are really intended for "crimp-on" connectors, not the solder-on kind, which obviously will expose the dielectric to very high temperatures during the soldering operation. Also, the nature of the foam dielectric is to absorb water easily, making the cable quicker to contaminate if the jacket is pierced or if a terminating connector leaks a bit of water. Solid dielectric cables are more robust and will withstand soldering heat better, and are also less prone to the absorption of moisture. Because of the operating temperature restrictions, no "foam" cable is mil-qualified. However, throughout this article I have recommended RG8X for some applications, and RG8X *is* a "foam" cable type. Use it carefully.

Why does "foam" cable have less loss?

Two reasons. One, the cellular polyethylene has a lower dielectric constant than solid, so dielectric losses are somewhat lower. Two, because of this same fact, the center conductor will be larger in diameter (for the same outside conductor diameter) to maintain 50 ohms impedance. (The nominal impedance is a function of the inner conductor diameter as related to the outer conductor diameter, and the constant of the dielectric used between them.) With a slightly larger diameter center conductor, ohmic losses (and skin-effect losses at RF) will be somewhat reduced, without impacting the overall diameter of the cable. Whether or not you'll really notice the difference in loss will depend on the length of cable you use.

What about "9913?" Is it as good as they say it is?

"9913" is excellent with respect to transmission loss and power handling ability. It is often called "poor man's hardline" because it might be nearly as good as hardline, while costing far less. "9913" is really just an extension of "foam" dielectric cable. Instead of using cellular polyethylene, Belden (the inventor of 9913) uses a thin spiral of polyethylene dielectric material as a spacer to hold the center conductor in place, and a lot of the dielectric is really the air between the spiral turns. Picture the dielectric in 9913 as a long spring, with lots of coils and air in the spaces between. As a result, the dielectric constant is even lower than in "foam" cables, the center conductor is even larger and has less resistance, and everybody is happy as a clam. Of course, braided outer conductors for 9913 would never work, as there'd be nothing rigid enough to hold the cable together. So the manufacturers use a very thin wall of polyethylene, covered with aluminum foil to make the outer coaxial conductor. Since you can't really solder to aluminum foil, they cover that with some tinned copper braid material. The braid serves no particular purpose other than giving you something to solder to (for a PL259) or clamp to (for a type N).

The problem (and there's always a problem with anything that seems too perfect) is that 9913 is far less flexible than conventional cables, will not withstand repeated bending (due mostly to that big, fat, solid center conductor and the fragile aluminum shield), is easily contaminated by the very first droplet of water that might enter in past a connector, and is too fragile to rigidly clamp to a tower leg or other solid support. If you use proper precautions, 9913 is great stuff. If you don't you'll wind up replacing it frequently. Belden will be glad to provide you with an applications note on how to use 9913 correctly. It was really intended for crimp-type connectors, not solder-on ones, so be *extra* careful.

I've heard that a solid center conductor in coax is better than a stranded one. Is that true? If so, why?

No, this really isn't true. Since the RF currents flow only on the perimeter of any conductor, only the outside diameter of the center conductor is of consequence in determining attenuation. (The same is true for the *inside* diameter of the outer conductor, because that's where the current flows there.) To maintain a constant and desired impedance, the ratio of the o.d. of the inner conductor to the i.d. of the outer conductor must be a fixed, predetermined quantity for any given dielectric material. It doesn't really matter if the inner conductor is solid or stranded, as long as its o.d. (outside diameter) is correct to maintain the desired nominal impedance. Solid conductors are generally used in cables that will not be exposed to repeated flexing, like 9913 and hardline, while stranded center conductors are used in cables intended for flexing and smaller-radius bends because the stranded conductors are far more flexible. For this reason, I'd always recommend cables with a stranded center conductor for routing in tight spaces, around rotators, in mobile installations, as "patch" cables for use around the shack and in other applications where flexibility is required. For example, rather than using RG58/U or RG58A/U, I'd recommend RG58C/U in almost all applications for small-diameter cable. The RG58C/U has a stranded center conductor while RG58/U and RG58A/U do not. A perfect example of the resilience of the stranded conductor cable is when it is used to attach a mobile "mag mount" antenna, where the car door may be repeatedly slammed against the cable. RG58/U might withstand this abuse only a few times before it finally breaks, while RG58C/U will withstand similar abuse hundreds of times because it is so much more flexible. (It's still not a great idea to slam a car door against the coax, but I know it's done, and will be done for years to come.)

"In amateur installations, the factors that detract from the operating life of coaxial cable are typically abrasion, moisture, and UV radiation."

I've heard that coax's ability to withstand UV radiation has something to do with the cable's suffix designator, like A/U, B/U, C/U, etc. What's the story on this?

Cables will last nearly forever if they're never exposed to excessive temperatures (hot or cold), weather, or ultraviolet radiation. Unfortunately, that means we really can't use them. In the real world, cables are exposed to all these things which impact operating life. In amateur installations, the factors that detract from the operating life of coaxial cable are typically abrasion, moisture, and UV radiation. UV radiation, which gives us such great tans in the summer, can cause the plasticizers in the jacket materials of coax to "migrate" and flow through the braid and into the dielectric material. When this happens, the dielectric becomes contaminated and the cable's attenuation increases. To avoid this occurrence, manufacturers—especially mil-qualified ones—began using "UV stabilized" jacket materials (usually polyvinylchloride, or "PVC") which will withstand UV radiation under normal conditions without migration. Unless you intend to use all your coax indoors, where it will never be exposed to the sun's rays, it certainly pays to use coax cable that has a "UV stabilized" jacket material. This material is commonly called "Type IIA," an industry buzz-word for the enhanced properties discussed here. Old-fashioned RG8/U was not Type IIA; RG8A/U supposedly was, and replaced RG8/U on the military QPL (Qualified Products List) for MIL-C-17D years ago. Because of the confusion created by two such similar part numbers, RG8/U and A/U were dropped from the QPL entirely and have been replaced with RG213/U, which should automatically have a UV stabilized jacket, if it is real mil-spec coax. A similar story exists for RG58/U: The old number was not Type IIA, but RG58A/U, B/U and C/U. This is a bit confusing, so it pays when purchasing cable to find out for sure if the product has a Type IIA jacket material. All the newer mil-spec products do, but many commercial products don't. RG8X, which is a purely commercial product (and is not mil-spec in any form) is made by a variety of manufacturers using different materials; some are UV stable and some are not. RG8X and other commercial cables are often available with a white-colored jacket material, which may be desirable for those wishing to "hide" the coax against the side of a light-colored building or interior walls. Whether the white jacket material is UV stable or not, it will reflect the sun's rays better than a black jacket and run cooler and absorb less UV radiation than black-jacketed coax. The white-colored stuff is often used in marine applications, where UV exposure is the norm.

I used RG58/U to feed my 2 meter antenna for years, and its VSWR was always 1.2:1. I just replaced the feedline with brand-new RG213/U of the same length and now the antenna VSWR measures almost 2:1. Why is the new coax so bad?

Congratulations! You've actually improved your whole system by a large factor, and your new VSWR measurement is far more accurate. You're obviously measuring the SWR down at the rig, and not up at the antenna feed point, which is where it *should* be measured. Since VSWR is a ratio of feedline to load impedance (*not* rig to antenna!), a "flat" (1:1) SWR will only exist when the antenna impedance is exactly the same as the feedline's. If there's any mismatch at all, some reflected power will result. When you used RG58/U, a large amount of that reflected power was absorbed by the coax because it had lots of loss. The reflected power just created some cable heating and never made it down to your VSWR bridge at the "rig" end of the line. Now that you're using less lossy cable, more of the reflected power is actually being conducted back to your bridge, and your rig, and less is being absorbed by the coax. This is a very normal condition. The new coax isn't "bad," it is probably far better than the old coax was. If you take the trouble to measure VSWR right at the antenna itself, you should find it will be the same with any 50 ohm feedline you connect to it. The best thing to do is re-tune the antenna, using a bridge connected directly to it (up on the roof, tower, or whatever) and try to optimize this match to 1:1 at the frequency of interest. If you can do this, there will be no standing waves on the feedline and the SWR will measure the same at the antenna, the rig, or anywhere in between. By the way, *all* the reflected power will eventually be absorbed by the feedline regardless of how much there is. This is an interesting subject on which much has been written, and there's insufficient space to cover it completely here.

How can I keep water out of my feedline?

A few simple precautions will prevent moisture from entering coax in most situations. The first is, when measuring, cutting and handling the cable, be careful not to create abrasion of the jacket. While some cables are nearly impervious to rough handling (like the ITT Impervion cables) because they are "self-healing," most are really quite fragile. Don't drag your coax across the pavement or roofing materials, and don't yank it through the legs of your tower. Treat it as though it were expensive silk fabric that could be easily damaged—because it can.

The second thing is, install the exposed connector (the one that attaches to your antenna) in a precise, proper and professional manner. Make sure the jacket ends *inside* the RF connector, and that no braid is exposed after the connector is installed. Then, weatherproof the connector as well as possible. "Coax Seal" weatherproof putty works well, if its directions are followed carefully. This stuff molds itself around the connector and the coax near the connector and is very weather resistant. Lacking "Coax Seal" or something similar, you can try spraying the connector and a few inches down the coax with Krylon "Klear Kote", then wrapping with overlapping layers of high-quality vinyl tape like 3M "Scotch 88" electrical tape, then spraying over the tape with another coating of "Klear Kote." It is not impossible to make an exposed RF connector totally weather resistant, it just takes some practice and some patience. Then, *don't* pull the coax straight away from the antenna connector and run it down a mast, boom or tower leg: Make a "drainage loop" in the coax, maybe 6" or so in diameter, by forming a 360-degree coil in the coax before routing toward the shack. Make this "loop" very close to the coax connector, preferably an inch or two away. Tape the loop in place so it will hold its form, and then carefully route the coax towards the shack, never pulling hard on it. When installing the "drainage loop," make sure the loop itself is all *below* the antenna connector, with the turn of the loop facing down towards the ground. This will help prevent any moisture that happens to enter the connector from "wicking" down the coax and contaminating the whole length, so if you do have a water problem in the future it will be confined to the first few inches near the antenna connector. If this *does* happen, at least you'll have enough coax left up there to cut off the old connector and the few inches of contaminated coax, install a new connector and reattach it to the antenna. You won't have to replace the whole line.

How can I tell if my surplus coax is any good? I got a real bargain on it, but am afraid to use it until I test it somehow.

First, cut a few inches off each end of the coax to get a "fresh end" exposed. Then, cut away the outer jacket to expose the braid. Is the braid shiny? (It may be pure copper, tinned copper or silver-plated copper, but in all cases it should have a shiny, new finish and not be discolored, green or black.) Now, pull back the braid and look at the dielectric material. Does it have a new-looking, consistent color? (It may be white, off-white, transluscent or nearly any color, but it should not be stained or discolored by the braid oxides or jacket plasticizers.) Now, cut back some of the dielectric and look at the center conductor. Is it shiny and new looking? (It may be pure copper, copper-plated, tinned, or silver-plated, but it should look shiny and new and not be oxidized.) If the answer to all these questions is, "Yes," then the cable is probably fine. But you may want to make an electrical measurement just to be sure.

"When measuring, cutting and handling the cable, be careful not to create abrasion of the jacket."

If you have a good VSWR bridge or directional coupler of high quality, you can make two simple measurements. First, install connectors on both ends of the coaxial line. Next, connect your VSWR bridge at the transmitter end of the line with a short "jumper" and connect the TX end of the bridge to your transmitter. Then, install a "dead short" circuit across the far-end connector, which would normally go to the antenna. You can make a good short circuit that will be effective up to 144 MHz or so by using a piece of #12 copper wire and soldering it between the center and outer conductors of a mating receptacle. Keep the wire very short, under one-fourth of an inch long. (At frequencies above 144 MHz, a commercial short-circuit RF termination, usually type N, will work better. These are available inexpensively via surplus outlets.)

Now transmit, using the lowest possible power to obtain a reasonable reading on your VSWR bridge or wattmeter. Switch the bridge back and forth between forward and reflected ranges. The VSWR should read infinity, or close to it: Forward and reflected power will both be the same if the cable has minimal loss. The *difference* between forward and reflected power indications is the power lost in the cable, but remember this will be the power lost by the signal traveling both up and down the cable (to the short-circuit termination and back to the transmitter), so the attenuation in just *one* direction is one-half the difference between forward and reflected power readings.

For example, if you transmit with 5 watts of power and measure a reflected power of 2.5 watts, a total of 3 dB is lost by the cable when the signal travels to the termination and back again. The single-trip loss (signal traveling from transmitter to termination only) will be one-half this amount, or 1.5 dB. The dB loss is calculated as follows:

$$\text{Attenuation (dB)} = 10 \log_{10} \frac{P1}{P2}$$

Where P1 is the transmitter forward power (5W), P2 is the reflected power (2.5 W) and the attenuation is for a "round-trip" in the cable; the one-way attenuation, which is a more relevant parameter, is one-half this amount.

If you'd prefer not to intentionally transmit into a short-circuit (and some solid-state rigs won't let you, due to their internal VSWR protection circuitry), you can make a similar analysis by taking a few extra steps and using a good 50 ohm "dummy" load, as follows:

Connect your wattmeter to your transmitter using a short "patch" cable, and terminate the far end of the coax line with a high-quality 50 ohm (non-reactive) dummy load. Connect the TX end of the coax to the antenna port of the wattmeter, and transmit with as much power as possible to achieve a high-scale reading on the meter. Read this indication and write it down. Then, disconnect the wattmeter from the transmitter, connect the coax directly to the transmitter, and re-install the wattmeter at the far end of the coax, right next to the dummy load. Transmit again using the same power as before and record this reading. Subtract the lower reading (which should be the second one) from the higher reading, and calculate the one-way cable loss using the same attenuation formula as before (10 times the log of the power ratio). Using this method should yield exactly the same results as using the "return loss" method described earlier.

In the example set forth, where the cable has 1.5 dB loss, you might measure 25 watts at the transmitter and 17.7 watts at the far end of the line. The loss of 7.3 watts in this case is exactly 1.5 dB.

I tend to use the "return loss" method, with a very high-quality short-circuit termination, for most of my cable evaluations because it is simpler, and does not require installing the meter at each end of the line. But I also usually use a signal generator running very low power (like 10 milliwatts, which is +10 dBm) and a very good directional coupler in my system, so I'm not relying on transmitters and high-powered wattmeters. Attenuation in any cable is a fixed number at a given test frequency and will not vary with power applied, so my system yields very accurate results and is a quick way to check lots of cable.

As discussed throughout this article, there is more to know about coaxial cable than just how much loss it has. Its overall quality of materials and construction, resistance to the effects of weathering and UV radiation, flexibility, ease of use and other factors can be equally, if not more, important. Yet, attenuation (or loss) is probably the most important criteria for the majority of users and applications, especially if the load cannot, for some reason, be matched to the line and a high SWR results.

One last note on this subject: Do not be misled into thinking that SWR, or the match between your feedline and its terminating load, is any indication of *efficiency*. The two parameters—SWR and efficiency—are mutually exclusive. It can be proven that if your feedline loss is *zero*, it won't matter what the SWR is because 100% of all the power generated by your transmitter will be coupled to the antenna and *no* power will be lost.

Table 1. Coaxial Cable Data

Cable Type	Z_0 Ohms	o.d. (in.V.F.)		Attenuation dB/100'					Dielectric
				50	144	222	440	1260	
RG58C/U	52	.195	66%	3.1	5.7	7.5	11	L9	PE
RG141A/U	50	.190	69.5%	2.1	4.0	5.2	7.6	16	TFE
RG59/U	73	.242	66%	2.4	4.2	5.4	7.8	14	PE
RG8X*	50	.242	78%	2.3	4.3	5.7	8.5	15	FPE
RG213/U	52	.405	66%	1.5	2.4	3.3	5.0	10.5	PE
RG11/U	75	.405	66%	1.3	2.4	3.2	4.9	9.5	PE
8214 Belden*	50	.405	78%	1.2	2.3	3.0	4.8	9.5	FPE
FM8 Times*	50	.405	80%	1.2	2.1	2.5	3.5	6.5	FPE
9913 Belden*	50	.405	84%	0.64	1.3	1.8	2.8	5.4	Air/PE
RG331/U*	50	.500	78%	0.60	1.1	1.5	2.4	4.0	FPE
RG17/U	52	.870	66%	0.50	1.0	1.3	2.3	4.4	PE
RG332/U*	50	.875	78%	0.35	0.65	0.80	1.3	2.5	FPE

Notes:

Cables denoted by an asterisk (*) are commercial cables and not qualified to any military specification.

V.F. = Velocity Factor of propagation. Not an important parameter unless cable is used in a tuned circuit, stub, trap or filter application or used as a precision phasing line.

Attenuation figures are plotted for 50 MHz through 1260 MHz only, as most cables have very little loss per 100 feet at frequencies below 30 MHz.

Dielectric type codes: PE = Polyethylene; TFE = Teflon; FPE = foam (cellular) polyethylene; Air/PE = helical dielectric of polyethylene and air.

Data taken by WB2WIK using 1000' lengths of each cable listed, measuring actual loss by "return loss" method, and dividing measured loss by 10 to calculate loss per 100 feet.

RG331/U and RG332/U are standard aluminum outer conductor "hardline" types which require specialized connectors. Used mostly for reference.

In my next article, I'll discuss the proper installation of coaxial connectors. To whet your appetite, I'll state now that *no* coaxial connector will take more than 90 seconds to install exactly right if you're armed with the proper tools and knowledge. 73