

Some Q&A About Coax and Stubs for Your HF Station

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Q: What do I look for when buying coax for my HF station?

A: First and foremost, look for a manufacturer you can trust. Don't buy un-branded or off-brand coax! Look for physical properties that match your use – UV resistant to stand up to sunlight, consider weight if it will feed a flat wire dipole, look for "flooded" or armored coax if it must lay on the ground and resist varmints. The most important electrical property is loss, and loss below about 250 MHz is entirely the result of conductor resistance.

Q: What do RG numbers mean?

A: Not much. For all practical purposes, RG-numbers describe only the impedance and approximate size. RG58 is a 0.2-inch diameter 50 ohm cable suitable for very short runs. RG59 is a 75 ohm cable of about 0.25 inches diameter. RG8X is about 0.25-inch, lower loss version of RG58, and RG6 is about 0.3-inch, lower loss version of RG59. RG8, RG213, and RG214 are about 0.4-inch diameter 50 ohm cables; 0.4-inch 75 ohm cables are called RG11. RG174 and RG187 are miniature (0.1-inch diameter) 50 and 75 ohm cables.

RG numbers were the original specification for coax during the military buildup for World War II, when not much happened above 30MHz (other than radar) and the only commercial use of radio was AM broadcasting. In those days, RG numbers did mean something, and defined everything that mattered. That all changed in the 50s, with the growth of FM and TV broadcasting, which brought about MATV (Master Antenna TV) receiving systems for buildings, and CATV (community antenna TV) receiving and distribution systems to serve entire communities. We learned how to reduce UHF loss with foam dielectrics, and to reduce cost and weight with lightweight foil shields and copperweld (copper coated steel) center conductors. A 1970 Belden catalog lists 14 RG59 cables; their 2006 print catalog lists 52 of them. These cables differ in many important ways – braid or foil shields that may be copper, aluminum, or both, solid or stranded copper center, or copper coated steel center. Their outer jacket may resist UV, or not. Many are designed for use indoors, where their jackets and dielectrics must not burn or create noxious fumes (the real Towering Inferno was caused by burning cables). Some have beefy copper shields for use with broadcast video or in transmitting applications, others have thin foil/braid shields for use in those MATV and CATV systems.

Q: Do I need cable with a "low loss" foam dielectric for my HF station?

A: Not necessarily. At HF, all that really matters is big copper, both in the center conductor and the shield. A foam dielectric reduces loss at UHF – it provides no benefit on the HF bands, and it costs more! However – a foam dielectric can require the use of a larger center conductor for a given shield diameter. That larger copper reduces loss, especially on the HF bands.

Q: Published specs for many cables don't show attenuation below 50 MHz.

A: That's because most coax is used at VHF and UHF, and because loss in coax is relatively small at lower frequencies. For short runs on 160M and 80M, it doesn't matter. But if you're running hundreds of feet, it can matter a lot. If there's no spec for attenuation at HF, the spec to look for is the DC resistance (DCR) of the center conductor and the shield. Add those two resistances together, and look for a value of 3 ohms/1000 ft or less for RG8, 7 ohms or less for RG8X.

Q: Doesn't skin effect make DC resistance irrelevant?

A: No! While skin effect concentrates current in the skin of the conductors, it is the resistance of that skin that adds IR drop that burns power and degrades shielding. The R-value that plugs into that equation is the resistance at the frequency of interest, and that resistance starts with the DC resistance and increase with frequency! Bottom line – reducing the DC resistance of that outer skin reduces loss and improves shielding!

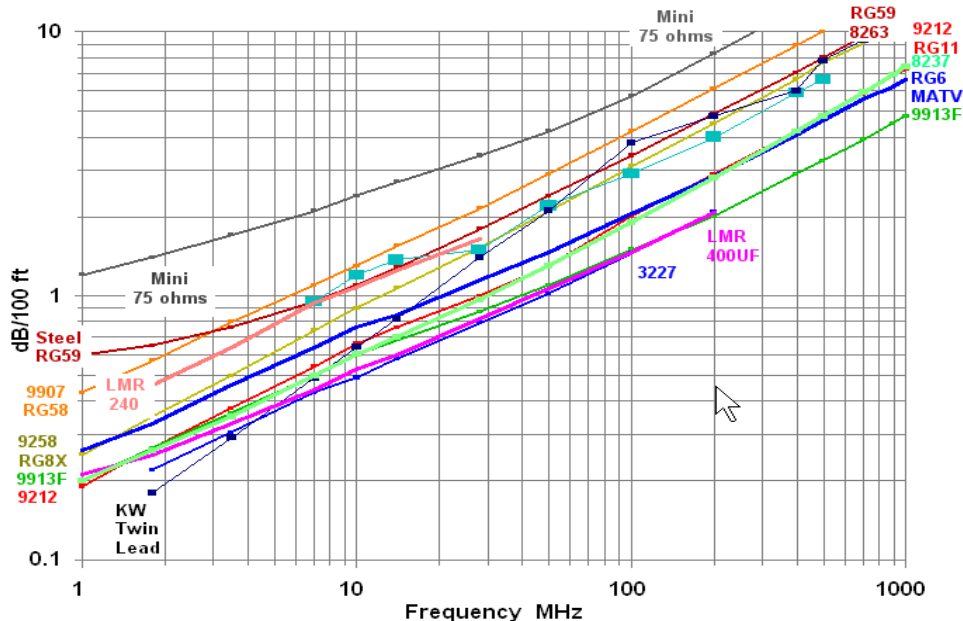
Q: What's the relationship between size and loss?

A: The characteristic impedance of cable depends on the ratio of the diameter of the conductors and their spacing, and the loss is directly related to the resistance. That means we need big copper to minimize loss! Bigger coax can also handle more power, but that's not the only reason we use it – it also provides lower loss.

Q: I'm only running 100 watts. Isn't RG8 or RG11 overkill for wire antennas?

A: It depends on the length of your feedlines, the operating frequency, and how much a dB (or two) is worth to you. Study the graph below, which shows the loss for 100 ft of the best coax on

the HF bands. If your feedlines are 100 ft or less, loss will be less than 1dB on 40M and below, so an RG8X like LMR240, Belden 9258, or the Wireman's CQ118 are a good choice. On the other hand, if you're running 200 ft to a tri-bander on a tower, that smaller coax would burn more than half of your transmitter's power on 15M and 10M! If you're using a dipole to cover all of 80/75M, the increased SWR away from resonance increases loss. Note also that these data are for very good coax cables by major manufacturers. Off-brand cables are often made with much less copper, and have greater loss.



Manufacturers Published Data, LMR400 and 3227 are measured data

Q: What about copper coated steel and copper coated aluminum?

A: For frequencies below 10 MHz, avoid copper-coated steel. At higher frequencies, skin effect takes over, and all the current is in the thin copper coating, but at lower frequencies, the steel increases the resistance (and the loss). Measurements of LMR400, which has a copper coated aluminum center conductor, show no increased loss due to the higher resistance of the aluminum, even as low as 1 MHz.

Q: What about shielding?

A: The shielding provided by coax depends primarily on two factors. First, the *resistance* of the shield – *the lower the resistance, the better the shielding*. Second, the *density* and *homogeneity* of the shield – that is, *a shield that is more dense and more uniform provides better shielding*. This is where quality of manufacture comes into play – cut into cheap coax and you'll find relatively thin copper braid. For best shielding, look for coax that combines a heavy copper braid with a dense layer of foil.

Q: I have a high power, multi-transmitter station. Can I use RG58 or RG8X between my transceiver and amplifier?

A: Smaller coax cables like RG58 and RG8X 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.

Q: How can I use 75 ohm coax for a transmitting antenna? Aren't all transmitters 50 ohms?

A: While most transmitters and power amps are designed to match 50 ohm loads, most of us use antennas that require a tuner to extend their bandwidth, or to load them on additional bands. That tuner will handle 75 ohm coax just as easily as 50 ohm coax. Some antennas are a better match to 75 ohms, and if you're trying to cover a ham band that is broad on a percentage basis, you'll achieve lower SWR over greater bandwidth within the antenna system with 75 ohm coax. Also, for the same copper (that is, resistance), 75 ohm cable has about one half the loss of 50 ohm cable because the current is about one third less. Looking at it the other way, 75 ohm coax will weigh a bit less than 50 ohm coax for the same loss, because it requires less copper. I have two 80/40 fan dipoles up at 120 ft, both fed with Belden 8213 (RG11 foam). In addition to reducing losses on

those bands, these antennas work quite well on 30M, 17M, 15M, 12M, and even 6M. I've made a dozen transcontinental and KH6 QSOs on 6M with 100 watts using these antennas.

Q: Aren't RG8 and RG11 too heavy for use with flat-top wire dipoles not supported at the center?

A: The additional weight of big coax is certainly significant, and requires that the construction of the antenna be more robust. My high dipoles are supported between tall trees that sway in the wind, so I use pulleys in the trees and a 100 pound weight on one end. After several years trying various constructions, I've settled on #10 solid or stranded copper, egg insulators at each end, and center insulators like the Alpha Delta or those sold by The Wireman. The Budwig coaxial feedpoint attachment works electrically, but is not easily rigged to handle the pulling stress on the wires. If you're going to use the Budwig for this kind of antenna, you'll also need an egg in parallel with it to relieve the stress.

Q: How does moisture affect coax? What should I do about it?

A: Moisture affects coax in two important ways. First, moisture accelerates corrosion of the braid, which degrades shielding and increases loss. Second, moisture in the dielectric (the insulation between center conductor and shield) increases dielectric loss. To keep moisture out of coax, all connections should be thoroughly weatherproofed.

Q: How do I keep moisture out of coax?

A: First, install connectors in a manner that minimizes the openings. If you're using solder-type connectors, try to completely fill the holes in the center pin and the shield. When installing cables outdoors, wrap every connection thoroughly with Scotch 88 or 33, and cover that with a rubber mastic tape like Scotch 2228. Alternatively, tape the connection with Scotch 88 and coat that with a product like Scotchcote. Prevent moisture from running down the cable to the connector by putting a downward loop in the cable that forms a "rain drip" below the elevation of the connector.

Q: I've heard that coax degrades with age, causing loss to increase drastically. Is that true?

A: 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 are 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. However – I recently acquired a lot of rather old coax from a neighbor who had become a silent key, and when I tried to sell it, no one was interested. All of it was good quality RG8, RG9, RG11, and RG213 from major manufacturers, and Mom and Dad, who had both been through the Great Depression, taught me to be frugal. So rather than throw it away, I used it to make stubs, and study their performance. So far, I've built more than a dozen stubs from this old coax, and with the exception of one piece that was obviously of poor quality to begin with, every one of those stubs performs very well, including those made from a length of RG9 (Belden 8242) that had been stored outdoors in a shed, probably for a decade or



two (see photo at right). This is very expensive cable – the center conductor is #13 silver-plated copper, an inner silver-plated braid shield, an outer copper braid shield, and a non-contaminating grey jacket. That green stuff on the outer braid is copper oxide, and even the braid without the green is a dull brown. Note the gap between the connector and the braid – the double shields make the outer diameter of this coax 0.424 inches, too big to fit in standard PL259 connectors. HF stubs I built from this coax produced a very deep notch, indicating very low loss.

Why are my results so different from conventional wisdom (old wives tales)? First, because dielectric loss is primarily a factor at UHF, not at HF, so degradation of the dielectric doesn't matter. Resistance of the shield certainly is important, but my stub data suggests that the real world degradation is a lot less than predicted by those old wives tales! Does this mean that we shouldn't be careful to keep moisture out of coax? Of course not – moisture and corrosion are a bad thing. But if I had runs of good low loss coax on my HF antennas that were installed and trouble-free, I'd find other ways to spend my money.

Q: What's the deal with Commscope 3227 and 2427K?

A: Some years ago, a large warehouse full of this cable on 1,000 ft spools came on the market at a

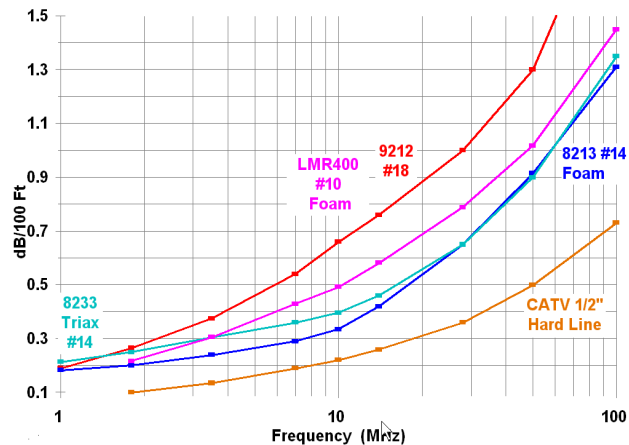
fraction of its normal cost as the result of a telecom bankruptcy. Until recently, some of that stock was still around, selling well below its normal price. It's excellent coax, equivalent in quality and construction to the best of Belden and Times. The two types are identical, except that 2427K, the plenum version, has a higher loss dielectric. The differences only matter above about 500 MHz. The center conductor is #10 solid copper, so it's not very flexible. 2427K is only 0.35-inch o.d., which makes it nice for coaxial ferrite chokes.

Q: You don't talk much about RG58 and RG59. Why not?

A: Primarily because smaller cables have more loss, thanks to the higher resistance of their smaller diameter center conductor and higher resistance shields. The higher resistance shields also degrades shielding. RG8X and RG6 cables are the smallest cables that make sense in a ham station. I recently bought a mag mount antenna so I could work a network of 1.2 GHz repeaters here in the SF Bay Area. The mount came with 12 ft of permanently attached coax that burns 3dB (half of the transmit power) at that frequency! On 20 meters, 160 ft of a good RG58 will burn 3dB, 110 ft will do it on 10M.

Q: I've heard about low loss 75 ohm "hard line" that is often given away by cable TV (CATV) companies in scrap lengths. Is this useful in my ham station? How do I use it?

A: The half-inch size of this cable has about the same low loss as 50Ω half-inch hard line. It's a bit delicate – the center conductor is 0.12-inch copper coated Aluminum, the shield is aluminum, and the dielectric is foam, so it's easy to kink it if you're not very careful. It's easy to fit PL259 connectors onto this cable. V_F depends on the dielectric used, and is typically on the order of 0.84.



Mfr data for some 75Ω cables, LMR400 shown for comparison

Q: Can I use 75 ohm coax on a 50Ω antenna?

A: Sure. For monoband antennas, we can take advantage of the fact that even with a mis-matched line, the impedance seen by a transmitter feeding a line that is a half wave long, or some multiple of half waves, will be the actual antenna impedance. In other words, if the line is some multiple of a half wave, it essentially disappears. To use this property, you'll need to carefully prune the feedline to the desired length. A good way to do this is to connect a short to one end and look for a short at the other end with an impedance bridge like the MFJ259. If you need more length, simply add 50 ohm cable at either or both ends.

Q: So if RG numbers don't mean anything, how do I know what coax to buy?

A: First, stick with the major manufacturers – Belden, Commscope, Times, and with the few cable vendors (Davis RF, The Wireman) who sell quality private-label cables that are well documented on their website. Study their data sheets, and pay only for the specifications that you need. For transmitting on the HF bands, look for beefy copper center conductor and shields, and don't consider any cable smaller than RG8X or RG6. Don't pay extra for a foam dielectric (unless it also gives you bigger copper), and don't buy a cable with unpublished specs. **"LMR400 equivalent" is not a specification, it's an advertising claim, and should be treated with the same mistrust as a sideshow barker!** Some high quality coax cables suitable for use on the HF bands are listed below.

RG8X: Belden 9258, Times LMR240, Wireman CQ116, CQ118 are approximately equal.

RG8: Lowest loss – Commscope 3227, 2427K, Times LMR400UF, LMR400; Belden 8268.

RG8: Slightly greater loss – Belden 8267, Belden 9913, Wireman CQ1000,

RG8 for stubs: Belden 8237 or 9251, Commscope 3227 or 2427K; Davis RF 213.

RG11: Lowest loss – Belden 8213; Davis RF RG11

RG11: More loss – Belden 9212

RG6: Lowest loss – Belden 8238, 8261

Q: What coax should I use on a Beverage or K9AY loop?

A: Neither loss nor impedance are important, but shielding and durability are. This is a great application for good quality RG58 or RG59. Even better, use coax that is "flooded" with a compound to resist moisture penetration, especially for runs that may be attacked by varmints.

Q: What are some good types of coax for my HF station?

A: The table below lists known good cables with full published specifications from known good vendors. Costs listed are those I found with internet searches in Feb 2010 from reputable vendors. Shorter lengths are more expensive per foot. Note that RG58 and RG59 are not on this list – they have too much loss for long runs, and their shielding is not as good as the larger cables. As I have time, I plan to add some RG6 cables to the list. For longer runs, you should consider bigger cables like LMR500, LMR600, and various hard lines. Within each cable type, cables are listed in order of their total DC resistance.

Manufacturer/number	Total DCR	Shield DCR	V _f	% Braid	Shield Mat'l	Center Conductor	Cost 1,000 ft
RG8 Cables Solid PE Dielectric							
Belden 8268	2.4	0.7	.66	97%	2-Cu/Ag	#13 Cu str	\$1,800
Belden 8267	2.9	1.2	.66	96%	Cu	#13 Cu str	\$1,200
Belden 8237	3.1	1.2	.66	97%	Cu	#13 Cu str	\$1,030
Davis 213	3.1	1.2	.66		Cu	#13 Cu str	\$570
RG8 Cables Foam Dielectric							
Commscope 3227, 2427K	2.3	1.4	.84	90% + Al	Cu/Al	#10 Cu	See text
Times LMR400UF	2.7	1.65	.85		Cu/Al	#10 Cu str	\$1,090
Wireman CQ102	2.7	1.8	.84		Cu/Al	Cu/Al	\$675
Wireman CQ106	2.9	1.8	.82		Cu/Al	#10 Cu str	\$693
Wireman CQ1000	2.9	2	.85		Cu/Al	Cu/Al	\$765
Belden 9913F7	3	1.8	.85	95%	Cu/Al	#10 Cu	\$1,242
Davis Buryflex	3	1.9	.83		Cu/Al	#10 Cu str	\$720
Times LMR400	3	1.65	.85		Cu/Al	#12 Cu/Al	\$730
RG8X Cables Foam dielectric							
Times LMR240	7.1	3.9	.84		Cu/Al	#15 Cu	\$540
Belden 9258	7.6	3.3	.82	95%	Cu	#16 Cu	\$560
Wireman CQ116	7.6	3.3	.78		Cu	#16 Cu str	\$270
Wireman CQ118	8.2	3.9	.8		Cu/Al	#16 Cu str	\$270
RG11 Cables							
Belden 8213 (75 Ω)	3.7	1.1	.84	97%	Cu	#14 Cu	\$1,030
Davis RF RG11	4.5	2	.84	97%	Cu	#14 Cu	\$740

Q: What PL259 connectors should I use? Are hamfest connectors OK?

A: Stick with branded connectors from Amphenol. Buy PL259s with a silver plated body – they are much easier to solder and cost only \$2.74 each in lots of 100, only slightly more than nickel plating. Cost is about 10% higher for 50 pieces, another 10% for 25 pieces. 83-ISP is the Amphenol part number. Off-brand and unbranded connectors often have poor mechanical fit, are often made with cheap plating that oxidizes and/or makes poor electrical contact, soft metals, dielectrics that melt when heat is applied.

And don't trust vendors just because they advertise in ham magazines. About six years ago I restocked my parts bins with an assortment of DIN connectors from The RF Connection. As I used them to make patch cables for my radios, I found contact plating I couldn't solder to and dielectric that melted, even with my temperature controlled iron, and even when I did think I'd made a solder joint, it soon failed. When I called to complain, I was told "Hams are cheap." Last I looked, they seem to be selling the same junk.

Q: I've heard that every connector adds a dB of loss. Is this true?

A: FALSE! This is an old wives' tale that has it's grain of truth in the use of junk connectors, which CAN introduce excessive loss, can overheat because the center conductor is too small or goes intermittent, and so on. REAL coax connectors do not introduce measurable loss at frequencies below high UHF. As a test, I recently spliced together 12 100 ft lengths of low loss coax that I had made up for a DXpedition, and measured the loss using HP equipment up to about 500 MHz. The total loss in that cable, including 24 PL259s and 11 barrels was a dB or so less than the loss specified for the cable by the manufacturer at 500 MHz. All connectors were Amphenols.

Q: How can I attach PL259s to half-inch CATV hard line?

A: Begin by removing about 3.5 inches of the outer jacket, then, strip the cable so that at least 1 5/8-inches of the center conductor is exposed. The hard part of this is that this cable often has a dielectric that is bonded to the shield and to the center conductor, so it is very difficult to strip. The only good way to do this is with a coring tool. My neighbor, K6XX, loaned me his, a Cablematic CST500, which works quite well. It's available from US sources for about \$75. You'll also want a basic tubing cutter to make the coring and stripping go faster. Be gentle with the tubing cutter – it's easy to crush the shield if you over tighten it. Once the center conductor is exposed, you'll need to scrape the foam that is still clinging to it. Be careful not to scrape off the copper coating.

For each connector, you'll need two hose clamps just large enough to fit over the cable. Slide them onto the stripped cable, then the retaining ring of the connector, then the connector body, positioning it snug up against the end of the cable shield. Now, solder the center conductor, slide the retaining ring over the connector body and screw it all the way onto the body. Find a UHF barrel, mate it with the PL259, and carefully tighten it with wrenches. Next, find some copper braid about 3/8-inch wide and cut it into two lengths of about 1.5 inches. We'll use this braid to bond across the joint between the connector shell and the cable shield. Using good electrical tape, carefully tape the two lengths of braid to opposite sides of the joint, and wind multiple layers of the tape so that the outer diameter is about the same as the diameter of the cable, going all the way to cover the connector. Now, slide the two hose clamps over the joint, making sure that one is around connector body and the other is around the cable shield, and tighten them carefully. Apply additional weatherproofing to the complete joints after mating it to cables at each end.



For more great advice on using CATV hard line, including methods for pruning to length and alternate methods for installing connectors, see QST, Jan 2000, p91, and websites by N1BUG, N9ZIA, W9XT.

Using Stubs in Your HF Station

Q: What's a Stub?

A: A stub is simply a short length of transmission line connected in parallel with the coax feeding an antenna. At the far end, the stub is terminated with either a *short* circuit or an *open* circuit. In their simplest form, stubs that are some multiple of a quarter wavelength are used to kill harmonics or sub-harmonics of the operating frequency. One property of a transmission line is that it inverts the impedance every quarter wavelength, so a quarter-wave stub with a short at one end looks like an open circuit at the other end. At the second harmonic, that same stub is two quarter-waves long, so the short is inverted twice, and looks like a short circuit to the harmonic. At the third harmonic, it's three quarter-waves, so it's an open circuit again, then at a full wavelength it's a short circuit again. Likewise, a quarter wave stub that is open at the far end looks like a short circuit, but an open circuit at the second harmonic.

Q: When do we use shorted stubs?

A: Shorted quarter-wave stubs are used to kill even-order harmonics (2nd, 4th, 6th, 8th). For example, a shorted quarter-wave 80M stub passes 80M, but kills 40M, 20M, and 10M. A shorted quarter-wave stub for 40M passes 40M but kills 20M and 10M. Shorted stubs are both transmitting and receiving stubs – they kill harmonics of our transmitter, and they also reject signals on harmonically related bands received from nearby transmitters.

Q: What about open stubs?

A: An open half-wave stub is primarily a receiving stub, used to minimize the received signal from transmitters on bands below the one where we're listening. For example, a half-wave open 40M stub will look "open" on 40M, but will be a quarter-wave on 80M, look like a short, and attenuate the 80M fundamental by about 25dB.

Q: Why Use Stubs?

A: Stubs can be used at the output of power amplifiers to attenuate harmonics; nearly all bandpass filters are rated for about 100 watts, so can be used only between the transceiver and the power amp. Stubs also add to the filtering provided by dedicated band pass filters (ICE, Dunestar, W3NQN), or they can function as a "poor-man's band-stop filter." Properly used, a stub can provide 20-30 dB of attenuation at one or more harmonically related frequencies. The lower the loss of the cable used for the stub, the more attenuation it provides.

Q: Does it matter where a stub is connected? Why?

A: A stub works by placing a short circuit across the line at the frequency of interference. Placing a stub on a line forms a voltage divider between the line impedance and the stub impedance. The higher the line impedance at the point of connection, the greater the attenuation. If the line is well matched at both ends, the position doesn't matter, because the impedance at every point along the line is the same. But if there's a mismatch, the impedance will vary along the length of the line, and if the impedance at the location of the stub is low, it won't be very effective. If the antenna is a tribander, it will be a good match at the second harmonic of 20M, which is 10M. But the impedance of a monoband antenna will usually be quite high at the second harmonic – this will also be true of that tri-bander operating on 15M and 10M.

Q: If I connect a stub between my transmitter and my antenna tuner, isn't that a matched line?

A: Not at the frequency of the harmonic the stub is intended to suppress. The high impedance points correspond to the high voltage/low current points, which are established by the impedance at the load end of the coax (in the case of this short cable between rig and tuner, the input of the antenna tuner).

Q: How do I find the high impedance points for my antennas?

A: For both conditions, we must measure the complex impedance ($R + j X$) at the harmonic frequency, at some convenient point on the line. We can then use that impedance measurement with software like N6BV's TLW (on the ARRL Antenna Book CD), AC6LA's Zplots Excel spreadsheet, his TLDetails Windows software, or AE6TY's SimSmith to find a high impedance point where it's convenient to add the stub.

Q: Does the length of coax between my rig or power amp matter?

A: Yes! All power amps include output networks designed to suppress their harmonics. The right place for a transmitting stub depends mostly on what kind of output network your power amp uses. If we have a "good" length for coax between stub and rig (that is, optimum for the power amp's output filter network), we get the full value of the output network's harmonic suppression plus the full suppression of the stub. If we a "bad" length, we can lose most of the output network's suppression. As a result, we may get little, if any benefit from adding the stub.

Q: How do I know what to do with my amp?

A: See the table below, or study the manual for your amplifier. One common form of amplifier output network is the so-called pi-L – starting with the tube, there's a shunt capacitor, a series inductor, a shunt capacitor, and an inductor in series with the feed to coax connector. A pi-L network will have the best harmonic suppression working into a low impedance, so for a Pi-L amp, a harmonic suppression stub should be right at the output terminals of the amp (or a multiple of half-waves away **at the frequency of the harmonic**).

That same circuit, but without the last inductor, is called a pi-network (because it looks like the Greek letter pi). Many lower cost tube amps, and most solid state amps use either a pi-network or a multi-stage elliptical filter with a shunt capacitor at the output. Pi-networks and elliptical filters will have the best harmonic suppression working into a high impedance, so there should be some odd multiple of quarter wavelengths of coax between the stub and the amp **at the frequency of the harmonic** (because the quarter-wavelength of line transforms the low impedance to a high impedance). For example, a quarter-wave shorted stub on the output of a 40M power amp with a pi-network output should be at a distance of 1/8 wavelength on 40M. When computing the length

to move the stub, use the velocity factor of the main transmission line, not the velocity factor of the stub. (Stubs need not be the same Z_0 or V_f as the lines into which they are connected.)_

Pi-L Network	Pi-network or Elliptical Filter	Pi-L on 160/80, Pi other bands
<i>0°, 180°, 360° coax from stub to amp at harmonic</i>	<i>90°, 270°, 450° coax from stub to amp at harmonic</i>	<i>0°, 180°, 360° to stub if operating on 160 or 8; coax 90°, 270°, 450° on other bands</i>
Acom 1000, 1010	Commander HF-1250, HF-2500	Ameritron AL80, AL82, AL-1200
Alpha 374, 76, 77, 87, 91B	Dentron Clipperton L, MLA-2500	Heath SB1000
Ameritron AL800H	Drake L4, L7	
QRO 2500DX	Elecraft KPA500 (Elliptical)	
Ten Tec Titan 425	Heath SB-200/SB201/SB-220/SB-221	
SPE 1K-FA	Kenwood TL-922A	
	Ten Tec Hercules II, Centurion	

Thanks to W5IFP, W4TV, K6XX, and K1HI for adding amplifier models to the table.

Q: I have a set of bandpass filters. Do I also need stubs?

A: Maybe. Nearly all ham bandpass filters are designed for 100-200 watts in matched lines, so in a high power station, they must be placed between the transceiver and the power amplifier. They protect the receiver from other nearby transmitters, but they can't reduce harmonics produced in your power amp. You could buy bandpass filters to go after the power amp, but they are very expensive! It also depends on the quality of your bandpass filters, how much power you're running, how much signal your receiver can tolerate, the spacing between your antennas, and their orientation. Some bandpass filters are much better than others. W3NQN-designed filters are generally acknowledged as the best, 5B4AGN's TXBPF filter set a close second, Dunestar well behind them, and ICE at the low end. The owner of ICE became a Silent Key several years ago, and the filter business has been taken over by others. 4O3A's high power bandpass filters are well regarded.

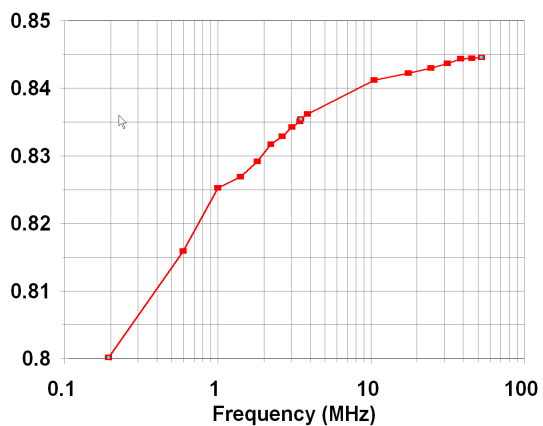
Q: Which coax works best for HF stubs?

A: The best coax for HF stubs is one that combines low loss with a low velocity factor. Low velocity factor means the stub will be shorter. Loss at HF is entirely the result of conductor resistance. It doesn't make sense to spend extra for a premium foam coax that offers low loss at UHF – foam has a high velocity factor, V_f , so the stub must be longer to resonate. Beefy cables like Belden 8237, 8267, and 9251 are great for HF stubs. Coax with a foam PE dielectric will work, but you'll need 25%-30% more cable, and you'll need a #10 center conductor with a heavy copper braid and heavy foil shield to be as good. Commscope 3227 fits this bill, and is great cable if you can find it.

Q: Can I measure a long spool of coax as a stub to find its length?

A: Yes, but there's a bit more to the measurement than meets the eye. That's because the velocity factor V_f is not a constant – it varies with frequency. The variation is small in the

HF spectrum, but, for many cables, can be quite significant at low radio frequencies. V_f starts out very low at audio frequencies, but quickly begins rising at low radio frequencies until it settles at the familiar published value. The graph at the right is measured data for Commscope 3227, a high quality RG213 coaxial cable. The published V_f for this cable is 0.84. Measurements were made by connecting a full 1,000 ft spool of cable as a stub in a precision 50 ohm system and observing the frequency of the nulls. The quarter wave resonance was 194.5 kHz. Additional nulls were measured up to 3.8 MHz (19 quarter waves).



To extend the measurement to higher frequencies, a 59 ft length of the cable was cut from the spool and measured as a stub in the same 50 ohm circuit, starting with its quarter wave resonance at 3.482 MHz, up to its 15 quarter wave resonance at 52.8 MHz. Because its 59 ft length was known precisely, it was used to compute V_f , and the data for measurement of the entire spool was adjusted so that the data agreed at the frequency where both lengths were measured. The two data sets were spliced together in the spreadsheet to get the full curve, and used to establish the actual length of the spool as 1,012 ft. The bump in the curve at 1 MHz is almost certainly a bad data point.

Q: Are there faster ways to measure coax Z_o , V_f , and attenuation?

A: Yes, if you own a high accuracy Vector Impedance or Network Analyzer that can make swept impedance measurements and the save data as a Touchstone file (.s1p). Touchstone is a plain text format for data interchange between measurement and modeling programs. Measure a random length of the type of coax you have with the far end shorted, then again with the far end open. Save both files, then export them to AC6LA's very useful **ZPlots** Excel spreadsheet using the **Measure TL Params** button. Dan developed ZPlots after seeing my data for V_f "the hard way." I now use the DG8SAQ VNWA to make the measurements. The AIM VIA and VNA analyzers, the Ten Tec TAPR VNA, and the N2PK VNA also produce good data for use with **ZPlots**. ZPlots and TLDetails are free downloads from ac6la.com

Q: Your measured data is for coax with a foam dielectric. How about a solid dielectric?

A: The variability of V_f is a fundamental property of all transmission lines. The only difference is the nominal (HF/VHF) value of V_f resulting from its dielectric and the frequency at which the curve for that cable starts to flatten out to its nominal value. For a tutorial discussion of this, see <http://audiosystemsgroup.com/TransLines-LowFreq.pdf> You may be surprised to learn from this tutorial that Z_o also varies with frequency, and for the same reasons! See also two excellent papers by Frank Witt, AI1H, in the ARRL Antenna Compendium Vol 6.

Q: Do I need to account for the variability of V_f when cutting a stub?

A: It depends on the cable you're using for your stub, the frequency where the curve of V_f flattens out for your cable, and the frequency of your stubs. For the cable shown in the graph, this would only be an issue on 160, 80, and 40M. Let's say you're building a shorted stub for 80M, and you don't know the variability of V_f for your cable. You would ordinarily cut the stub 5% long, then trim it to length by observing the null with an open circuit at the fundamental frequency, allowing about one-quarter inch or so extra length to trim and short the end. To correct for the variability of V_f , simply trim the open stub for a null at the third harmonic of the operating frequency rather than the fundamental! Now, when you short the stub, the null at the second harmonic is likely to be exactly where you want it.

Q: What's the best way to measure a stub?

A: Connect a 50 ohm generator to a 50 ohm receiver, placing a Tee connector in line. Connect the Male output of the Tee to the receiver, use any convenient length of 50 ohm cable to connect the generator to one female end of the Tee, connect the stub to the remaining female end.

Q: What's the best way to add a stub to a transmission line?

A: At the desired junction point in the line, connect one side of the junction to one female end of the Tee, connect the other side of the junction to the Male output of the Tee (a coax barrel is required) and connect the stub to the other female end of the Tee.

Q: How do I connect double stubs in a line?

A: You need two Tee connectors, two PL259 connectors, and one barrel connector. Interrupt the transmission line and add PL259 connectors to the line on each side of the break. Reconnect one end to the male of the first Tee (using the barrel), connect the other end of the line to one of the females on the first Tee. Connect the Male of the second Tee to the remaining female of the first Tee, and connect the two stubs to the female ends of the second Tee. -



Q: Wouldn't this be easier with a Tee that has three females?

A: Yes, but the "triple-female" tees I've seen are real junk connectors. Make an iron-clad rule to avoid junk connectors. Those shiny, unbranded barrel, elbow, and tee connectors often have nothing but a tiny spring inside. They can easily overheat or become intermittent. I've had both happen to me more than once, and. I've had triple female tees and cheap N to UHF adapters fall apart with only modest pressure. Stick to brand name Amphenol connectors or old connectors with MIL numbers stamped onto them. They're the real thing. They cost more, but they're well worth it. They're also one of the things I look for at hamfest flea markets – they may have lots of oxidation because they're old, but they're well built.

Q: How do I kill the 3rd harmonic of 40M on 15M?

A: In his book (referenced above) George Cutsageorge, W2VJN, describes a number of very useful double-stub solutions. One of them, also described by Ward Silver, N0AX, in Nov 2007 QST, solves this problem quite neatly. At the same point on the line, insert two stubs – one a $\lambda/6$ Shorted stub and the other a $\lambda/12$ Open stub. On 40M, the Shorted stub looks like 86.6Ω of inductive reactance, and the Open stub looks like an equal value of capacitive reactance, so they cancel and are invisible on 40M. But at the third harmonic (15M), the Shorted stub is $\lambda/2$ and the Open stub is $\lambda/4$, so both stubs look like short circuits and null the harmonic.

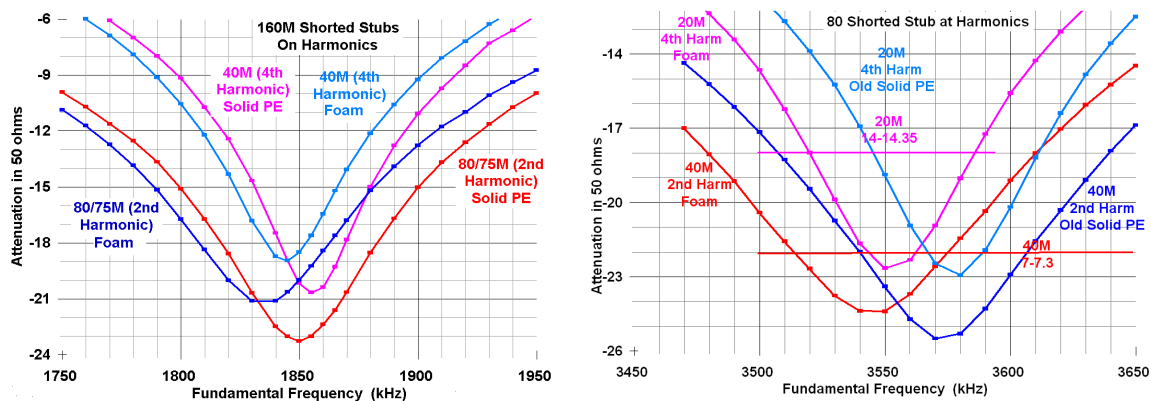
To trim the $\lambda/12$ Open stub, you simply look for the null on 15M. To trim the $\lambda/6$ stub, trim it where it is $\lambda/4$ (at 10.5 MHz), cut it 1/4-inch long, and then short it.

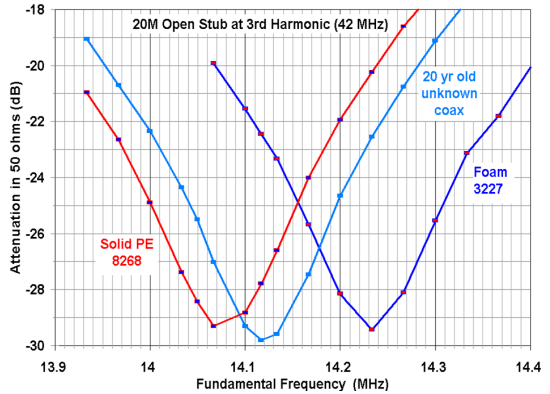
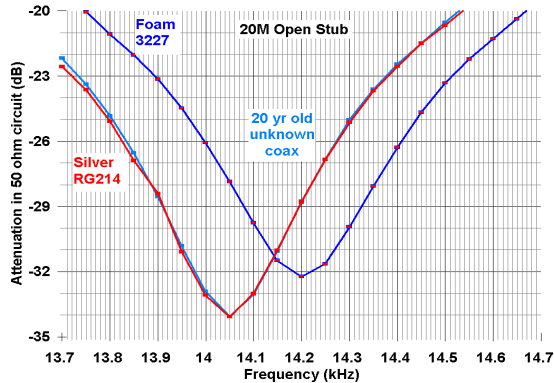
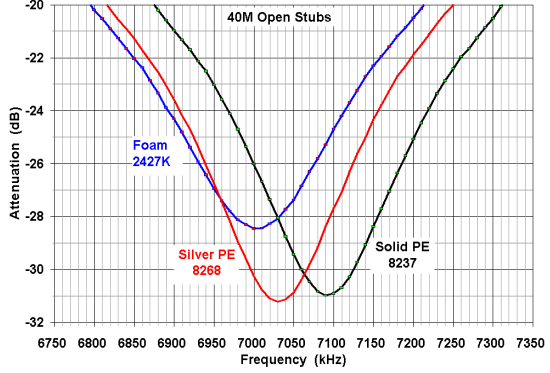
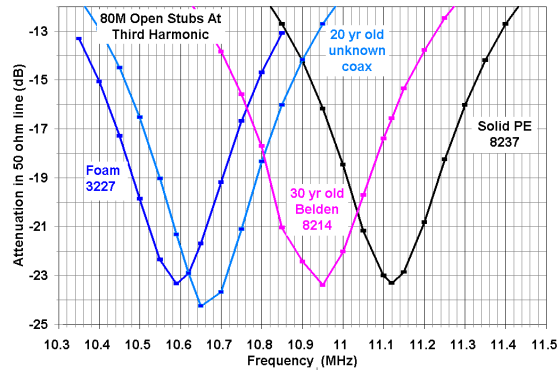
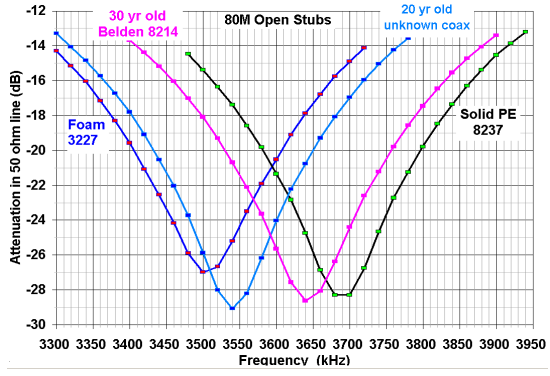
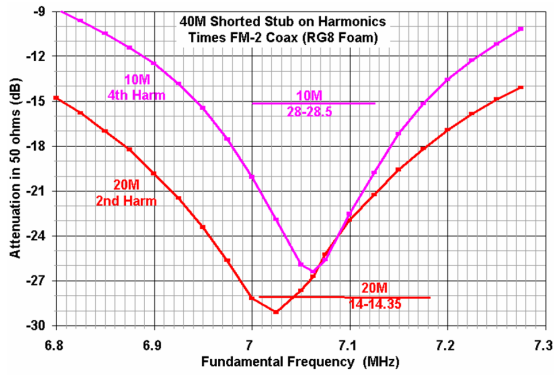
Q: How much attenuation can we get from a stub?

A: It depends on the frequency, the coax used to build the stub, and the impedance on the line at the frequency of the harmonic at the point where the stub is connected. For the best coax, at an ideal location on the line, attenuation of a second harmonic ranges from about 20dB from a 160M transmitter to 30dB or more on 10M. The null depth of a stub at its first resonance is approximately proportional to frequency. The table summarizes best case performance of stubs made with good quality solid PE RG8.

Frequency	$\lambda/4$ Open	$\lambda/2$ Shorted, 2nd Harm
160M	18-21 dB	
80M	20-23 dB	23-27 dB
40M	23-26 dB	25-27 dB
20M	26-29 dB	26-29 dB
10M	28-30 dB	

A few years ago, I measured a random collection of stubs that I had built from a variety of cables for the contesting bands. My test set was the HP generator/calibrated voltmeter rig described above for fine-tuning stubs and measuring V_F . Here are the results.





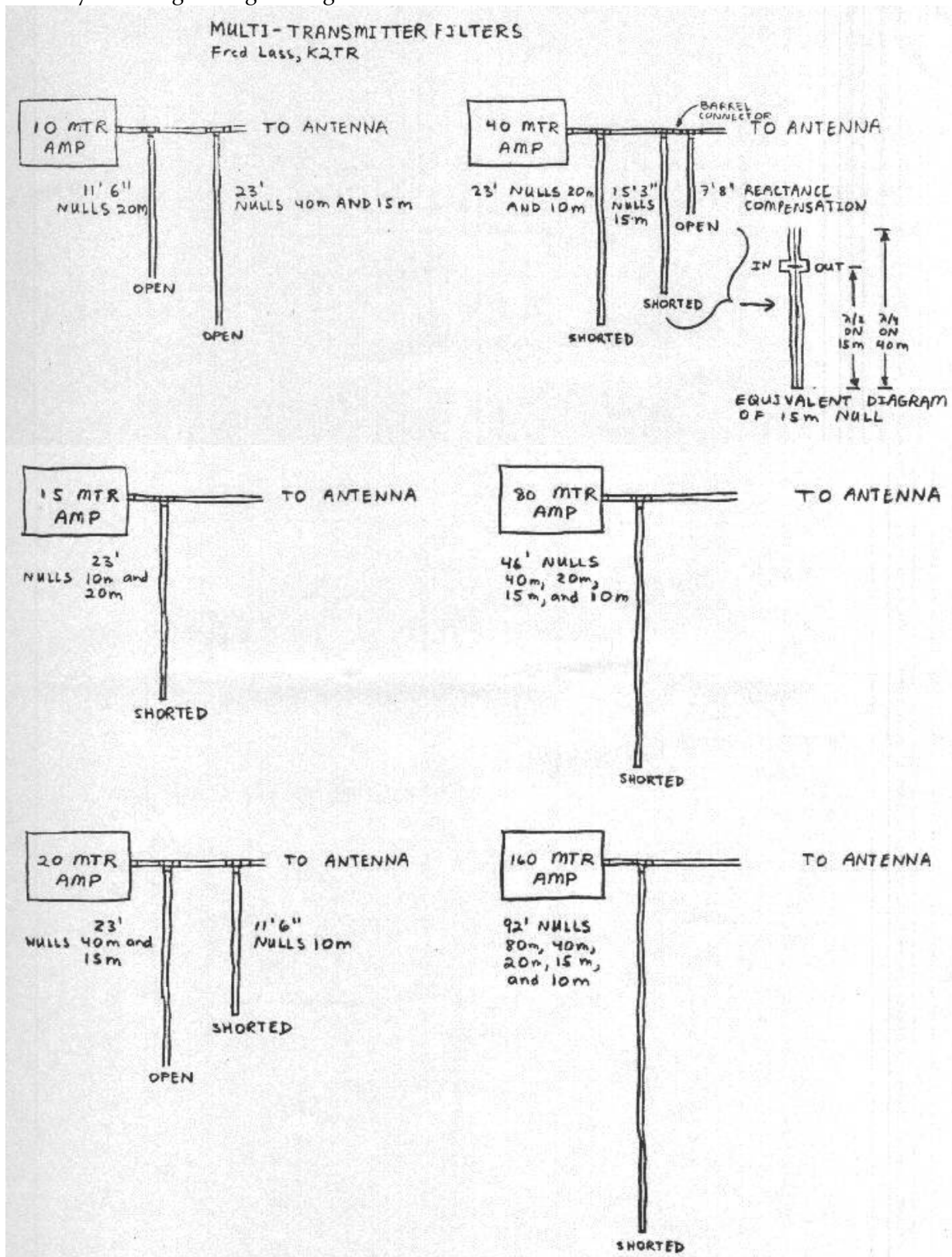
Q: What stubs do I need for a typical SO2R contesting station?

A: A good start is outlined in the table below. It was developed many years ago by Fred Lass, K2TR.

Band	Stub(s)	Approx Length ($V_f = 0.66$)
160	$\lambda/4$ <u>Shorted</u> stub to kill harmonic on 80/75M	89 ft
80	$\lambda/4$ <u>Shorted</u> stub protects 40, 20, 15, 10	46 ft
40:	$\lambda/4$ <u>Shorted</u> stub protects 20, 10	23 ft
	$\lambda/2$ <u>Open</u> stub kills harmonic from 80	46 ft
	$\lambda/6$ <u>Shorted</u> stub + $\lambda/12$ <u>Open</u> stub kills 15M harmonic	16 ft, 8 ft
20	$\lambda/4$ wave <u>Shorted</u> stub protects 10	11.5 ft
	$\lambda/2$ <u>Open</u> stub protects 15 (3/4 on 15), kills 40M harmonic	23 ft
15	3 $\lambda/4$ wave <u>Shorted</u> stub protects 20 and 10 (1/4 wave on 40M)	23 ft
10	$\lambda/2$ wave <u>Open</u> stub protects RX from 20M	13 ft
	1 λ wave <u>Open</u> stub protects RX from 40M and 15M ($\lambda/4$ wave on 40M)	23 ft

Note: All lengths are approximate. All stubs must be trimmed to length. See text.

These drawings, from K1TTT's website, illustrating K2TR's stub recommendations, assuming cable with a 0.66 velocity factor. Take these lengths as starting points, cutting them a bit long and carefully trimming to length using one of the methods noted above.



Q: Where can I learn more about stubs?

A: Recent editions of ARRL Handbook have a very good introduction to stubs, and covers use of

these simple stubs to solve harmonic problems. It was written by W2VJN, whose self-published book "*Managing Interstation Interference*" goes into far greater detail, and has long been considered "the Bible" for hams designing multi-transmitter stations. It covers a lot more than stubs, and it also shows how to build multi-element stub filters that provide much greater attenuation, and to filter bands that can't be tackled with the simple stubs described here! Buy it from Inrad (the filter people) for \$20. They're selling the latest edition, and you want it, because it includes additional techniques and designs that are worth knowing about. Ward Silver, NOAX, has written four very nice pieces on stubs for his excellent "Hands-On Radio" series in QST. They were published in Nov 2004, Oct and Nov 2007, and Jan 2008.