Experiment #22—Stubs

Most hams know about transmission line matching and VSWR, but the mechanics of stubs and using them for filtering is often considered mysterious. Like most mysteries, stubs are not hard to design and use if you know the secret. This month, not only will you learn the secret, but you'll build a useful gadget in the bargain.

Terms to Learn

- *Electrical length*—the length of a transmission line in terms of the wavelength (λ) of the energy traveling through it.
- *Termination*—a load attached to a transmission line.

Background

So what is a stub and how does it work? A stub is just a length of transmission line terminated in a fixed impedance, usually a short or open-circuit, in parallel with another transmission line to create a tuning or canceling effect. The tuning and canceling are the result of interference between the RF energy in the two transmission lines. That was simple, wasn't it? Take a deep breath and read on.

Before proceeding, we'll need to review some fundamentals of transmission lines.

Because energy in a transmission line travels slower than in free space, the *physical* length of the transmission line is always *shorter* than its *electrical* length. For example, if a piece of RG-58 is 1 λ long to energy traveling through it, the physical length of the cable will be about two-thirds as long as the wavelength of the same energy traveling in free space.

Impedances in a transmission line repeat every $^1/_2\,\lambda$ along the line. (If terminated in its characteristic impedance, Z_0, however, impedance is the same everywhere along the line.) If I terminate any transmission line with a load whose impedance is 100 Ω at some frequency, f, then every $^1/_2$ electrical wavelength away from that load, the transmission line will again present a 100 Ω impedance. If the line is perfectly lossless, I can't tell how many half wavelengths I am from the load.

Open and short circuits reflect 100% of the energy in a transmission line. For an open-circuit, the incoming (or *incident*) and reflected voltages are in phase and add together. The incident and reflected currents are out-of-phase and cancel so that there is zero current at the open-circuit. For a short circuit, voltages cancel and currents add.

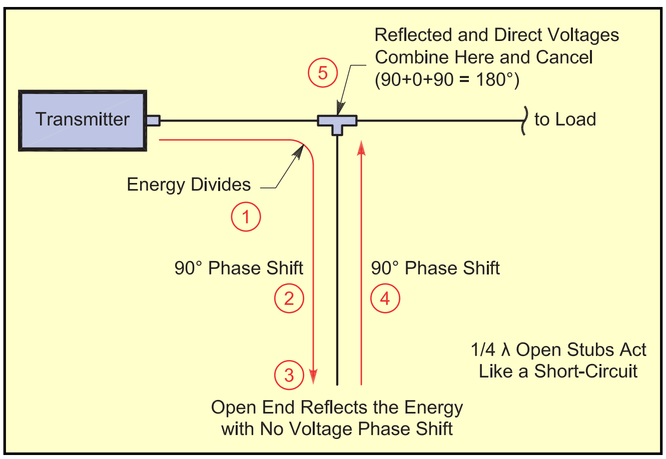

Figure 1—A $^1/_4\,\lambda$ stub uses reflections to cancel energy at its free end.

Stub design is based on these three key elements.

Figure 1 illustrates how a $^1/_4\,\lambda$ open stub (stubs are referred to by their electrical length and terminating impedance) creates an apparent short circuit. Imagine a single packet of RF energy just a few cycles long—a very short CW dit. The energy travels in the line from the transmitter, encountering the junction of the stub and the rest of the line. The energy divides between the line and stub. The wave traveling down the stub is phase shifted by 90° because the stub is an electrical $^1/_4\,\lambda$ long. At the open-circuit, all of the energy is reflected with the voltages in phase (no additional phase shift). The reflected wave gets another 90° of phase shift going back along the stub for a total phase shift of 180°. At the junction, the out-of-phase voltages cancel or *null*, creating an apparent short circuit. The quarter-wave open stub presents a short circuit at its free end!

Complete reverse only occurs if the stub is completely lossless and exactly $^1/_4\,\lambda$ long. Loss reduces the returning voltage, preventing a complete cancellation. Being off-frequency means that the net phase shift won't be precisely 180°. Nevertheless, the range of frequencies over which most of the voltages cancel is sufficient to be useful across a ham band.

What happens if the stub is shorted, instead of open? At the termination, the wave is reflected with voltage phase shifted 180° instead of zero, making the total phase shift 360° in the stub. The voltages now add back together, as if no stub was connected at all. The quarter-wave shorted stub acts like an open-circuit at its free end.

Longer stubs take advantage of the $^1/_2\,\lambda$ repetition of impedance. If the quarter-wave stub is doubled in physical length, to become $^1/_2\,\lambda$ long, its terminating impedance repeats at the free end. Leaving the physical length alone and doubling the frequency (halving the wavelength) has exactly the same effect so that the terminating impedance appears again at the free end. A stub any number of $^1/_2$ wavelengths long acts as if it were just $^1/_2\,\lambda$ long, although with a little more loss.

Harmonic Filtering

By far the most common application of stub is to act as a filter for transmitter harmonics. The free end of a $^1/_4\,\lambda$ shorted stub presents an open-circuit at its *fundamental frequency*, but a short circuit at the second harmonic where it is $^1/_2\,\lambda$ long. The free end also presents a short circuit at the fourth, sixth, eighth, and so on, harmonics where it is an integral number of $^1/_2$ wavelengths long. While passing energy at the fundamental frequency untouched, all even harmonics are canceled!

Half-wavelength stubs also filter harmonics, but in a slightly different manner. The free end of a shorted $^1/_2\,\lambda$ stub presents an open-circuit at one-half its fundamental frequency because there it is a $^1/_4\,\lambda$ stub. The stub acts like a short circuit at the fundamental and all harmonics.

Table 1 lists the filtering effect of $^1/_4$ and $^1/_2\,\lambda$ stubs cut for

H. Ward Silver, NØAX ♦ 22916 107th Ave SW, Vashon, WA 98070 ♦ n0ax@arrl.org

Table 1
Useful 1/4 and 1/2 λ Stubs for Filtering

Stub Type	*Passes*	*Nulls*
1/4-λ 160-m shorted	160	80,40,20,15,10
1/4-λ 80-m shorted	80	40,20,15,10
1/4-λ 80-m open	40,20	80
1/4-λ 40-m shorted	40,15	20,10
1/4-λ 40-m open	20,10	40,15
1/4-λ 20-m shorted	20	10
1/4-λ 20-m open	10	20

different ham bands.[1] The possibilities are endless!

The 60, 30, 17 and 12 meter bands are absent from the table because stubs cut to pass or null these bands don't have a similar response in any of the other HF bands. These bands are not *harmonically-related* to other bands.

Design and Build a Multi-Band, Switchable Stub

Taking a look at rows four and five of Table 1, you can see that if a 1/4-λ 40-meter stub could be changed from short to open, it would pass or null signals from any of the four highest harmonically related HF bands, 40 through 10 meters. By attaching a switch to the end of an appropriate length of cable, you can do just that, as shown in Figure 2.

Cut 24 feet of coax with a solid polyethylene center insulator, such as RG-58 or RG-213. (You can use foam-insulated coax if you adjust for the different velocity of propagation.) Install a coax connector on one end.

Trim about a half inch of jacket and center insulator from the cable. Twist the shield and center conductor together and attach the stub to your SWR analyzer as shown in Figure 3. Any type analyzer that displays reactance can be used.

Tune for the *lowest* frequency at which the reactance "X" goes to a minimum. Don't watch the SWR value—it will remain high—or the R value. At this frequency the stub is acting like a 1/2 λ shorted stub, so the frequency should be *twice* the 40 meter design frequency. Measure stubs at a short-circuit frequency because the SWR analyzers give a much sharper and clearer response than for high impedances.

Since you're starting with the stub too long, trim 1 inch at a time and repeat the measurement until the short occurs at twice the desired 40 meter frequency, that is, 14.200 MHz for a 7.100 MHz stub.

When you've reached the desired frequency, replace the short with a toggle switch as shown in Figure 2, cover it with the plastic container and attach the stub to your radio's output with a T connector.

Attach an antenna and listen to signals as you switch the stub from open to shorted on the different bands. You should hear a difference of around 3 S units as you change the stub between "pass" and "null."

Tips on Stubs

I hope you'll try your hand at other types and uses of stubs. If you do, here are some helpful hints:

- Keep the shorting leads *short*!
- Trim open stub shields back from the end of the center insulator by 1/8 inch to prevent arcing from the extra voltage.
- Insulate and waterproof stub ends with shrink wrap or tape to prevent arcing or degrading the cable.
- Use low-loss cable to get the deepest null. RG-213 is good; surplus hardline is even better!

[1]G. Cutsogeorge, *Managing Interstation Interference*, Table 11, International Radio (**www.qth.com/inrad**), 2003.

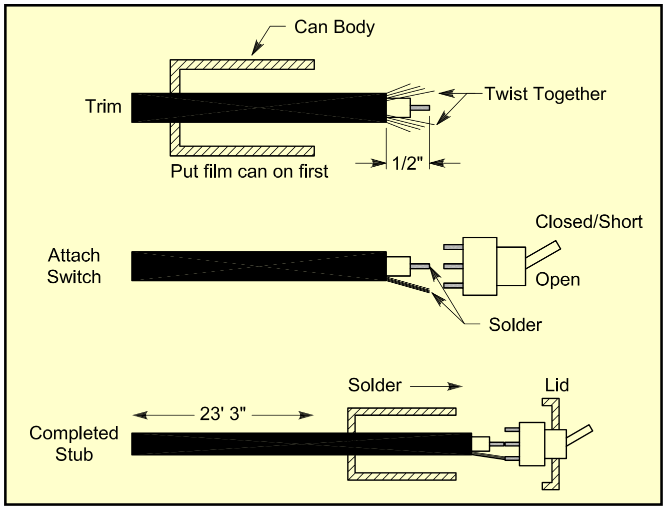

Figure 2—The switched-stub can pass or null energy on 40, 20, 15 and 10 meters.

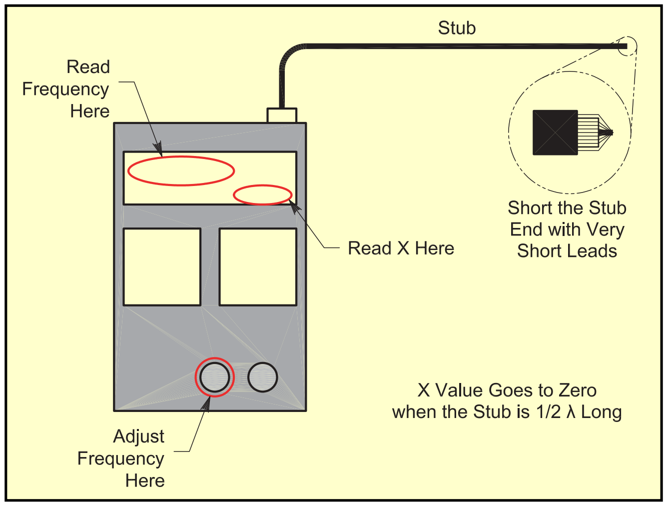

Figure 3—Use an SWR analyzer to measure the frequency at which the stub is 1/2 λ long.

- Remember that the stub's electrical length must include all adapters, connectors and switches. If possible, trim to length with all such extra items attached.

Suggested Reading

The best book available today on the subject of stubs is W2VJN's *Managing Interstation Interference*[2] with lots of information about all kinds of interesting stubs and applications. The May 2001 *QST* article, "Making a Stub," by Dean Straw, N6BV, may also be helpful.

Shopping List

- Plastic film can or pill bottle
- SPST or SPDT toggle switch
- 25 feet of RG-58 coaxial cable (any solid polyethylene 50 Ω cable will do)

Next Month

It's time for a holiday open house at NØAX's workbench and ham shack! I'll show off my tool box and gadgets to encourage all the Hands-On Radio homebrewers and experimenters. I'd better get started on the clean-up right away!

[2]See Note 1.