Jim Brown, K9YC / k9yc@arrl.net

Building Contest Scores by Killing Receive Noise — Part 1

As a West Coast contester, I'm not competitive in DX contests, so I often operate QRP in pursuit of the personal challenge of attaining 5BDXCC with 5 W. I've been very pleasantly surprised at how much I can work, when the station on the other end can hear well. The problem is that many stations with big signals have poor receiving capability. When you can't hear well, it's easy to turn into a CQ machine, and miss a lot of QSOs.

So, let's talk about how to track down and kill the noise that is costing you contacts! We'll begin by discussing the three basic kinds of noise, how to identify each, how to track down noise, and how to suppress it.

How Much Noise is "Normal?"

The noise we hear when the band is open is propagated, as is any other signal, from various places and at various distances from your antenna. A good rule of thumb is that, at a reasonably quiet location, noise should increase by at least 10 dB when the band opens. A location within most cities and suburbs may be a lot noisier, but increasing the observed difference at your location will help you hear more of the weaker stations on the band.

Types of Noise

Noise on our ham bands is of three basic types. The one we're most familiar with is ***impulse noise****,* most often generated by defective equipment in the electrical power distribution system and by lightning. In the power system, impulse noise is generated by arcing, typically at a defective insulator, transformer, or intermittent conductor. Defective neon signs are another source of impulse noise. WX5L notes that forced-air attic ventilator thermostats can create impulse noise as they age, especially if they are near the fan as it vibrates the surrounding area.

The ordinary "static" we hear from the AM broadcast band up to about 7 MHz is impulse noise — lightning from millions of sources, propagated just like any other radio wave from discharges near and far. The loudest crashes are nearby; the more-distant lightning blends together to form a more uniform din. Impulse noise is quite broadband. It consists of the infinite harmonics of the impulse.

The strength of impulse noise tends to fall off both with increasing frequency and increasing distance from the source. The strength of power line noise, if present at all, also varies with weather, especially humidity.

Referring to Figure 1, the horizontal lines in the waterfall are static crashes, the vertical lines are signals. The one around 1828 kHz is a CW signal, the weak ones around 1831 and 1839 kHz are probably electronic noise, and there's an LSB signal around 1854 kHz.

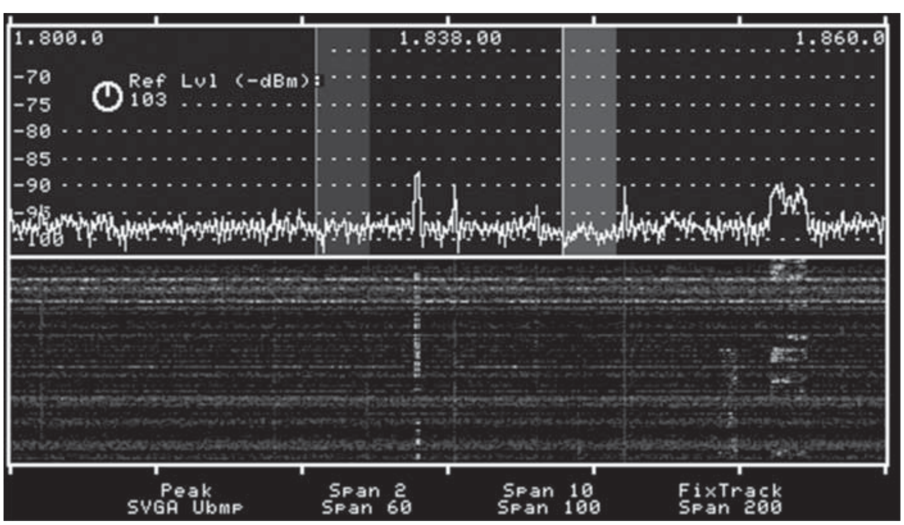

Figure 1 — Static crashes on 160 meters.

Electronically generated noise is the second basic type, and, in recent years, it has become the dominant noise source for most of us. Electronic noise can emanate from anything with a microprocessor, any digital electronics, variable-speed motor controllers, and switch-mode power supplies (SMPS). These devices — mostly in the range of 5 to 24 V dc — power cable boxes, home entertainment systems, and low-voltage lighting. They often come in the form of "wall warts" and cord lumps that also charge batteries for everything from mobility scooters and power tools to cell phones. They may also be built into the electronics themselves — TV sets, computers, refrigerators — virtually anything that plugs into a 120 V ac outlet. The charge controllers and dc-to-ac inverters that are part of solar power systems also can generate high noise levels if poorly designed and/or poorly installed. We'll discuss solar power systems in Part 2 of this article.

The average home typically has at least 30 such potential noise sources and often more, and we hear not only our own but those in our neighbors' homes. The noise produced by these sources is mostly radiated by the wires and cables attached to the noise-generating sources, although in larger appliances, such as refrigerators and variable-speed motors, wiring internal to the source may radiate the trash. It's simple antenna action. By virtue of poor design, the noise source leaks *common-mode* current onto external cables and *differential current* onto internal wiring, both of which become antennas.

Signal leakage from equipment or wiring is a third type of interference. Figure 2 shows leakage from a VDSL modem from about 3.7 to 5 MHz that strongly affects the 75 meter band. With help from WØQE, Tom, WØIVJ, captured this spectral plot from an SDR as he drove around his neighborhood.[1] The broad hump of noise is from the modem. The spikes are from electronics or an SMPS in his vehicle, as well as from other neighborhood noise sources. The spike at 5 MHz is WWV's carrier. This RFI will be heard as noise or hash. We'll have more to say about this form of RFI in Part 2 of this article, where we address issues and solutions associated with specific product types.

Tracking Power Line Noise

Power line noise current — and the current from arcing neon signs — flows on wires connected to the arcing source, and is radiated by those conductors just as an antenna would. Low-frequency components of the noise use very long lengths of those conductors, while higher-frequency components use those parts of the conductors that are very close to the source. Those low-frequency components can travel pretty long distances. It's not at all uncommon for hams in rural areas to hear arcing power lines 10 to 20 miles away on the lower ham bands.

It's quite difficult to locate the source of power line noise at low frequencies, both because the wires radiating those components are so long, and because the noise may travel along the lines as a differential signal. The key to locating the source of power line noise is to search for it at VHF and UHF. I have several tools that work well for this.

If the source is within walking distance, a handheld AM receiver that can tune to VHF and/or UHF is a big help. I have two — a Kenwood TH-F6A hand-held transceiver and a Tecsun PL-660. The Tecsun PL-660 (and the PL-880) receives AM on the MF and LF bands and from about 2 MHz to nearly 30 MHz. The PL-660 also receives AM on the 118-137 MHz aviation band (the PL-880 does not).

The Tecsun radios use DSP technology and happen to be excellent AM and FM receivers for both SWLing and entertainment. The TH-F6A can receive AM from just above the audio spectrum to 1.3 GHz (although it's not very sensitive below VHF), and it maintains maximum sensitivity to about 550 MHz. If the source is beyond easy walking distance, a VHF/UHF FM mobile rig that also offers AM mode is a great tool. My current favorite is a Kenwood TM-V71A.

The two Kenwood rigs have many programmable memories. In addition to repeater frequencies, I've programmed my TH-F6A and TM-V71A for AM on 160, 200, 300, 400, and 550 MHz. When searching for the source of power line noise, I drive around tuned to 160 MHz looking for the signal. When I find it, I switch to higher frequencies as it gets stronger. Once it peaks at 550 MHz, I get out of the car with the receiver tuned to that frequency.

By participating in club foxhunts, I learned that placing a hand-held with a rubber duck close to my chest would block signals coming from behind me, making it possible to determine the direction of the noise, and then to move toward it. Even more directivity is possible by attaching a small 440 MHz Yagi and setting the radio for AM around 440 MHz.

Ideally, we want to identify the source as precisely as possible before calling the power company. By all means, get an address, intersection, utility pole number, or latitude and longitude coordinates from your GPS. The closer to the source you can direct the utility's investigating team, the more likely it will be that the noise problem will be found and fixed — and the more your expertise will be respected. ARRL can provide advice on contacting the power company and what to do if things don't go as well as you hope.[2] In most areas, utility companies will cooperate in locating a noise source, because these often point to potentially dangerous conditions or likely points of failure.

Electronic Noise Sources

Just as with power line noise, our first task is to identify the noise as electroni-

Figure 2 — VDSL modem.

Figure 3 — Some RFI-hunting tools.

cally generated, zero in on the source, and, once found, suppress it. Electronic noise sources, except for those sources that generate arcing, are some form of square wave. Square waves produced by switch-mode power supplies typically show up in the 10 kHz to 30 kHz range and are not stable in frequency. These are free-running oscillators, and, to get around FCC rules for radiated noise at a single frequency, they are frequency modulated by random noise. This produces the characteristic carriers spaced 20 to 60 kHz apart (twice the frequency of the square wave), each carrier surrounded by sidebands of noise, that drift up and down the band as they warm up, or as their load condition changes. When we hear (or see on our rig's spectrum display) these drifting carriers surrounded by humps of noise, we know that the culprit is some form of switching power supply or dc-to-ac inverter. If the carriers do *not* move, the source is most likely circuitry linked to the clock for a microprocessor or other digital electronics.

Figure 4 shows the classic spectral signature of a SMPS, as well as of 11 signals that are likely generated by a stable clock for digital electronics. This screen shot shows the lower 60 kHz of 160 meters; the total height of the waterfall displays about 165 seconds. The noise source in this instance was an SMPS in my shack (about 30 seconds above the bottom of the waterfall). The repetition rate of this SMPS is about 14 kHz, half the spacing between frequency peaks. The straight vertical lines in the waterfall are electronic noise produced by digital equipment, probably from several sources. At least one — the weak signal just to the right of the pulsed signal at around 1840 kHz — is drifting down in frequency at a much slower rate, so it is also an SMPS. An SMPS sounds like a gurgling carrier surrounded by noise. If it's weak, we'll hear only the carrier.

Electronically generated noise generally is *not* broadband, but rather is stronger in some frequency ranges than others. The 33 V power supplies that SteppIR provided for using their controllers with long cable runs generated extremely strong RFI on the higher HF bands, especially on 12 meters. Despite heroic efforts, I was unable to choke it effectively, and I eventually replaced the manufacturer's supply with a homebrew linear supply.

Wired Ethernet cables radiate what sounds like white noise at VHF, and individual carriers in the HF and low-VHF spectrum. These carriers are stable in frequency and synchronized to the Ethernet switch, but the frequency tolerance is wide enough that you'll typically hear your own and your neighbors' at slightly different frequencies centered around 14,030 kHz, 21,052 kHz, the low ends of 10 meters and 6 meters, and a few frequencies on 30 meters. These are only some of the carriers, but I'm a CW guy, so they're the ones I've identified. I don't know of any Ethernet noise components below 30 meters.

Begin at Home!

When chasing electronic noise, it's always best to start at home. In doing so, we lower our noise level so that we can hear our neighbors' noise, and we also learn to identify the sources and suppress them. A good start is to first kill electrical power to your home while listening to a battery-powered receiver. You may be able to use your transceiver; most draw only 1 or 2 A on receive, so a 12 V battery of relatively modest capacity is sufficient for short listening periods.

There are a couple of bear traps here, though. First, we may need power for accessories such as antenna switching. This can be tricky in some stations. Second, we must make sure that an uninterruptible power source (UPS) doesn't keep noisy equipment running when we think it's turned off. For most of us, that means powering down and unplugging laptops and tablets, and temporarily shutting down other computers. Most UPSs generate noise when regenerating ac from their batteries, and they may be noisy even in stand-by mode, so they should also be turned off. The noise that remains once electrical power has been removed from your own home is coming *outside* your home.

For this series of tests, it's best to use

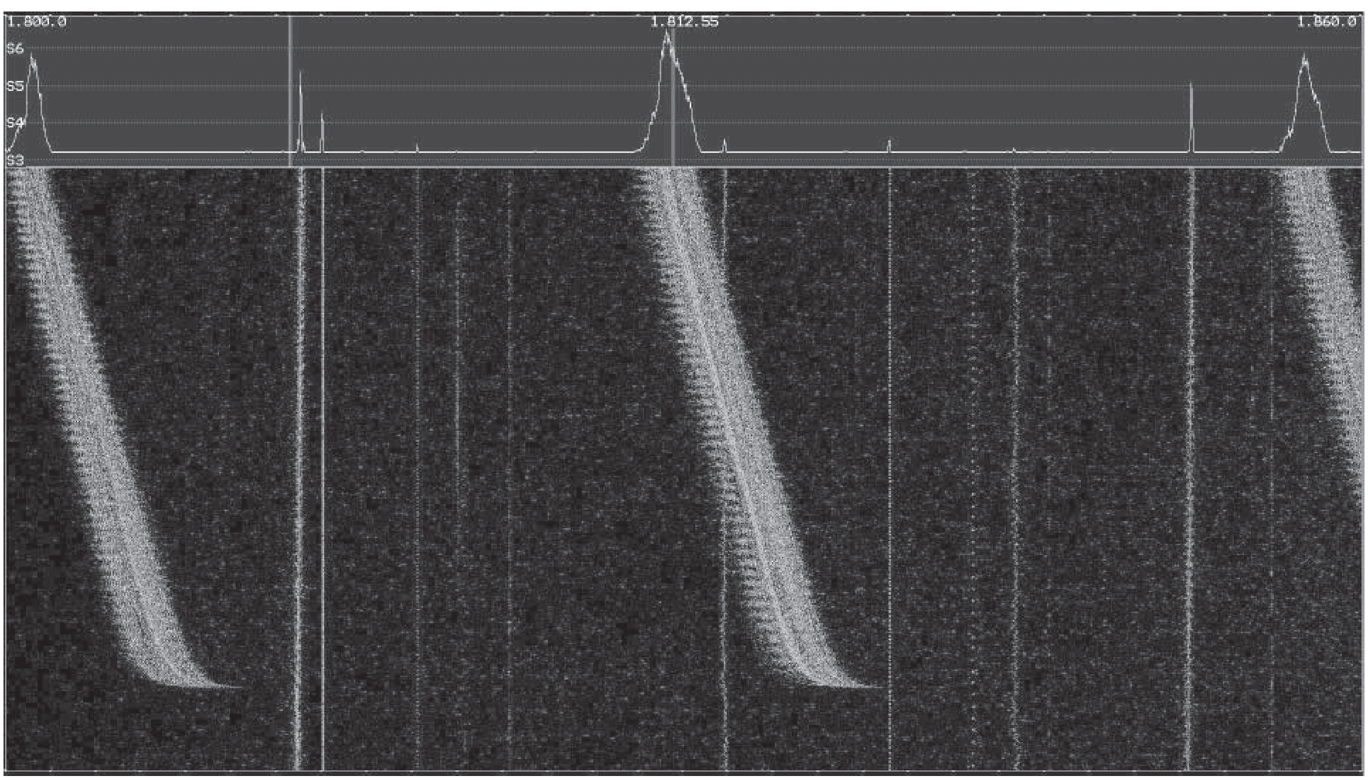

Figure 4 — Spectrum of a switch-mode power supply.

antennas that are close to the house; if your primary antennas are more distant, try rigging a random wire near the house.

The next step is to turn electrical power back on, *one circuit at a time*, all the while listening carefully to all bands and all antennas for any noise that was *not* there with the power shut off. Each time a new source appears, identify and record what is connected to the circuit just turned on. Then, use your portable radio as a signal probe to see if you hear noise. Alternatively, turn off each piece of equipment on a given house circuit, and listen for the noise to disappear. As you identify each source, suppress it before moving on to the next one. This testing goes a lot faster and more easily with help from another ham, one flipping breakers, the other listening to the radio. Consider that most SMPSs drift as they warm up and will have shifted in frequency, so it may be necessary to tune around to find them (a spectrum scope is a big help, set to its maximum scan width). Turn possible sources on and off to make certain of what you're seeing. If necessary, you can use VHF/UHF radios (or even FRS) to communicate.

The ARRL website lists common household appliances that can be RF noise sources. Simply being on this list does not mean that a given device *will* cause RFI, but that *some* appliances of its type have been found to generate RFI. The list includes electric blankets, heating pads, clean-air machines (portable and furnace type) aquarium heaters, furnaces and furnace-control circuits, refrigerators, amplified antennas, doorbell transformers, light dimmers, ceiling light fixtures, low-energy compact (screw in) fluorescent lights, touch-control lamps, and photocells.

Peeling the Onion

All of us in the real world hear noises from many sources, the strongest ones obscuring the weaker ones. Finding and killing RFI is a multi-layered process, like peeling an onion; when we kill those strong ones, we can go after the weaker ones.

According to W6GJB, a MFJ-805 current probe can be helpful in finding RF noise currents on cables. The unit is quite simple, and a similar probe can easily be homebrewed. It's just a coupling coil wound on a ferrite core that is then temporarily clamped around the cable we want to check for noise; the coil feeds a diode detector, filter capacitor, dc potentiometer (to adjust sensitivity), and dc meter. There's more information on this topic online.[3]

Portable radios that use a ferrite loopstick antenna make a much more sensitive probe for common-mode current at frequencies where the radio uses the loopstick (below 10 MHz in the case of the TH-F6A). Simply hold the loopstick perpendicular to the cable you're probing. At higher frequencies, use the rubber duck as an RF probe. A TH-F6A menu selection also allows the SMA connector to be used at any frequency, and the Tecsun PL-660 has an antenna input via a 1/8-inch TRS jack.

Noise is conducted from equipment onto cables when cable shields are not bonded to a shielding enclosure at the point of entry, or when unshielded cables are not properly bypassed to the shielding enclosure. The failure to properly terminate shields was first addressed by Neil Muncy, ex-W3WJE (SK), in a landmark paper that appeared in June 1995 in the *Journal of the Audio Engineering Society*. He called it "The Pin One Problem," because pin 1 of the XL connectors used for microphones and other audio interconnections is the shield contact. Pin One problems are a primary cause of RFI, providing a path both into and out of equipment for hum, buzz, and RF noise.

Figure 5a illustrates the Pin One problem, and Figure 5b shows how it couples shield current into active circuitry. Shield current on the output cable flows to the shielding enclosure and from there to the power system equipment ground conduc-

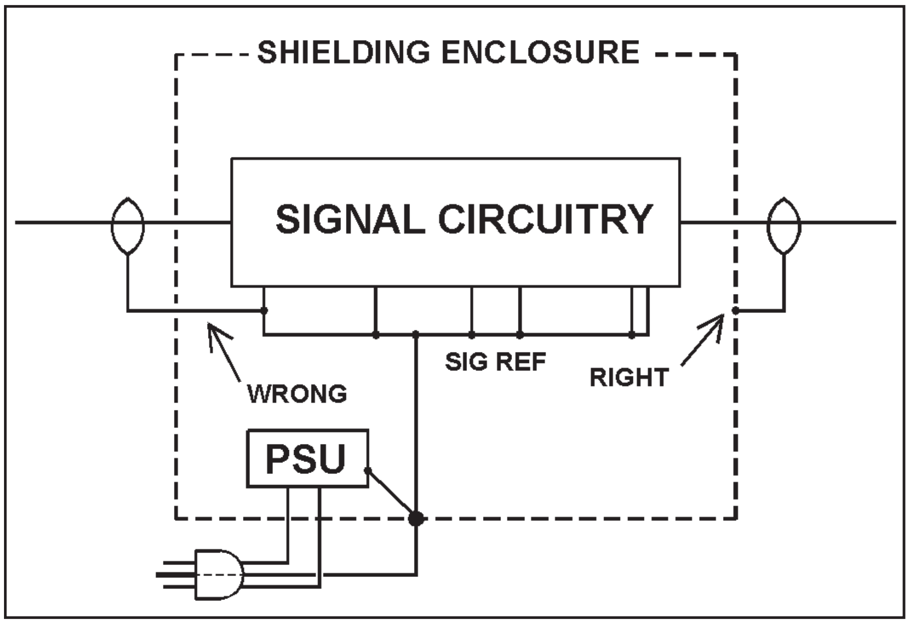

Figure 5a — A depiction of the "Pin One" problem.

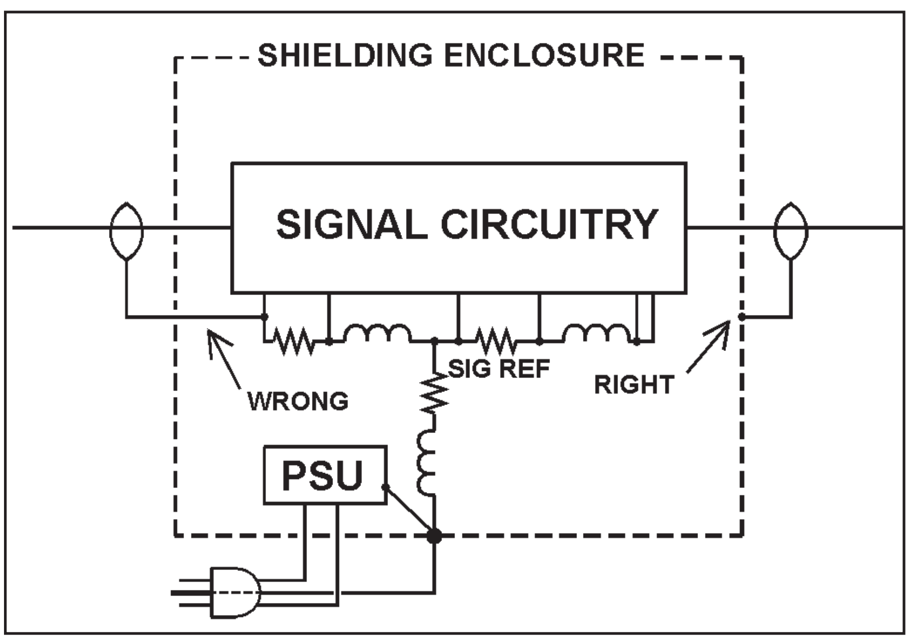

Figure 5b — How the "Pin One" problem couples shield current into active circuitry.

tor (the "green wire"). All noise current stays outside the equipment, so it can't couple to the equipment.

Shield current on the input cable flows to a return trace on the circuit board on a path at the whim of the PC board layout artist, and eventually gets to the same power system ground conductor. As it traverses the return trace(s), IZ voltage drops are established across the R and L of the path, and the potential difference is injected at the input of one or more active stages, where it is amplified (and, if it's RF, detected by diode action at a stage input).

Pin One problems on both input and output cables cause hum, buzz, and RFI; signal-flow logic cannot be used to find them, because layout of the signal-return path, which often has nothing to do with the signal path, determines where noise is injected. And because the cable shield connects to some random point inside the unit, any noise present at that point will couple onto the cable shield and be radiated by the shield. *This is a major cause of RFI from equipment.*

Because of the way printed circuit boards are manufactured and mounted in equipment, it is rarely practical to correct Pin One problems without major surgery that is likely to turn into a major engineering project. Of course, we don't want to do anything that affects a product warranty, nor do we want to open up our neighbor's TV set, computer, or WiFi router. A far better solution is to kill the current on the cable shield by (1) choking it with a suitable ferrite choke, and (2) shunting the current away from it by bonding all equipment chassis together and to the ground system for the shack and the building.[4]

Magnetic Field Coupling

Magnetic field coupling of noise is proportional to the strength of the current, the area of the loop in which the current flows, and the loop area of the receiving circuit. Loop area is minimized when forward and return conductors are run closely in parallel, and it is increased when conductors are spread out — for example, at battery terminals of a solar power system or to circulate through multiple batteries wired in series. Magnetic field coupling is a primary coupling mechanism in dc power circuits such as solar power systems and variable speed motor control systems. Magnetic field coupling is dominant in the near field of the source, which, on the lower frequency ham bands, can be hundreds of feet.

Noise can be radiated by the equipment itself if the circuit layout is poor and the unit is unshielded or poorly shielded. One common design error is wiring that forms an antenna or a current loop with a large loop area. A common design error producing this result is breaking the "ground" layer on a multi-layer printed circuit board. At radio frequencies, the return current for a trace on a circuit board with a ground layer will be confined to a narrow area directly underneath the trace; the trace and the ground layer form a transmission line, so there can be no radiation from that circuit trace. All of that breaks down if the ground layer is broken under the trace — it's like any other coax with an open shield. When this happens, the return current takes whatever unintended path is available, and the result is both an antenna and strong magnetic coupling.

The only known fixes for such equipment are to (1) rewire/rebuild the equipment to eliminate the current loops, (2) completely shield it, bypassing all cables that penetrate the shield to the shielding enclosure, or (3) give it "the bucket treatment," ie, find a bucket large enough to hold the defective device, fill it with water, put the defective equipment in twice, and take it out once.

A twisted pair is far superior to a parallel-conductor cable (such as zip cord) in minimizing noise coupling. All noise-sensitive circuits and all circuits carrying noise currents, especially those carrying large currents, should utilize a twisted pair. It's easy to make your own twisted pair. All the dc wiring for my small solar system uses #10-2 THHN that I twist by cutting equal lengths of black and white stranded #10, clamping one end of both conductors in a bench vise and twisting them with a portable drill. Over the years, I've solved many RFI issues with home entertainment systems by replacing the zip cord used for loudspeaker wiring with twisted pairs.

Suppressing Electronic Noise

Now that we've identified a source and know how noise is coupled, it's time to suppress it. There are two good ways to skin this particular cat. Often it's easiest to replace the noisy component with one that isn't noisy. I've scoured flea markets and second-hand stores to put together a large box of old wall warts for equipment that I no longer own. They're bigger and heavier than a modern switch-mode wall wart, because they contain a linear power supply — that is, a simple transformer followed by a rectifier and a filter capacitor. They're a bit less efficient, but they're dead quiet!

There are at least two good ways to utilize these old linear supplies. First, determine their open circuit voltage and their voltage under load. Next, determine the voltage and current needed by the electronics that it must power. When we find a linear supply that matches the equipment in question, we simply cut the cables for the two supplies and splice the linear supply to the cable that feeds the equipment. For greater flexibility, I install a pair Powerpole® connectors on cables from the linear power supply and the equipment.

A second technique I've used extensively is to obtain a fairly small ordinary sealed lead-acid battery of the voltage used by the equipment and use a linear wall wart to float-charge it. I use Powerpole connectors universally for dc power in my home and shack. It's easy to make a few parallel adapters to connect the charger and several pieces of equipment to a single battery. In my home, one such setup powers my cable modem and Wi-Fi router. (El Niño rains caused us to lose power for 18 hours during the ARRL DX SSB; the Internet router and WiFi system were still running when power was restored!) Another float-charged battery powers four 12 V accessories in my home entertainment system (a cable box, a Roku box, a DVD player, an Apple TV, and a "trucker's" FM modulator that feed an Internet "radio" around my home and yard). I have three more small float-charged batteries powering computer monitors that run on 12-14 V dc.

Likewise, in the shack, all the rigs and their 12 V accessories run from a big battery that is float-charged by a 20 A supply and, during the summer months, by four solar panels. Equipment powered from this system includes three more computer monitors and my antenna switching system. Each functions as a simple UPS. When power fails, my Internet, WiFi, Internet radio, FM modulator, and computer monitors keep right on going. Since those computers are laptops, so do they. Good bye, switch-mode power supply noise!

Killing Current with Ferrite Common-Mode Chokes

Sometimes it isn't practical to get rid of noisy equipment. It may be expensive, something rather specialized, your spouse's favorite lamp, or something in your neighbor's home. In those cases, we have to suppress the noise.

The most useful technique is to apply a suitable ferrite common mode choke to the cable(s) that carry the noise current and radiate or receive the noise current. Our weapons of choice for the HF bands are clamp-on cores and toroids made with Fair-Rite Products #31 and #43 material. The #31 material is superior below 5 MHz, #43 is a bit superior above 14 MHz. I've always recommended #31 because it's a far more universally usable part, so we can save money by buying only #31 in larger quantity.

Start by choking every cable connected to each noise source that you discover. If you can't kill the noise from that source, turn it off and move on to the next source. Continue choking all the noise sources until all are either successfully choked or turned off. Now you know what products are not fixable, and you can start thinking about replacing them with something better.

For 40 through 10 meters, wind five turns through the clamps in Table 1; for 80 and 160 meters, wind 7 turns, and for 6 meters use two turns, with several chokes in series.[5] When counting turns, it's the number of times the cable passes through the ferrite core (one more than visible in the loop). See Figure 6.

Most RF noise is transmitted as a *common mode* signal on wiring connected to the source — that is, the wiring radiates, because noise current is flowing on a coax shield or in the same direction on all conductors. It's simple antenna action. *Differential mode* transmission is a voltage *between* the wires that make up the path, with current on the pair flowing in opposition. Very little RFI is the result of differential mode transmission, so filters are rarely of any use. If a filter *is* used, it must be carefully designed so that it does not degrade transmission of the desired signal.

Commercial power line filters are generally effective *only* if installed *inside* equipment and bonded to the shielding enclosure. They are generally *not* effective when mounted outside equipment. The reason is simple. RF noise gets onto the equipment ground conductor (the "green wire") when it is not properly terminated to the chassis where it enters the noisy product. Just as in the Pin One problem, the green wire does not go through the filter. This fact is further confused by the way in which the terms "differential mode" and "common mode" are defined for power systems. Differential mode voltage is that between line (hot) and neutral; common mode is that between neutral and the equipment ground (the green wire). This is very different from how we, as communications engineers, define common mode, and the way we define it is what causes antenna action. Filters are specified as having common-mode suppression, but they do *nothing* to suppress common-mode current! The same sort of common-mode choke we would use on coax will be equally effective on power wiring.

A common-mode choke on receive (and transmit) antennas helps reduce receive noise, because it prevents the antenna feed line from becoming part of the antenna. This helps, because (1) our antennas are typically up in the air and more distant from noise sources, so they receive less noise by virtue of their distance from sources in our own home and those of our neighbors, and (2) antennas reject some noise by virtue of their directivity. An effective choke on the feed line at the feed point prevents signals picked up on the feed line from filling in the nulls of the antenna's directional pattern. My website has general and specific guidelines for feed line chokes.[6]

We'll continue this discussion in the next issue.

Table 1 — Useful ferrite cores (measurements are in inches).

Fair-Rite P/N	Shape	i.d.	o.d.	Length
0431164181	Clamp-on	0.5	1.55	1.22
0431173551	Clamp-on	0.74	1.15	1.65
0431177081	Clamp-on	1.0	1.7	2.2
2631803802	Toroid	1.4	2.4	0.5

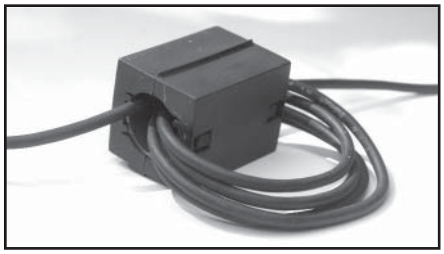

Figure 6 — A 5-turn choke, suitable for 7 MHz to 30 MHz.

NOTES

[1] WØIVJ has posted a video on YouTube. Search on "VDSL2 Up Link Modem Leakage RFI."

[2] E-mail **rfi@arrl.org** or visit the ARRL website, **www.arrl.org/power-line-noise**.

[3] See **www.w8ji.com/building_a_current_meter.htm; www.interferencetechnology.com/the-hf-current-probe-theory-and-application/**, or **www.nonstopsystems.com/radio/frank_radio_antenna_rf-ammeter.htm**

[4] See **http://k9yc.com/GroundingAndAudio.pdf**

[5] For chokes wound on toroids, use the data for small-diameter wire in Appendix 1 of **http://k9yc.com/RFI-Ham.pdf** or the guidelines for small-diameter coax in the "Choke Cookbook" in the same document.

[6] See **http://k9yc.com/RFI-Ham.pdf** and the companion *PowerPoint* slides, **http://k9yc.com/CoaxChokesPPT.pdf**