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Building Contest Scores by Killing Receive Noise — Part 2

In Part 1, we examined the fundamentals of RFI — the nature of noise sources, how the noise they produce ends up in our receivers, and the beginnings of how we can kill that noise. In Part 2, we'll concentrate on killing the noise from those sources once we've found them, and discuss issues specific to various common product types.

Optimize Your Station First

There are some things we can do with our stations to minimize RF noise, and that we *should do* before chasing noise sources: (1) **Use antenna directivity** to point away from noise and toward the stations we want to work; (2) **Locate antennas** as far as practical from noise sources — height helps and generally makes for a better DX antenna; (3) **Use an effective ferrite common-mode choke** at the feed point of every antenna; (4) **Use horizontal antennas**, where practical. They are usually — but not always — quieter than vertical antennas, and (5) **Implement proper bonding and grounding** within your station and throughout your home.(see **http://k9yc.com/GroundingAndAudio.pdf** and W9RE's "Station Tending" column in the September/October 2015 issue of *NCJ*).

Evaluate Equipment for Noise

When people tell you that a certain piece of equipment produces no noise on the ham bands because they can't hear any noise on their radio, should you believe that equipment is clean? *No!* The equipment may be noisy, but other noise from the neighborhood could be covering up the noise that the device in question is generating. Figures 1 and 2 compare the daytime 80 meter spectra at K6GFJ in a San Jose residential neighborhood and at K9YC 30 miles to the south in the Santa Cruz Mountains. The difference in the noise floor is 10 dB. It's not dead quiet in the mountains, either. Everything on the displays from both sites is noise, either from switching power supplies or other electronic sources.

Proximity to Antennas is What Matters

Noise radiates from sources on wires *connected* to noise sources, and it enters our receivers via our *antennas*. My SteppIR, which is up 120 feet and 200 feet from the shack, doesn't hear much noise from the shack, but the 160 meter T vertical, just 25 feet from the operating position, does. When someone tells you that a particular model of Internet router or video monitor sits next to his power amp and there's no RFI, ask how far it is from the station *antennas*, not the radio.

Several years ago, ON4WW put up an excellent web page with more than 20 case histories documenting the successful pursuit of a variety of RF noise. It's well worth reading, **http://www.on4ww.be/emi-rfi.html.**

Issues With Specific Product Types

Low-Voltage Lighting: This generic type consists of any lamps that run on dc, including those in most architectural lighting fixtures, many track lights, and LED lighting. Incandescent lamps *can* run on an ordinary transformer, but transformers large enough to power them don't fit in the electrical enclosures within walls or ceilings, so switch-mode power supplies (SMPS) are almost universally used. All that I have seen are unbranded, unlabeled, and noisy, sold by electrical supply houses where they are called "electronic transformers."

Track lighting now comes in several forms. The track itself can carry line voltage (120 V ac) or low voltage (12 or 24 V dc). Track that carries low voltage is fed by a 12 or 24 V supply, which could be a transformer (quiet), but is usually an SMPS (noisy). Fixtures for line voltage track can utilize 120 V ac lamps, in which case they will be as quiet as any other lamp. Sadly, over the last decade or so, manufacturers have gradually shifted to low-voltage lamps with an SMPS built into the base of each lamp holder, so that it can be connected to a line voltage track. Any noise produced by those supplies will be radiated by the wiring within the track and the wiring feeding the track. The only practical place to choke these noise sources is where external wiring feeds the track, but the parallel wires within the track are efficient radiators.

LED Lighting: LEDs are very efficient, requiring relatively low dc voltage and current for a lot of light, but there still must be a dc power supply somewhere. For screw-in 120 V ac LED replacements, the dc power supply is built into the base of the lamp. Any noise produced will be radiated by the ac line. To suppress that noise, the line should be choked as closely as practical to the lamp. A noisy outboard supply, if there is one, should be choked at its input and output terminals. Several years ago, ARRL tested a broad selection of LED screw-in lamp replacements and found them relatively clean. The bad news is that things change when products become a commodity. Local hams report that off-brand LED bulbs from the big box stores are quite noisy, while Phillips lamps, among those ARRL reviewed, are relatively quiet. My advice: Try a few lamps in fixtures that are close to your antennas and see if you hear them. If they're noisy, return them, and make sure you tell the vendor that "they made noise in your radio."

Faced with noisy low-voltage lighting, I'd still look for LED replacements. Their much lower current requirements could make it practical to replace the existing noisy supply with a quiet linear supply that's small enough to fit within the available space. I'm lighting my shack with five LED strips that I bought at Pacificon from Wired Electronics. The combined load is about 1.25 A from the 12 V system that runs my radios. The shift to LED lighting has already produced some LED lamps that are direct replacements for existing fixtures, and that trend is certain to continue.

Grow Lights: These can be a very powerful source of RF noise that can be heard a half mile away! These 600–1000 W sodium or metal halide lamps run from ballasts that include switching power supplies operating in the range of 50-75 kHz. None are certified meet FCC Part 15 or Part 18 FCC rules. Wiring between the ballast and the lamp is usually fairly long and can form a large loop, so it's rather efficient at ham frequencies — both as an antenna and as a magnetic loop.

Tom Thompson, WØIVJ, and Larry Banks, WØQE, have researched these lamps extensively, and Tom has developed an effective filter designed to be applied between the ballast and the lamp. He found that a filter on the power line side of the ballast was less effective. A commercial

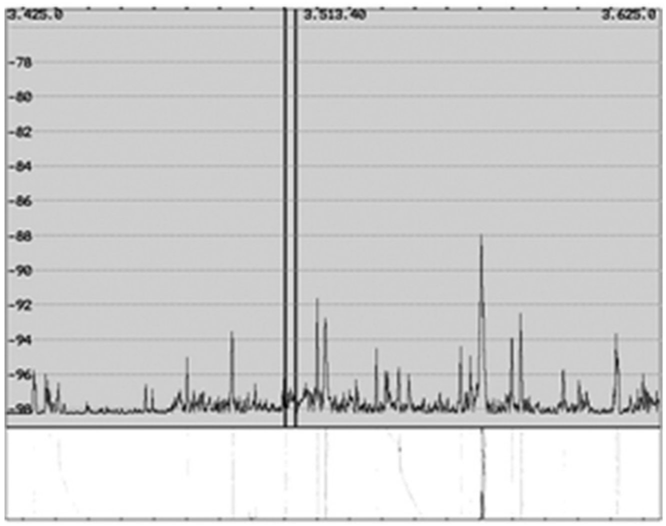

Figure 1 — 80 meters at K6GFJ: Noise floor –98 dBm.

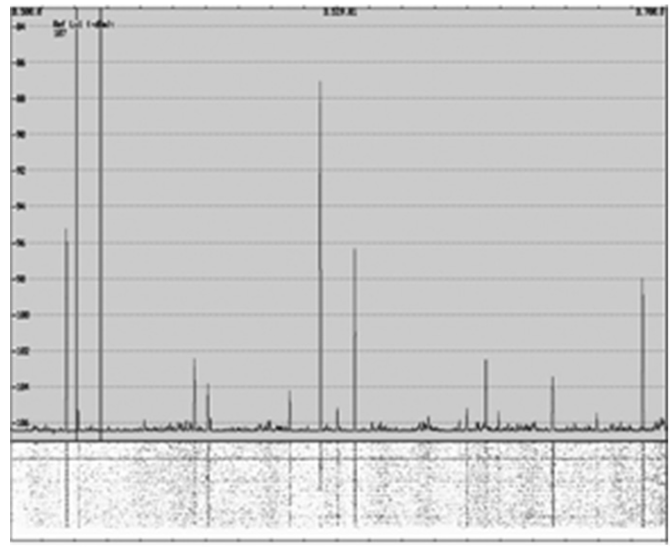

Figure 2 — 80 meters at K9YC: Noise floor –108 dBm.

version of Tom's filter, built by W7LOZ, is available at **http://growershouse.com/revolution-ballast-emi-filter-reduce-rf-emi**.

A report on Tom's and Larry's work, including a schematic of the filter, is at **http://tomthompson.com/radio/GrowLight/GrowLightBallastFilter.html**. Also, there's recent good news from WØIVJ: Some ballast manufacturers are starting to place the ballast on the lamp hood, which reduces the loop area, thus reducing the both the magnetic field and the size of the antenna that can radiate the noise. In addition, Tom thinks that the Galaxy Grow Amp model 90220 may pass Part 18, but the extent to which this kills emissions will likely depend strongly on the loop area of the connection to the lamp.

Tom's filter suppresses only noise radiated by wiring on the lamp side of the ballast. That may be sufficient for many installations, especially where the noise is at 5 MHz and higher. In more severe cases, or where RFI is present below 5 MHz, a common-mode choke on the power line side of the ballast may also be required. Follow the recommendations in the *Choke Cookbook* (in **http://k9yc.com/RFI-Ham.pdf**) for small-diameter coax (RG-8X) for RFI in the frequency range where you hear the noise, running the line cord through the choke. WØQE shows a very different filter design on his website, **www.w0qe.com/RF_Interference/grow_light_electronic_ballasts.html**.

Switch Mode Power Supplies: If you must use an SMPS, plan on adding suppression to it. Start with common-mode chokes on both the 120 V ac and low voltage dc lines for the frequency range(s) where you hear noise. Capacitors across the dc output terminals and the ac input terminals can also help. Select capacitors for low ESR (equivalent series resistance) at the frequency of interest and on the ac line side; use only type X1, X2, Y1, and Y2 capacitors, which are specifically rated for use on the ac line and designed to withstand the 3-6 kV spikes that can occur on power wiring. Choose this capacitor carefully! If it fails, it could catch on fire!

dc-to-ac Inverters: The Samlex PST series of "pure sine wave" dc-to-ac inverters carry an FCC Part 15 Class B rating for RF noise and are relatively quiet. But these may not be quiet enough for any given installation, depending on the proximity to antennas for the bands you want to operate. (Part 15 Class A is a much looser specification for industrial applications, and it allows 20 dB higher noise levels than Class B, which is for residential use.) The Pure Sine Wave inverter in Figure 3 carries FCC Part 15 Class B certification but had to be extensively choked to kill radiated noise. The smallest clamp-ons are for 144 MHz; these and the three smaller multi-turn chokes (0.75 inch I.D.) were sufficient when powering the logging computer for our 7QP mobile operation. As an experiment, the two larger (1 inch I.D.) chokes were added in an attempt to suppress RFI to the 160 meter vertical 25 feet from my shack, and were not nearly enough.

Uninterruptable Power Supplies (UPS): These come in two basic types: Online types supply power continuously, while standby units monitor the ac line and supply back-up power only when the ac mains fail. Both types include batteries to provide power in an outage, a dc power supply to keep those batteries charged, and a dc-to-ac inverter that operates when the unit is producing ac power. If the dc power supply is an SMPS, it will likely produce RF noise while charging the battery. All of the comments about dc-to-ac inverters and SMPS apply equally to UPS units.

Variable Speed Motor Controllers: These are often used in furnaces and HVAC systems. These controllers are notoriously noisy. They consist of an SMPS, the dc output of which is then pulsed at variable width and speed to control the speed of a motor. Both of those pulses are rich in harmonics, and they are radiated by wiring both internal and external to the unit. This radiation tends to be quite strong, because the designers have failed to consider the impact of circuit layout on noise. Thus, loop area tends to be quite large, which increases antenna action and greatly increases the magnetic field produced by the noise current. Variable speed controllers are also widely used for motors in elevators and geothermal systems, where both motor currents and loop areas are even greater.

Solutions include rewiring circuits with large loop area carrying motor current with twisted pair. Some product manufacturers sell optional filters to prevent noise from being conducted onto the power line, but that does not prevent that interior wiring from radiating.

N9TF reports electronic noise in the range of 20-23 MHz spaced about 17 kHz. The source is a Samsung washing machine, and it lasts for the duration of the wash cycle. Peaks on 15 meters are

18-20 dB *above* his noise level. Gene provided videos of this noise, **k9yc.com/SamsungWasher1.mp4** and **k9yc.com/SamsungWasher2.mp4**.

Plasma Television Sets: Plasma TVs produce strong RFI that extends up to at least the 12 meter band, and it is just about impossible to suppress. The best solution is to replace the TV with an LCD model. The noise is produced by the current required inside the display structure to light up each pixel turning on and off, and the resulting magnetic and electromagnetic fields. In other words, the noise is *not* radiated by external wiring but by the display itself. There's no way to suppress it short of major redesign of the display to either shield it or to confine the fields by means of microstrip or stripline construction. Chokes on external wiring will have no effect at all on noise radiated by the currents within the display. Fortunately, plasma TVs are no longer manufactured, but existing units will continue to be used for years.

Typical plasma TV noise spectra are shown in Figures 4, 5, and 6. Note that the spectra will be strongly dependent on which of the dozen or so common DTV video standard signals are being viewed at the time.

There can, of course, be other noise radiated by a plasma TV — a switching power supply and other circuitry separate from the display itself, for example. These noise components would most likely be radiated by cables connected to the unit and *can* be suppressed with chokes.

Wired Ethernet RFI: Ethernet circuits can generate noise on HF (carriers are around 14,030, 21,052, and the low end of 10 and 6 meters) that can be suppressed by choking every cable connected to the Ethernet switch. Both ends of the cable are potential noise sources; cables shorter than about 0.10 λ at the frequency of interference can be choked in the middle with a single choke. Longer cables should be choked at both ends. Don't forget to choke the power supply cable. As noted earlier, you'll hear *both* your own carriers and those of your neighbors; to identify yours, kill power to the Ethernet switch and note which carrier disappears. Gauge your success on the reduction in strength of your carrier in each group. To kill the carriers from your neighbors, you'll have to choke their cables. When setting up a network, always try to avoid the use of wired Ethernet; use WiFi if it will work reliably for your installation.

Figure 3 —A 12 V dc-to-120 V ac 1 A inverter with required RF filtering.

VDSL and Cable Modem Uplink Leakage: VDSL and cable modem leakage in the range of 3.7–5 MHz may be radiated by wires connected to modem itself or from the telephone or cable company's wiring between homes. WA7JHZ and WØIVJ have documented this problem with spectrum measurements of the common-mode signal on coax carrying CenturyLink and Comcast systems in Idaho and Colorado. It should be possible to suppress leakage from the modem with a 6-7 turn choke on each cable wound around a 1 inch #31 clamp-on, but so far, cable and telephone companies have stonewalled.

Computers: Some computers are RF-quiet, but many radiate RF from internal wiring and from wiring for power and connected accessories. Some are quiet at HF, but noisy at VHF. If a computer is noisy, choke all cables connected to it.

Some computer displays are noisy, some are not. Choke both video and power cables on the noisy ones. Some cannot be suppressed. W4UAT gave me a Samsung with "touch" controls that he couldn't use, because it went nuts when he keyed a radio feeding a nearby antenna. Nothing I tried could kill the noise it made in my receiver, nor prevent it from turning flips when I transmitted. Not all Samsung monitors are noisy. I've replaced all the monitors in my home and shack with 24-inch Samsung models sold with outboard 14 V dc switching power supplies that I toss, running the monitors from float-charged 12 V batteries.

USB Powered Equipment: Equipment powered via a USB connection, such as USB sound cards and computer extension speakers, often includes a switch-mode power supply to convert the 5 V USB voltage to something the powered unit can more effectively use. Add equipment like this to the list of potential noise sources and treat them as any other: Choke the cable(s), and if that doesn't kill the noise, replace the noisy product. W6GJB

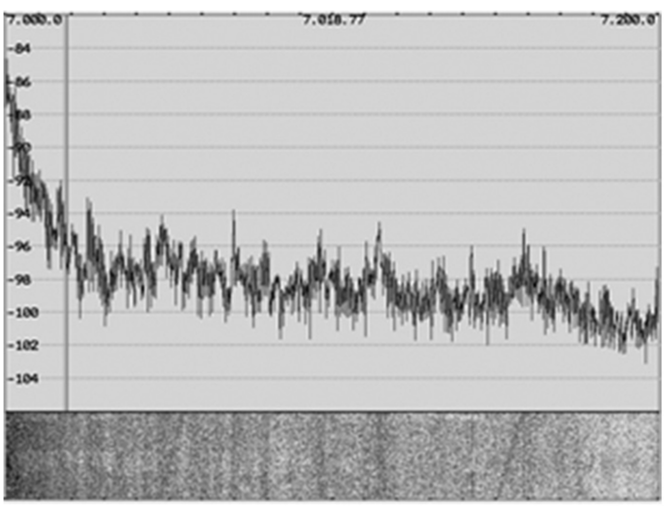

Figure 4 — Plasma TV, 7–7.2 MHz.

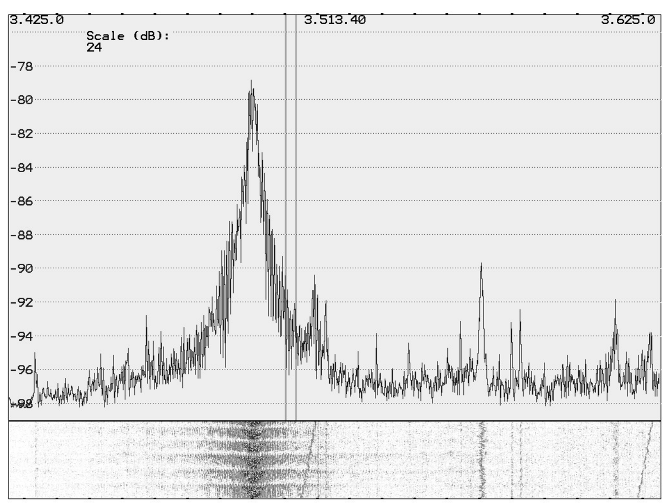

Figure 5 — Plasma TV, 3.425–3.625 MHz.

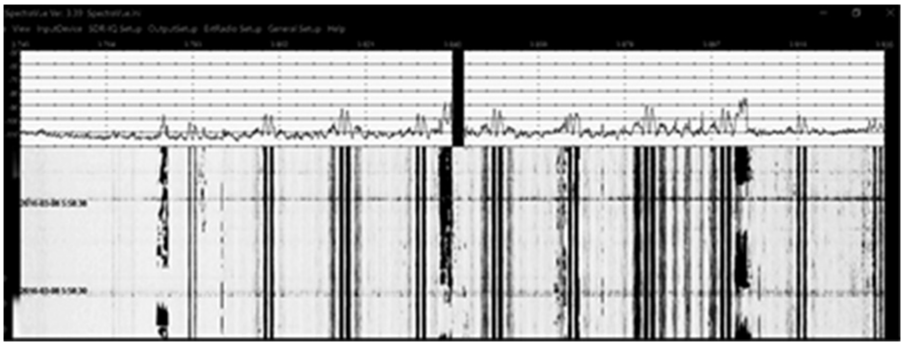

Figure 6 — A neighbor's plasma TV at K7PI: 3754–3935 kHz, 10dB/div.

reports that very strong noise from a pair of USB-powered speakers radiated not only on their own USB cable, but also on every cable connected to the computer!

Noisy Doorbell Transformers: Often buried in the walls, doorbell transformers can be nasty sources of impulse noise. WX5L reports, "The older type doorbell transformer has a safety feature built in. A thermistor monitors the heat in the windings. If it detects overheating it, it opens a relay to disconnect power, so it doesn't combust. But even with a normal situation this relay can become pitted and chatter away causing RFI." The defective transformer should be replaced with one that is UL or ETL listed. If the transformer is inaccessible but its ac wiring is accessible, it should be disconnected and an alternate doorbell system installed. Most building codes require that all wiring associated with the ac mains (120 and/or 240 V) must be accessible.

Solar Power Systems: Solar power systems can be *very* strong noise sources as a result of poor design, poor installation, or both. The best charge-current regulators are dc-to-dc converters, and most are noisy. The dc-to-ac inverters that provide 120 V ac are also often noise sources. Both charge and discharge circuits carry large pulsed currents with strong harmonics; those harmonics will radiate if the current flows through large-area magnetic loops. A large system with *all* wiring in steel conduit has the best chance of being quiet, *provided that the conduit is continuous and bonded to all equipment enclosures at both ends.* Solar power systems should always be wired with twisted pair. Genesun, a relatively new company, makes a line of MPPT (the most efficient type) solar charger regulators for small systems that is dead quiet.

There has been a trend in recent years toward solar panels with self-contained regulators and inverters; properly built and installed, these can greatly reduce the loop area and, thus, the noise. Because the power leaves the panel as 120 V ac (or even 240 V), wiring from the panel is usually in conduit. And because the output of the panel is at the higher line voltage, the current is proportionally less than if it were at battery voltage. RF trash produced is directly related to current, so all of these factors can combine to result in less radiated noise, if the units are well designed and properly installed.

The April 2016 edition of *QST* includes a feature article on modern home solar power systems with respect to RF noise. While I did have some issues with this article, it does include a good discussion of overall system architectures in general and for this system in particular, recognition of the interconnection of solar panels and batteries as a magnetic loop, recommendation for the use of twisted pair for that loop with return circulating through the loop to minimize radiation and the loop area, recommendations that wiring be installed in steel conduit, and recommendations for the use of ferrite common mode chokes for suppression of noise currents. It also shows how much work can be involved in fixing a bad system!

Active Noise Cancellers: When we've done our best and *still* have noise, an active noise canceller can make a big dent in a *single* source, but it won't help with more than one source at a time. Noise cancellers work by combining signals from our receive antenna with the signal from a "sense" antenna located near the source of the noise. The adjustable phasing network within the unit must then be carefully tweaked, so that the two signals are equal in level and 180° out of phase. This adjustment is frequency sensitive, and it must also be readjusted for every noise source. The MFJ-1026 and the DX Engineering NCC-1 are generally well regarded. Be careful when using any unit in line with the transceiver output. The carrier detector in my Timewave ANC-4 generated considerable IMD.

Buying Ferrite Cores: My advice is never to buy ferrite cores from vendors that advertise in ham radio magazines; they're selling at insanely high markups, and often the wrong parts for what we need. Instead, put together a quantity order for members of local ham clubs and buy from one of several good industrial vendors, such as Allied, Newark, Dexter Magnetics, and Lodestone Pacific. Don't go by catalog prices. Once you have some idea about quantity, call the supplier for a quote (and to ask about any price breaks) on the quantities you think you might buy. Add the cost of shipping and sales tax to those quotes.

Always buy full boxes. Ferrites are brittle and break easily, but there will be virtually no breakage if they have been packed at the factory. Ask about box quantities. These vendors can ship a single order to two or three different locations, if that makes it easier for you to deliver, but don't ask them to split boxes. Never re-ship ferrite cores. They must be very well packed to prevent breakage, they're heavy, and they're expensive to re-ship. Insist that all buyers in the group pick up their orders, at a club meeting, for example.

Table 1 in Part 1 of this article lists part numbers for cores I find most useful for suppression at HF and on 160 meters. All are Fair-Rite #31 material. Lately I've been buying the 0.74-inch I.D. clamps, because I find them most universally useful. They're large enough for the medium-size cables I need to choke, such as cables to video monitors and many power cables. The 0.5-inch I.D. clamps are large enough for smaller cables and cheaper. The 1-inch I.D. cores are pretty expensive (about $10) but are equivalent to three 2.4-inch O.D. toroids; I save them for the largest cables.

Action Summary for Killing RF Noise

Study a Spectrum Analyzer Plot to determine whether it is impulse noise or electronically generated, and if electronically generated, its characteristics. (Review Part 1.)

Is it impulse noise? Broadband, no variation within a band, strongest at low frequencies, gets weaker with increasing frequency, covers a fairly wide area? If yes, it's probably something arcing within the power company's distribution system, or, occasionally, a neon sign. Try to get a bearing with a directional antenna, and then listen with a mobile rig tuned for AM mode at around 160 MHz. When the noise gets loud, zero in on it by listening with an AM detector at UHF. When you hear it loud at UHF, get out of the car with an HT tuned to that range. Then tell the power company what you've learned.

Is it electronically generated noise? Harmonically related carriers that repeat every 10 to 100 kHz, stronger in some bands than in others? If the carriers are wobbly in frequency, are surrounded by humps of noise, and drift a bit over time, the source is likely an SMPS. If the carrier(s) are relatively stable in frequency, the source is likely within digital equipment. Begin your search by listening while powering your radio from a battery as you kill power to everything in your home. Then find and suppress each noise you hear as you turn on one circuit breaker at a time.

Remember that most of us hear many noise sources, both impulse noise and electronic noise, and from many sources. The key to success is to identify and tackle them one at a time.

Kill electronically generated noise by replacing noisy products with clean ones, or by applying common mode chokes to all wiring connected to each source, one at a time. If there are multiple sources on a circuit, turn all off but one, and suppress it. Then turn that source off and move on to the next. When you find a source you cannot suppress, turn it off and work on the others.

When a new noise appears, think like Sherlock Holmes. What new product have you (or your neighbor) bought? Is there a pattern to when you hear it? Can you connect that pattern to patterns of use of something that could be a noise source? Is it the same every day (perhaps tied to a circuit that senses daylight) or appliances that are used at certain times?

How Ferrite Chokes Work

Common mode chokes work by adding a large value of *resistive* impedance in series with the common-mode circuit. Most hams think of a common-mode choke as an inductor. That is incorrect. Common-mode chokes work using the *resistance* of the *parallel resonant circuit* formed by the inductance of the winding, the stray capacitance of the winding, and the resistance coupled from the core.

The self resonance of a conductor passing once through most ferrite cores used for suppression is in the range of 150 MHz, and this is where a core simply clamped around a cable will be effective. To obtain good suppression in the range of 1-50 MHz, we must wind multiple turns through the ferrite core to lower the resonant frequency. Inductance, of course, is the inductance of a single pass through the core multiplied by N^2, where N is the number of times the wire passes through the core. Because that resistance is inductively coupled, it is also multiplied by N^2. C is mostly the capacitance *between* turns, so it increases in approximate proportion to the number of turns and is a bit greater with large-diameter cables. It can also be increased by squeezing the turns very closely together (outside the core), or reduced by forcing them apart.

At low frequencies, the fundamental equivalent circuit is simply that series R and L (because the value of C is too small to matter at low frequency), but as frequency increases and we approach resonance, C is in parallel, and for an octave or two both sides of resonance (an octave is a 2:1 frequency range), the circuit simplifies to parallel R, L, and C, where L is the inductance at low frequencies, C is the capacitance well above resonance, and R is the parallel equivalent resistance transformed from the series value.

The reason we want high resistance in our choke is that in the common-mode circuit, which is really an antenna, the rest of the circuit can look inductive or capacitive, depending on its length. A simple example is a dipole fed with coax, with the shield grounded at the transmitter. The common mode circuit consists of the dipole plus the coax — the coax looks like a grounded vertical long wire with top-loading wires. If, for example, that vertical wire is between 0.25 λ and 0.75 λ, it will look inductive; if it is shorter than 0.25 λ or between 0.75 λ and 1.25 λ, it will look capacitive. These relationships will repeat as the electrical length increases. If we had a choke with little resistance, it would still have parallel L and C values, which would form a series resonance with the L or C of that wire at some frequencies. When that happens, the common mode current will *increase* and be limited only by the resistance of the choke. But if the choke has enough resistance, that R will limit the current. Another example of a common-mode circuit is a cable running between two pieces of equipment. Note that velocity factor for coaxial cable does not apply to the common-mode circuit. Rather, the velocity factor is typically around 0.97 due to the cable diameter and the outer jacket as an insulator.

In the real world, we rarely model these circuits, because there are far too many variables that are subject to change from one installation to another. Instead, we take a “brute force” approach, making the resistive component of the choking Z as high as possible for the widest practical frequency range in which we need suppression. If we need suppression over a wider range than one choke can cover, we add a second choke tuned to the rest of the operating range.

Ferrite materials that have good suppression characteristics are lossy in the frequency range where suppression is desired, although nearly all have low loss at much lower frequencies. Fair-Rite materials #31, #43, #44, #61, and a few others are optimized for suppression, and in that operating range, the circuit Q of their parallel resonance is on the order of 0.5. This allows a choke with a well-placed resonance to cover a bit more than an octave (2:1 frequency range). The #61 material is an example of a material that is lossy at UHF and thus useful for suppression above about 400 MHz, but it has low enough loss below 20 MHz that it can be used as a core for high-power transformers for the HF bands.

Most of these materials are NiZn compounds and possess only the circuit resonance described above. The #31 material is unique, because it is a very special MnZn compound; it exhibits both the circuit resonance at higher frequencies and a dimensional resonance at lower frequencies. When the circuit resonance is below about 6 MHz, this gives its impedance curve a very broad “double-humped” response, much like a stagger-tuned IF, providing nearly an extra octave of effective suppression. Its equivalent circuit is two parallel resonant circuits in series. Note that all MnZn materials exhibit dimensional resonance, but only in Fair-Rite’s #31 is it carefully controlled to provide the broadband suppression described here.