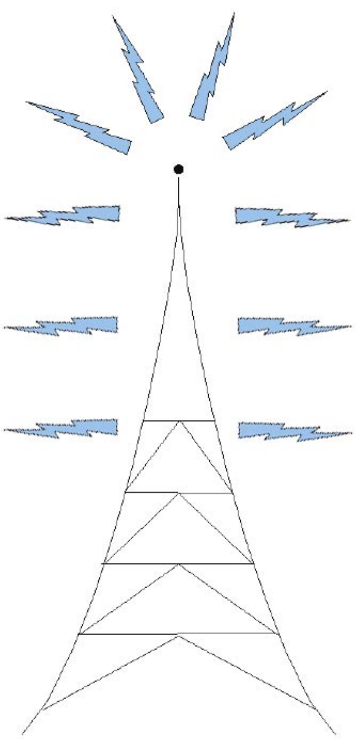
SCIN
Shield Current Induced Noise

Causes and Solutions Part 2

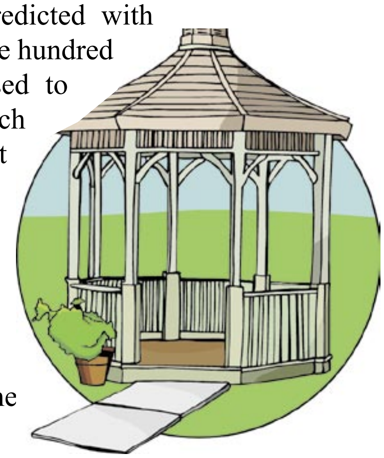
In the last issue, we learned how current flowing on the shield of audio cables will be converted to voltage on the signal pair by a defect in the cable called Shield Current Induced Noise (SCIN). We also know that this current can enter equipment that has a pin 1 problem. One of the obvious questions is, "How much current can there be on the shield of audio cables in a given installation? Research by Neil Muncy and others suggests that 100mA of power-related current (i.e., 50/60Hz and harmonics) is not uncommon where the source of the current is the power system within buildings. Muncy's 1994 SCIN measurements and John Wendt's "Hummer" tester for pin 1 problems, both used this level of current. But how much current might an AM broadcast transmitter induce in the shield of the mic cables running through the loft of a wood frame church?

To answer that question, I devised a set of experiments using 125ft lengths of mic cable connected to a Hewlett Packard 3586C Selective Level Meter. The 3586C is essentially a calibrated voltmeter in the form of a radio receiver that can tune to any frequency between a few kHz and 32MHz. It can also measure the frequency of a signal within that range to an accuracy of about 0.1 parts/million. Data were taken at two locations. Location #1 was a wood frame pagoda in an open park where Ron Steinberg (who assisted with the measurements) had installed a small sound system. It is within about 4 miles of three high power AM broadcast transmitters. The 125 ft length of mic cable was supported about 7 ft above moist earth by low limbs of small trees and connected to the 3586C, which was set up in the pagoda. Location #2, roughly 20 miles from the first, was the 120 year old wood frame house that also serves as my office and lab. Here, the same 125 ft length of mic cable ran from one end of the third floor, around the house to my laboratory at the front of the second floor. In both cases, the 3586C was powered from a grounded 120V AC outlet.



At each location, the cable shield was connected to the center conductor of the 50 ohm coaxial input of the 3586C, and the voltage produced by the carrier of several dozen AM broadcast stations was measured. Ohm's law then told us the current for each station. The FCC's website lists the locations, transmitting antenna characteristics, and power level of each station. The URL is http://www.fcc.gov/mb/audio/. Select AM Query.

All of the stations measured were within about 40 miles of the measurement location (but each was at a different distance and azimuth) so their propagation was by ground wave. In the far field, the drop in field strength of a ground wave signal has two principal components that are additive -- inverse square law, plus a term due to the loss caused be the current flowing in the earth that varies with the resistivity of the soil and the frequency of the signal. As part of their AM broadcast regulations, the FCC has long published empirically determined families of curves that allow the ground wave field strength to be predicted with good accuracy to more than one hundred miles. These curves were used to take the data measured for each station and estimate the current that would flow in the same cable if it were only 1 mile from the transmitter and at the same azimuth.



AM broadcast antennas are always vertical, typically one quarter wave tall. The entire tower is the antenna.

Some (mostly the highest power stations) use half-wave or 5/8-wave tall antennas, producing a field strength in the horizontal plane that is respectively 1.9 or 3.2 dB greater than a quarter wave antenna (as with loudspeaker directivity, you don't get something for nothing -- the gain is at the expense of reduced output at higher angles, but with radio, that's good). Most (but not all) AM broadcast stations are omnidirectional during daylight hours but switch to directional operation at night; some are always omnidirectional, and some are directional at all times. Several different power levels are used. The highest power stations use 50kW to cover several states; others operate at 10kW, 5kW, 1kW, or even 250W to cover smaller areas.

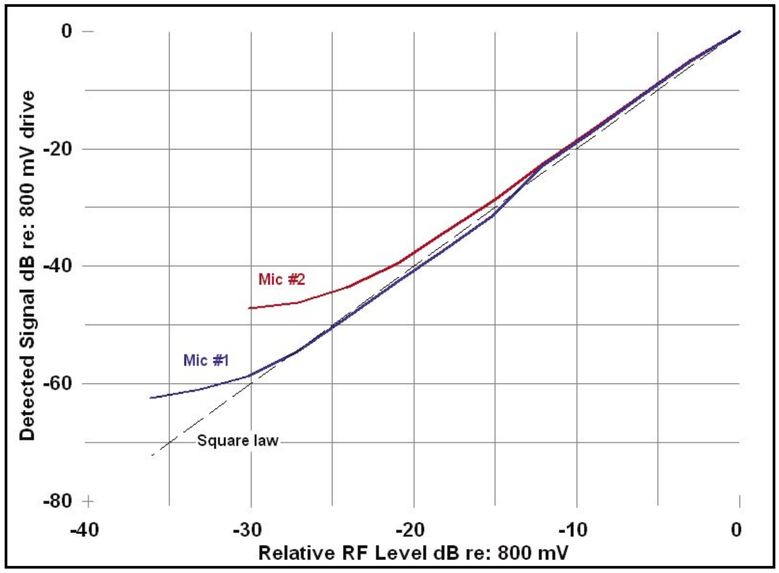


Figure 1 - Square law response of two typical microphones

My measurements showed that the 125ft cable shield (antenna) will typically see about 5mA at 1 mile from an omnidirectional 50kW station with the taller antenna. Currents were typically 1.5mA and 0.75mA for 5kW and 1kW, respectively. The shield current will likely vary by ±10 dB depending on the orientation, height, and geometry of the receiving antenna and another +10/-12 dB based on any directionality of the transmitting antenna. Thus typical shield currents on the order of 1-20 mA should be expected 1 mile from a 50kW transmitter in a 125ft mic cable that is unshielded by conduit or building steel, 0.5-10mA at 1 mile from a 5kW transmitter, and 0.2-2mA at 1 mile from a 1kW transmitter. These data, although carefully measured, can hardly be taken as precise. They will, however, give us some idea of the general order of magnitude of the RF signal that might be expected. More important, circuit designers ought to be applying these estimates to the SCIN data to predict how much RF immunity their equipment might need in the real world!

When diagnosing and eliminating RF interference in systems, it is quite helpful to realize that a relatively small reduction in RF signal level can make a large reduction in the audible interference. In other words, a reduction in RF level of only 10 dB will reduce the audible interference by 20 dB. In practice, this means that we may not need to go after RF interference with a sledge hammer (i.e., a very costly solution), but rather may be able to use much simpler ones. I'm currently doing some research on RFI solutions, and hope to be able to report on them before long.

Figure 3 shows the results of testing a very good product, the Sound Devices Mix Pre. Ron Steinberg loaned me this unit for the condenser mic RF testing I described this past spring, and it's the most "bullet-proof" product I've tested so far. The red curve shows the detected RF when you drive pin 1 of channel 1 and listen to channel 1. The blue curve shows the crosstalk you hear when you inject at the same point, but listen on channel 2. This sort of crosstalk happens with virtually every piece of gear I've tested, and the reason should be obvious -- the RF is getting injected into the circuit board via a common impedance, which in turn adds it at multiple points in the signal chain. The peaks and dips in the response are probably the result of the addition of detection from multiple points in a circuit as the phase and amplitude relationships between those detected signals vary with frequency.

Figure 4 shows test results for a small mixer in a family notorious for picking up AM radio stations. The mixer shown in Figure 5 was designed in response to a

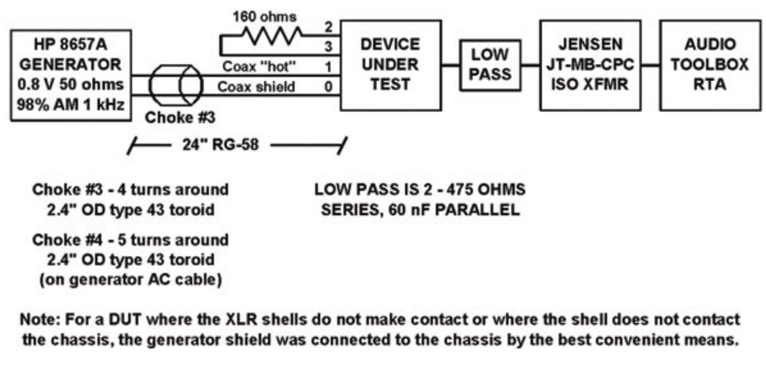


Figure 2 - A test rig for RF pin 1 problems

chorus of complaints, and it fixed the problem in most installations. But note that while the mixer of Figure 5 is at least 40 dB better on the AM broadcast band, it is at least 30 dB worse in the VHF spectrum, and was thus unusable for my microphone testing in downtown Chicago!

Test results for a small rack mount compressor/ limiter are shown in Figure 6. In this unit, the pin 1 problem is at it's worst between 20 and 50 Mhz -- it probably makes a wonderful CB radio! The 1/4" connectors used for inputs and outputs have plastic bushings that insulate them from the chassis. This is a fixed threshold unit, and the pin 1 problem is so severe that the rectified audio from the pin 1 test is hitting that threshold! When I spoke with the designer of this unit a few years ago at AES about the pin 1 problem, he loudly proclaimed that that Whitlock guy didn't know what he was talking about.

Last summer, I talked about pin 1 problems in microphones, concurring with Neil Muncy's hypothesis that the majority of RF susceptibility in audio gear was the result of a pin 1 problem. I've always wanted to devise a method of measuring pin 1 susceptibility of audio gear. Figure 2 shows the setup that I settled on. In effect, all I've done is replace the wall wart in John Wendt's hummer with an RF generator and cooked up a way to plot the result using audio gear that I already owned. I used the same generator I used for the SCIN measurements, but any good RF generator will work.

I've also devised a method for injecting differential-mode RF onto the signal pair in much the same way that SCIN would do it in that typical church. As you might guess, I've also applied both of these techniques to microphones, and have measured many of those I field tested last winter. In the next newsletter, we'll look at these tests in more detail, as well as some of the data that resulted from these measurements. A detailed discussion of the test setups and loads of data are included in the two papers I presented to the AES in New York this fall. They are available from the AES, although last I looked they were not on the website yet.

And this footnote: Russ O'Toole called me the other day to tell me about a contractor whose work he was inspecting who insisted on un-twisting several inches of twisted pair cables before connecting it to equipment. He was looking for something in print saying that this was a bad idea. Well, here it is!

Cable Shields

Nearly all interference below a few hundred kHz is magnetically coupled. Cable shields provide almost no magnetic shielding in this range. On the other hand, twisting is very effective against magnetically coupled interference. In general, rejection of magnetic fields is proportional to the number of twists per unit length (called the "lay") and the uniformity of the twisting. Structured cable (CAT5, etc.) achieves its relatively high noise rejection by virtue of a high twist ratio. For a century, virtually all telephone lines have run for miles on unshielded twisted pairs.

In his seminars, Neil Muncy demonstrates the importance of twisting by running a very long string of mic cables around a lab and using them to connect a mic in an acoustically isolated container to a small mixer/amp that feeds loudspeakers for the audience with a lot of gain. He then takes a tape eraser (for you younger guys, that's a big coil driven by the power line to generate a big enough 60 Hz magnetic field to erase

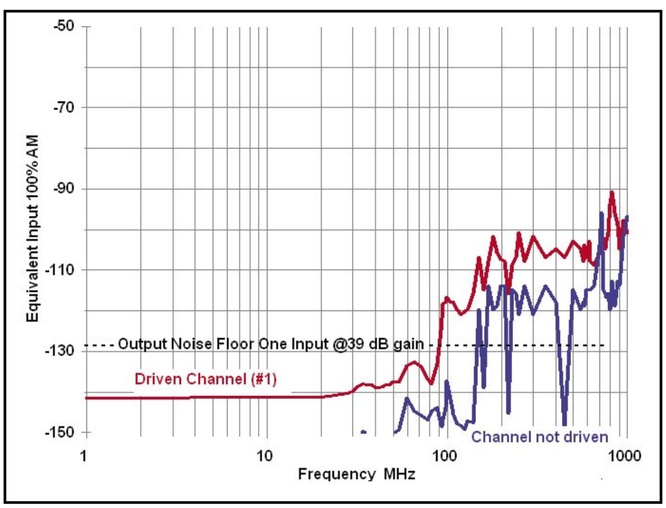


Figure 3 - The pin 1 test for a very good product

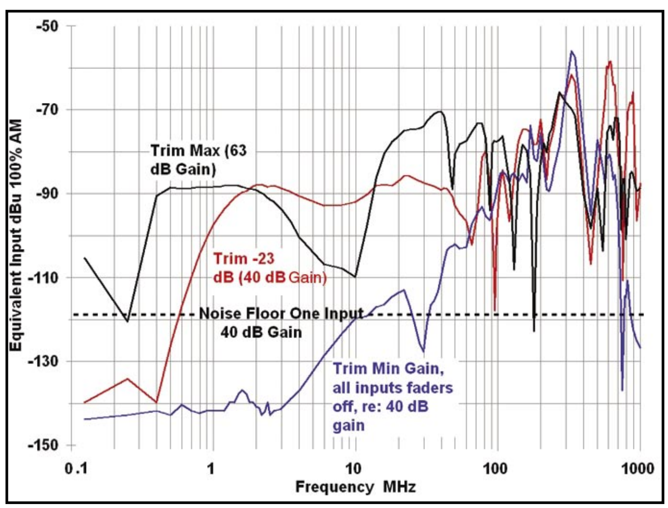


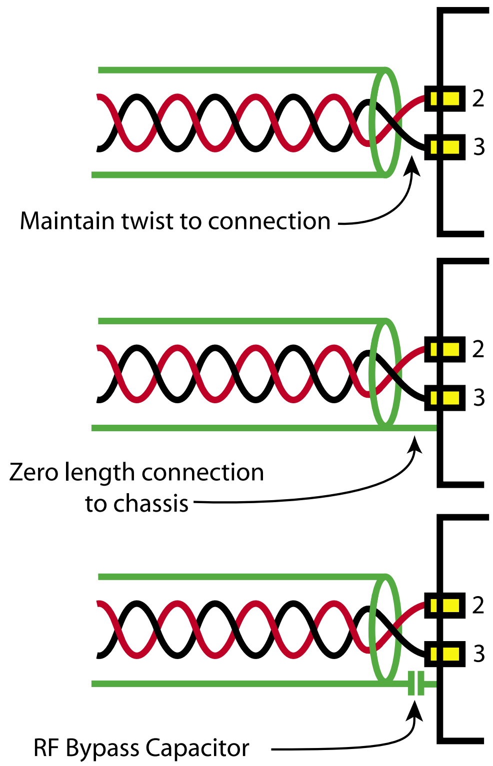
Figure 4 - The pin 1 problem in a small mix console known for picking up AM radio stations

magnetic tape) and moves it along the mic cable. No hum is heard with the demagnetizer anywhere along the cable except at the connectors, where it can get fairly loud. Why? The twisting is interrupted at the connectors!

Twisting is also important for good RF rejection. It's quite common for untwisted parallel cables (zip cord) to couple RF into equipment when used as loudspeaker cable, and for the interference problems to be solved when it is replaced by an unshielded twisted pair. Yet another reason to avoid most high futility loudspeaker cables! [I never cease to be amazed at how little real science the purveyors of all that pseudo-science actually understand. After one of my rep friends went through the "training" sessions held by the manufacturer of one of the better known of these product lines, he asked them for some data he could show his technically inclined clients to back up their claims. They responded that they had no such data and no gear to measure it, but they would appreciate any data he could provide!]

Cable shields are effective against electric fields, and can be quite important where there is RF interference. If the cable is short as compared to the wavelength of the interference, the shield only needs to be connected at the sending end. If the cable is much longer than about 1/10 wavelength, the shield needs to be as continuous as possible and connected at both ends. As noted in an earlier newsletter, the ideal connection is a concentric one. Next best is the shortest practical pigtail.

So, to summarize, the "right" way to terminate balanced cable, whether for audio or data, is to maintain the twisting as carefully as possible right to the point where it enters equipment (ideally there should be "zero length" of untwisted cable). If the shield is to be terminated, there should be either a concentric connection or the shortest possible pigtail, and it should go straight to the shielding enclosure of the equipment. If the connection is needed to shield against VHF RF but needs to be interrupted at lower frequencies to prevent shield current, a capacitor should be used in series with the shield connection (also with very short leads or a concentric connection), and only at the receive end.



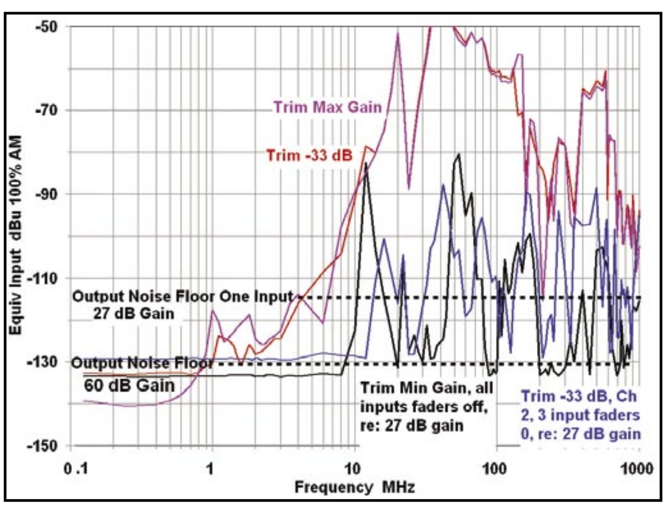


Figure 5 - The console that "fixed" the problem in many installations (but not at VHF!)

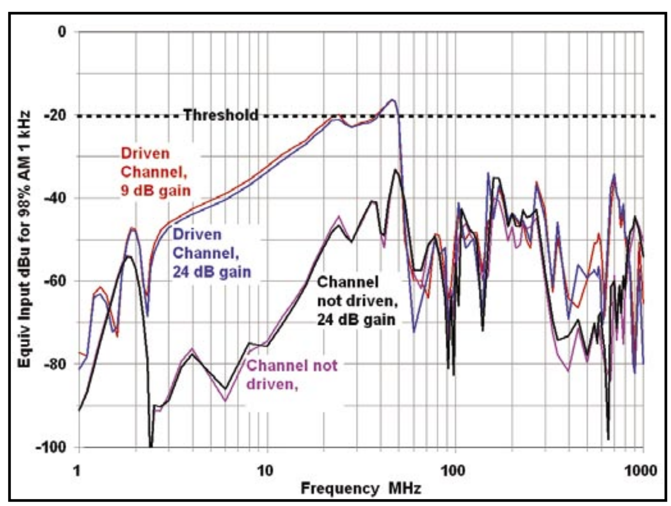


Figure 6 - A dual compressor/limiter with a serious pin 1 problem