Contents

Chapter 27

RF Interference

This chapter is a complete revision of the "Interference" chapter in editions prior to 2011. A team of knowledgeable experts supported the greatly expanded scope. The topics listed for each of these individuals represent only their primary area of contribution.

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Amateurs live in an increasingly crowded technological environment. As our lives become filled with technology, every lamp dimmer, garage-door opener or other new technical "toy" contributes to the electrical noise around us. Many of these devices also "listen" to that growing noise and may react to the presence of their electronic siblings. The more such devices there are, the higher the likelihood that the interactions will be undesirable.

What was once primarily a conversation about "interference" has expanded to include power systems, shielding, intentional and unintentional radiators, bonding and grounding, and many other related topics and phenomena. These are all grouped together under the general label of *electromagnetic compatibility (EMC)*. The scope of EMC includes all the ways in which electronic devices interact with each other and their environment.

The general term for interference caused by signals or fields is *electromagnetic interference* or *EMI*. This is the term you'll encounter in the professional literature and standards. The most common term for EMI involving amateur signals is *radio frequency interference (RFI)* and when a television or video display is involved, *television interference (TVI)*. RFI is the term used most commonly by amateurs. Whether it's called EMI, RFI or TVI, unwanted interaction between receivers and transmitters has stimulated vigorous growth in the field of electromagnetic compatibility! (This chapter will use the term RFI to refer to all types of interference to or from amateur signals, except where noted.)

This chapter begins with an overview of dealing with interference and includes relevant FCC regulations. This section is an excellent resource when you are confronted with an interference problem and are wondering "What do I do now?" The information here is based on the experiences of ARRL Lab staff in assisting amateurs with RFI problems.

The second part of this chapter is a discussion on identifying and locating RFI-related noise and signal sources then presents some effective ways of resolving the problem. A glossary of RFI terminology concludes the chapter.

The material in this chapter may provide enough information for you to solve your problem, but if not, the ARRL Web site offers extensive resources on RF interference at **www.arrl.org/radio-frequency-interference-rfi**. Many topics covered in this chapter are covered in more detail in the *ARRL RFI Book* from a practical amateur perspective.

Throughout this chapter you'll also find references to "Ott," meaning the book *Electromagnetic Compatibility Engineering* by EMC consultant Henry Ott, WA2IRQ. EMC topics are treated in far greater depth in Ott's book than is possible in this *Handbook*. Readers interested in the theory of EMC, analysis of EMC mechanisms, test methodology and EMC standards can purchase a copy through the ARRL Publication Sales department or the ARRL Web site.

27.1 Managing Radio Frequency Interference

Sooner or later, nearly every Amateur Radio operator will have a problem with RFI, but temper your dismay. Most cases of interference can be cured! Before diving into the technical aspects of interference resolution, consider the social aspects of the problem. A combination of "diplomacy" skills and standard technical solutions are the most effective way to manage the problem so that a solution can be found and applied. This section discusses the overall approach to solving RFI problems. Specific technical causes and solutions are described in subsequent sections.

27.1.1 Responsibility for Radio Frequency Interference

When an interference problem occurs, we may ask "Who is to blame?" The ham and the other party often have different opinions. It is natural (but unproductive) to assign blame instead of fixing the problem.

No amount of wishful thinking (or demands for the "other guy" to solve the problem) will result in a cure for interference. Each party has a unique perspective on the situation and a different degree of understanding of the personal and technical issues involved. On the other hand, each party has certain responsibilities and should be prepared to address them fairly. (Given the realities of amateur operation, one of the parties is likely to be a neighbor to the amateur and so the term "neighbor" is used in this chapter.)

Always remember that every interference problem has two components — the equipment that is involved and the people who use it. A solution requires that we deal effectively with both the equipment and the people. The ARRL recommends that the hams and their neighbors cooperate to find solutions. The FCC also shares this view. It is important therefore to define the term "interference" without emotion.

27.1.2 Proper Station Operation

A radio operator is responsible for the proper operation of the radio station. This responsibility is spelled out clearly in Part 97 of the FCC regulations. If interference is caused by a spurious emission from your station, you must correct the problem there.

Fortunately, most cases of interference are not the fault of the transmitting station. If an amateur signal is the source of interference, the problem is usually caused by fundamental overload — a general term referring to interference caused by the intended, fundamental signal from a transmitter. If the amateur station is affected by interference, electrical noise is most often the culprit. Typical sources include power lines and consumer devices.

27.1.3 Personal Diplomacy

Whether the interference is to your station or from your station, what happens when you first talk to your neighbor sets the tone for all that follows. Any technical solutions cannot help if you are not allowed in your neighbor's house to explain them! If the interference is not caused by spurious emissions from your station, however, you should be a locator of solutions, not a provider of solutions.

Your neighbor will probably not understand all of the technical issues — at least not at first. Understand that, regardless of fault, interference is annoying whether your signals are causing interference to the neighbor or a device owned by the neighbor is causing interference to you.

Let your neighbor know that you want to help find a solution and that you want to begin by talking things over. Talk about some of the more important technical issues, in non-technical terms. Explain that you must also follow technical rules for your signal, such as for spurious emissions, and that you will check your station, as well.

27.1.4 Interference To a Neighbor's Equipment

Your transmitted signals can be the source of interference to a neighbor's equipment. Assure your neighbor that you will check your station thoroughly and correct any problems. You should also discuss the possible susceptibility of consumer equipment. You may want to print a copy of the RFI information found on the ARRL Web site at **www.arrl.org/information-for-the-neighbors-of-hams**. (This document is also included on the CD-ROM accompanying this book.)

Your neighbor will probably feel much better if you explain that you will help find a solution, even if the interference is not your fault. This offer can change your image from neighborhood villain to hero, especially if the interference is not caused by your station. (This is often the case.)

Here is a good analogy: If you tune your TV to channel 3, and see channel 8 instead, you would likely decide that your TV set is broken. Now, if you tune your TV to channel 3, and see your local shortwave radio station (quite possibly Amateur Radio), you shouldn't blame the shortwave station without some investigation. In fact, many televisions respond to strong signals outside the television bands. They may be working as designed, but require added filters and/or shields to work properly near a strong, local RF signal.

> ## Warning: Performing Repairs
>
> You are the best judge of a local situation, but the ARRL strongly recommends that you do not work on your neighbor's equipment. The minute you open up a piece of equipment, you may become liable for problems. Internal modifications to your neighbor's equipment may cure the interference problem, but if the equipment later develops some other problem, you may be blamed, rightly or wrongly. In some states, it is even *illegal* for you to do *any* work on electronic equipment other than your own.

27.1.5 Interference From a Neighbor's Equipment

Your neighbor is probably completely unaware that his or her equipment can interfere with your operation. You will have to explain that some home electronics equipment can generate radio signals many times stronger than the weak signals from a distant transmitter. Also explain that there are a number of ways to prevent those signals from being radiated and causing interference. If the equipment causing the problem can be identified, the owner's manual or manufacturer of the device may provide information on the potential for RFI and for its elimination.

As with interference appearing to be caused by your station, explain that your intent is to help find a solution. Without further investigation it is premature to assume that the neighbor's equipment is at fault or that FCC regulations require the neighbor to perform any corrective action. Working together to find a mutually acceptable solution is the best strategy.

27.1.6 Being Prepared

In order to troubleshoot and cure RFI, you need to learn more than just the basics. This is especially important when dealing with your neighbor. If you visit your neighbor's house and try a few dozen things that don't work (or make things worse), your neighbor may lose confidence in your ability to help cure the problem. If that happens, you may be asked to leave.

Start by carefully studying the technical sources and cures for RFI in this book and in other references, such as the *ARRL RFI Book*. Review some of the ARRL Technical Information Service and *QST* articles about interference. If you are unfamiliar with any of the terms in this chapter, refer to the glossary.

LOCAL HELP

If you are not an expert (and even experts can use moral support), you should find some local help. Fortunately, such help is often available from your ARRL Section's Technical Coordinator (TC). The TC knows of any local RFI committees and may have valuable contacts in the local utility companies. Even an expert can benefit from a TC's help. The easiest way to find your TC is through your ARRL Section Manager (SM). There is a list of SMs on the ARRL Web site or in any recent *QST*. He or she can quickly put you in contact with the best source of local help.

Even if you can't secure the help of a local expert, a second ham can be a valuable asset. Often a second party can help defuse any hostility. When evaluating and solving RFI problems involving your station, it is very important for two hams to be part of the process. One can operate your station and the other can observe symptoms, and, when appropriate, try solutions.

PREPARE YOUR HOME AND STATION

The first step toward curing the problem is to make sure your own signal is clean and that devices in your home are not causing any problems. Eliminate all interference issues in your own home to be sure your station is operating properly and that your own electronic equipment is not being interfered with or causing interference to your station!

This is also a valuable troubleshooting tool for situations in which your station is suspected of being the source of interference: If you know your signals are "clean," you have cut the size of the problem in half! If the FCC ever gets involved, you can demonstrate that you are not interfering with your own electronics.

Apply RFI cures to your own consumer electronics and computer equipment. What you learn by identifying and eliminating interference in your own home will make you better prepared to do so in your neighbor's home. When your neighbor sees your equipment working well, it also demonstrates that filters work and cause no harm.

To help build a better relationship, you may want to show your station to your neighbor. A well-organized and neatly-wired station inspires confidence in your ability to solve the RFI problem. Clean up your station and clean up the mess! A rat's nest of cables, unsoldered connections and so on can contribute to RFI. Grounding is typically not a cure for RFI, but proper grounding will improve lightning safety and can greatly reduce hum and buzz from power systems. Make sure cable shields are connected properly and that RF current picked up from your transmitted signal by audio and power wiring is minimized.

Install a low-pass or band-pass transmit filter. (In the unlikely event that the FCC becomes involved, they will ask you about filtering.) Show your neighbor that you have installed the necessary filter on your transmitter. Explain that if there is still interference, it is necessary to try filters on the neighbor's equipment, too.

Operating practices and station-design considerations can cause interference to TV and FM receivers. Don't overdrive a transmitter or amplifier; that can increase its harmonic output.

Along with applying some of the interference-reducing solutions in this chapter, you can also consider steps to reduce the strength of your signal at the victim equipment. This includes raising, moving, or re-orienting the antenna, or reducing transmit power. The use of a balun and properly balanced feed line will minimize radiation from your station feed line. (See the **Transmission Lines** chapter.) Changing antenna polarization may help, such as if a horizontal dipole is coupling to a cable TV service drop. Using different modes, such as CW or FM, may also change the effects of the interference. Although the goal should be for you to operate as you wish with no interference, be flexible in applying possible solutions.

27.1.7 Contacting Your Neighbor

Now that you have learned more about RFI, located some local help (we'll assume it's the TC) and done all of your homework, make contact with your neighbor. First, arrange an appointment convenient for you, the TC and your neighbor. After you introduce the TC, allow him or her to explain the issues to your neighbor. Your TC will be able to answer most questions, but be prepared to assist with support and additional information as required.

Invite the neighbor to visit your station. Show your neighbor some of the things you do with your radio equipment. Point out any test equipment you use to keep your station in good working order. Of course, you want to show the filter you have installed on your transmitter's output.

Next, have the TC operate your station on several different bands while you show your neighbor that your home electronics equipment is working properly when your station is transmitting. Point out the filters or chokes you have installed to correct any RF susceptibility problems. If the interference is coming from the neighbor's home, show it to the neighbor and explain why it is a problem for you.

At this point, tell your neighbor that the next step is to try some of the cures seen in your home and station on his or her equipment. This is a good time to emphasize that the problem is probably not your fault, but that you and the TC will try to help find a solution anyway.

Study the section on Troubleshooting RFI before deciding what materials and techniques are likely to be required. You and the TC should now visit the neighbor's home and inspect the equipment installation.

AT YOUR NEIGHBOR'S HOME

Begin by asking when the interference occurs, what equipment is involved, and what frequencies or channels are affected, if appropriate. The answers are valuable clues. Next, the TC should operate your station while you observe the effects. Try all bands and modes that you use. Ask the neighbor to demonstrate the problem. Seeing your neighbor's interference firsthand will help all parties feel more comfortable with the outcome of the investigation.

If it appears that your station is involved, note all conditions that produce interference. If no transmissions produce the problem, your station *may* not be the source. (It's possible that some contributing factor may have been missing in the test.) Have your neighbor keep notes of when and how the interference appears: what time of day, what channels or device was being interfered with, what other equipment was in use, what was the weather? You should do the same whenever you operate. If you can readily reproduce the problem, you can start to troubleshoot the problem. This process can yield important clues about the nature of the problem.

The tests may show that your station isn't involved at all. A variety of equipment malfunctions or external noise can look like interference. Some other nearby transmitter or noise source may be causing the problem. You may recognize electrical noise or some kind of equipment malfunction. If so, explain your findings to the neighbor and suggest that he or she contact appropriate service personnel.

If the interference is to your station from equipment that may be in the neighbor's home, begin by attempting to identify which piece of equipment is causing the problem. Describe when you are receiving the interference and what pattern it seems to have (continuous, pulsed, intermittent, certain times of day, and so on).

Confirm that a specific piece of equipment is causing the problem. The easiest way to do this is to physically unplug the power source or by removing the batteries while you or the TC observe at your station. (Remember that turning a piece of equipment OFF with its ON/OFF switch may not cause the equipment to completely power down.) Removing cables from a powered-up piece of equipment may serve to further isolate the problem.

At this point, the action you take will depend on the nature of the problem and its source. Techniques for dealing with specific interference issues are discussed in the following sections of the chapter. If you are unable to determine the exact nature of the problem, develop a plan for continuing to work with the neighbor and continue to collect information about the behavior of the interference.

Product Review Testing and RFI

The ARRL Laboratory mostly considers RFI as an outside source interfering with the desired operation of radio reception. Power line noise, power supplies, motor controls and light dimmers are all *outside* a radio receiver and antenna system and can be a major annoyance that distracts from the pleasure of operating. Have you ever considered RFI generated *inside* your own receiver or by another legally operating Amateur Radio station?

Harmonics

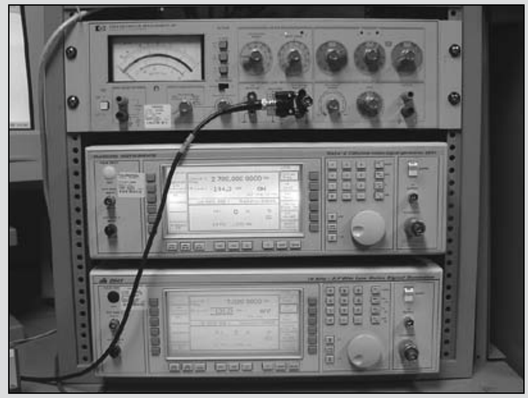
RFI is just that: radio frequency interference. For instance, a harmonic from another radio amateur's transmitter could be interfering with the desired signal you're tuned to. One might think in this day and age, harmonics are minimal and do not cause interference. I ask you to reconsider.

The maximum spurious output of a modern amateur transmitter must be 43 dB lower than the output on the carrier frequency at frequencies below 30 MHz. While that figure may be "good enough" for an FCC standard, it's not good enough to eliminate the possibility of causing interference to other radio amateurs or possibly other services. Here at the ARRL Laboratory, the measurement of harmonic emission level is a measurement I make of RFI generated *outside* your receiver.

A radio amateur contacted me, concerned about a report that he was causing interference to operators on the 80 meter CW band while operating at full legal limit power during a 160 meter CW contest. Knowing FCC rule part 97.307, he made the effort to measure his 80 meter harmonic. Easily meeting FCC standards at 50 dB below carrier output on 160, he wondered how his transmitter could cause interference.

Here's a breakdown of power output and signal reduction:
0 dB down from 1500 W = 1500 W
10 dB down from 1500 W = 150 W
20 dB down from 1500 W = 15 W
30 dB down from 1500 W = 1.5 W
40 dB down from 1500 W = 150 mW
43 dB down from 1500 W = 75.2 mW (this is the FCC legal limit)
50 dB down from 1500 W = 15 mW

While 15 mW may seem too low of a power to cause interference, it wasn't in this case; the interfering signal was reported to be S9. QRP enthusiasts know that at 15 mW, signals can propagate well with the right conditions. Using a single band, resonant antenna will reduce interference caused by harmonics located on other bands, but today many stations employ antennas resonant on more than one ham band.[1]



The Lab uses these signal generators to test receivers for internally generated intermodulation distortion, as well as other key performance parameters.

Signals Generated in the Receiver

What about RFI generated *inside* the receiver you're operating? You're tuning across the 15 meter band when, all of a sudden, you hear what seems to be an AM broadcast station. Is it a jammer? It is definitely interference — radio frequency interference — caused by two strong shortwave stations! In this particular case, a Midwest radio amateur experienced interference on 15 meters and figured out what was happening. One station was transmitting near 6 MHz and another transmitting above 15 MHz. These two strong stations added up to created a second order IMD (intermodulation distortion) product at the 1st IF stage, and this unwanted signal was passed along to subsequent stages and to the speaker. The RFI in this case was caused by insufficient receiver performance (second order IMD dynamic range) where the frequencies of the two stations added up to exactly the frequency that the operator was tuned to. Third-order IMD products from strong in-band signals are another form of RFI created within a radio receiver.

Nearby stations transmitting at or near the IF frequency will cause interference not because the transmitter is at fault, but because of a receiver's insufficient IF rejection. The same interference will be heard if a nearby transmitter is operating at an image frequency.

Power Supplies

RFI can also be created from another part of a radio system, such as an external power supply. In addition to transmitter and receiver testing, the Lab also measures the conducted emission levels of power supplies. This is an indication of the amount of RF at given frequencies conducted onto power lines from a power supply as described in this chapter.

Through our published Product Review test results in *QST* magazine, readers can compare the above figures of modern HF transceivers when considering the purchase of a new or used transceiver. Our published data tables spawn friendly competition between radio manufacturers who in turn, strive to perfect their circuit designs. The result is a better product for the manufacturer and a better product for you, the radio amateur. — *Bob Allison, WB1GCM, ARRL Test Engineer*

The ARRL Lab maintains an RF-tight screen room with a full suite of equipment for Product Review testing.

[1]In this case, the use of a bandpass filter designed for 160 meters would significantly attenuate the harmonic on 80 meters, eliminating the interference.

27.2 FCC Rules and Regulations

In the United States most unlicensed electrical and electronic devices are regulated by Part 15 of the FCC's rules. These are referred to as "Part 15 devices." Most RFI issues reported to the ARRL involve a Part 15 device. Some consumer equipment, such as certain wireless and lighting devices, is covered under FCC Part 18 which pertains to ISM (Industrial, Scientific and Medical) devices.

The Amateur service is regulated by FCC Part 97. (Part 97 rules are available online at **www.arrl.org/part-97-amateur-radio.** See also the sidebar "RFI-related FCC Rules and Definitions.") To be legal, the amateur station's signal must meet all Part 97 technical requirements, such as for spectral purity and power output.

As a result, it isn't surprising that most interference complaints involve multiple parts of the FCC rules. (The FCC's jurisdiction does have limits, though — ending below 9 kHz.) It is also important to note that each of the three parts (15, 18 and 97) specifies different requirements with respect to interference, including absolute emissions limits and spectral purity requirements. The FCC does not specify *any* RFI immunity requirements. Most consumer devices therefore receive no FCC protection from a legally licensed transmitter, including an amateur transmitter operating legally according to Part 97.

Licensed services are protected from interference to their signals, even if the interference is generated by another licensed service transmitter. For example, consider TVI from an amateur transmitter's spurious emissions, such as harmonics, that meet the requirements of Part 97 but are still strong enough to be received by nearby TV receivers. The TV receiver itself is not protected from interference under the FCC rules. However, within its service area the licensed TV broadcast signal is protected from harmful interference caused by spurious emissions from other licensed transmitters. In this case, the amateur transmitter's interfering spurious emission would have to be eliminated or reduced to a level at which harmful interference has been eliminated.

27.2.1 FCC Part 97 Rules

While most interference to consumer devices may be caused by a problem associated with the consumer device as opposed to the signal source, all amateurs must still comply with Part 97 rules. Regardless of who is at fault, strict conformance to FCC requirements, coupled with a neat and orderly station appearance, will go far toward creating a good and positive impression in the event of an FCC field investigation. Make sure your station and signal exhibit good engineering and operating practices.

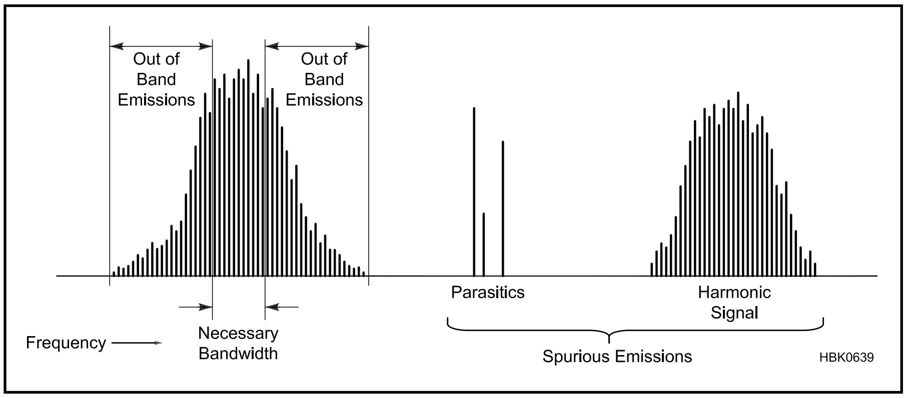


Fig 27.1 — An illustration of out-of-band versus spurious emissions. Some of the modulation sidebands are outside the necessary bandwidth. These are considered out-of-band emissions, not spurious emissions. The harmonic and parasitic emissions shown here are considered spurious emissions; these must be reduced to comply with §97.307.

What If the Police Are Called?

Many amateurs have had a similar experience. You are enjoying some time in front of the radio when the doorbell rings. When you answer the door, you find an irate neighbor has called the police about your transmissions interfering with their stereo (or cordless telephone or other home electronics). The officer tells you that you are interfering with your neighbor and orders you to stop transmissions immediately.

The bad news is you are in the middle of a bad situation. The good news is that most cases of interference can be cured! The proper use of "diplomacy" skills to communicate with a neighbor and standard technical cures will usually solve the problem. Even more good news is that if you are operating in accordance with your license and employing good engineering practices, the law and FCC rules are on your side.

Most RFI is caused by the unfortunate fact that most consumer equipment lacks the necessary filtering and shielding to allow it to work well near a radio transmitter. The FCC does not regulate the immunity of equipment, however, so when interference is caused by consumer-equipment fundamental overload, there is no FCC rules violation, and licensed stations have no regulatory responsibility to correct interference that may result.

Further, in 1982, Congress passed Public Law 97-259. This law is specific and reserves exclusive jurisdiction over RFI matters to the Federal Communications Commission. This national law preempts any state or local regulations or ordinances that attempt to regulate or resolve RFI matter. This is a victory for amateurs (and other services operating with the legal and technical provisions of their licenses).

Simply put, 97-259 says that cities and towns may not pass ordinances or regulations that would prohibit someone from making legal radio transmissions. But what do you do when your neighbor (or the police) confront you about RFI to their consumer electronics? First and foremost, remain calm. In all likelihood the officer or your neighbor has probably never heard of 97-259. Don't get defensive and get drawn into an argument. Don't make comments that the problem is with the neighbor's "cheap" equipment. While inexpensive radios are usually big culprits, any home electronics are potential problems due to inadequate technical designs.

Begin by listening to the complaint. Explain that while you understand, you are operating your equipment within its technical specifications. If your equipment doesn't interfere with your own home electronics, offer to demonstrate that to the officer. Also explain the basics of PL 97-259. If the officer (or neighbor) continues to insist that regardless of the law that you cease, consider temporarily complying with his or her request, with the understanding that you are doing so until the matter is resolved.

Work with your neighbors to understand that steps can be taken that should help resolve the problems (for example, placing toroids and filters on the consumer electronics). The ARRL Web has lots of helpful information as you work to resolve the problems. If your club has a local RFI committee or ARRL Technical Specialist, get them involved — their expertise can really be helpful. But above all, remember that when you practice easy, level-headed "diplomacy" you can usually keep the situation from escalating. — *Dan Henderson, N1ND, ARRL Regulatory Information Manager*

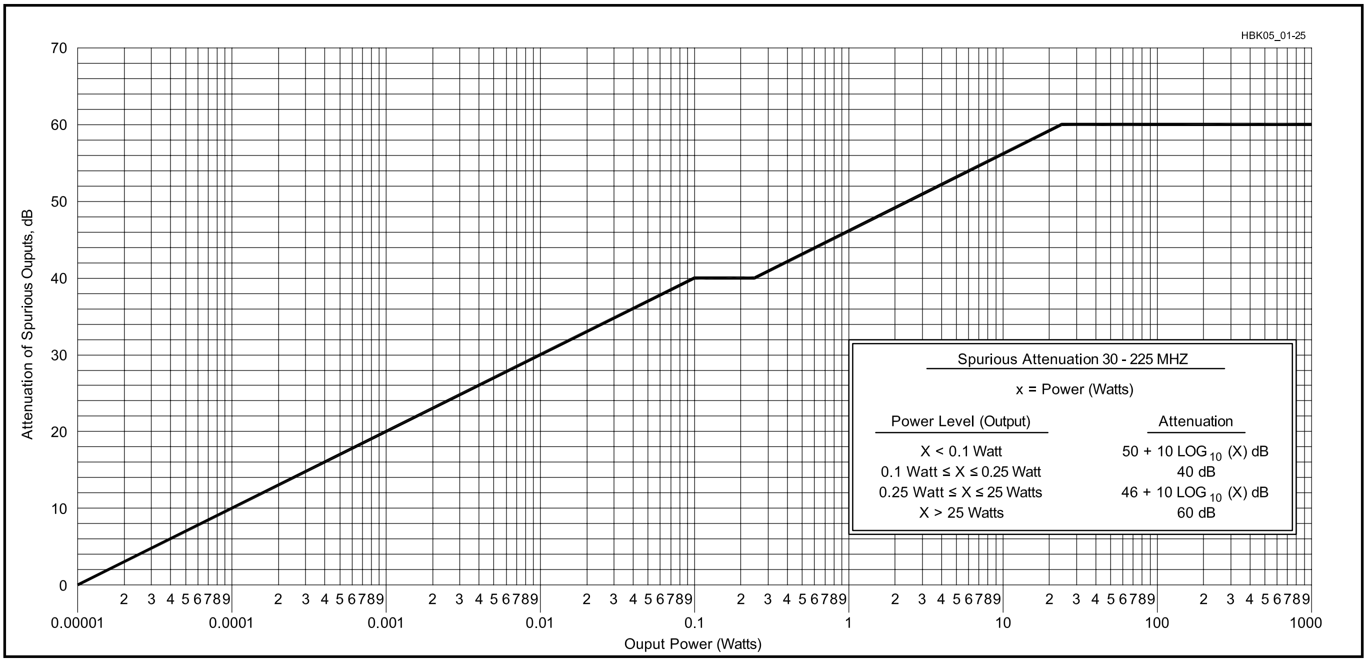


Fig 27.2 — Required attenuation of spurious outputs, 30-225 MHz.

The bandwidth of a signal is defined by §97.3(a)(8) while the paragraphs of §97.307 define the technical standards amateur transmissions must meet. Paragraph (c) defines the rules for interference caused by spurious emissions. As illustrated in **Fig 27.1**, modulation sidebands outside the necessary bandwidth are considered *out-of-band* emissions, while harmonics and parasitic signals are considered *spurious emissions*. Paragraphs (d) and (e) specify absolute limits on spurious emissions, illustrated in **Fig 27.2**. Spurious emissions must not exceed these levels, whether or not the emissions are causing interference. If spurious emissions from your transmitter are causing interference, it's your responsibility to clean them up.

Strict observance of these rules can not only help minimize interference to the amateur service, but other radio services and consumer devices as well.

27.2.2 FCC Part 15 Rules

In the United States, most unlicensed devices are regulated by Part 15 of the FCC's rules. While understanding these rules doesn't necessarily solve an RFI problem, they do provide some important insight and background on interference to and from a Part 15 device. (Part 18 devices and rules are similar in some respects) and will not be discussed separately — see the sidebar.)

There are literally thousands of Part 15 devices with the potential to be at the heart of an RFI problem. A Part 15 device can be almost anything not already covered in another Part of the FCC rules. In fact, many Part 15 devices may not normally even be associated with electronics, RF or in some cases, electricity. While televisions, radios, telephones and even computers obviously constitute a Part 15 device, the rules extend to anything that is capable of generating RF, including electric motors and consumer devices such as baby monitors, wireless microphones and intercoms, RF remote controls, garage door openers, etc. With so many Part 15 consumer devices capable of generating and responding to RF, it isn't surprising therefore that most reported RFI problems involving Amateur Radio also involve a Part 15 device.

TYPES OF PART 15 DEVICES

Part 15 describes three different types of devices that typically might be associated with an RFI problem. A fourth type of device, called a *carrier current device*, uses power lines and wiring for communications purposes. As we'll see, the rules are different for each type.

Intentional Emitters — Intentionally generate RF energy and radiate it. Examples include garage door openers, cordless phones and baby monitors.

Unintentional Emitters — Intentionally generate RF energy internally, but do not intentionally radiate it. Examples include computers and network equipment, superheterodyne receivers, switchmode power supplies and TV receivers.

Incidental Emitters — Generate RF energy only as an incidental part of their normal operation. Examples include power lines, arcing electric fence, arcing switch contacts, dc motors and mechanical light switches.

Carrier Current Devices — Intentionally generate RF and conduct it on power lines and/or house wiring for communications purposes. Examples include Powerline and X.10 networks, Access or In-House Broadband-Over-Power-Line (BPL), campus

FCC Part 18, Consumer Devices

Some consumer devices are regulated by Part 18 of the FCC Rules which pertains to the Industrial, Scientific and Medical (ISM) bands. Some lighting devices, such as the now ubiquitous compact fluorescent lamp (CFL), and home microwave ovens operate under Part 18.

Consumer Part 18 devices are generators of RF but not for communications purposes and can cause interference in some cases. However, there are no rules that protect them from interference. The purpose of Part 18 is to permit those devices to operate and to set up rules prohibiting interference.

From the standpoint of an RFI problem, Part 18 rules aren't much different than Part 15. Like a Part 15 device, a Part 18 device is also required to meet specified emissions limits. Furthermore, it must not cause harmful interference to a licensed radio service.

RFI-related FCC Rules and Definitions

Here are some of the most important rules and definitions pertaining to RFI and the Amateur Radio Service. Definitions in Part 2 are used in regulations that apply to all radio services.

§2.1 Definitions

Harmful Interference. Interference which endangers the functioning of a radionavigation service or of other safety services or seriously degrades, obstructs, or repeatedly interrupts a radiocommunication service operating in accordance with [the ITU] Radio Regulations.

Interference. The effect of unwanted energy due to one or a combination of emissions, radiations, or inductions upon reception in a radiocommunication system, manifested by any performance degradation, misinterpretation, or loss of information which could be extracted in the absence of such unwanted energy.

Out-of-band Emission. Emission on a frequency or frequencies immediately outside the necessary bandwidth which results from the modulation process, but excluding spurious emissions.

§97.3 Definitions

(a) The definitions of terms used in Part 97 are:

(8) Bandwidth. The width of a frequency band outside of which the mean power of the transmitted signal is attenuated at least 26 dB below the mean power of the transmitted signal within the band.

(23) Harmful interference. (see the previous Part 2 definition)

(42) Spurious emission. An emission, on frequencies outside the necessary bandwidth of a transmission, the level of which may be reduced without affecting the information being transmitted.

§97.307 Emission standards

(a) No amateur station transmission shall occupy more bandwidth than necessary for the information rate and emission type being transmitted, in accordance with good amateur practice.

(b) Emissions resulting from modulation must be confined to the band or segment available to the control operator. Emissions outside the necessary bandwidth must not cause splatter or key-click interference to operations on adjacent frequencies.

(c) All spurious emissions from a station transmitter must be reduced to the greatest extent practicable. If any spurious emission, including chassis or power line radiation, causes harmful interference to the reception of another radio station, the licensee of the interfering amateur station is required to take steps to eliminate the interference, in accordance with good engineering practice.

(d) For transmitters installed after January 1, 2003, the mean power of any spurious emission from a station transmitter or external RF amplifier transmitting on a frequency below 30 MHz must be at least 43 dB below the mean power of the fundamental emission. For transmitters installed on or before January 1, 2003, the mean power of any spurious emission from a station transmitter or external RF power amplifier transmitting on a frequency below 30 MHz must not exceed 50 mW and must be at least 40 dB below the mean power of the fundamental emission. For a transmitter of mean power less than 5 W installed on or before January 1, 2003, the attenuation must be at least 30 dB. A transmitter built before April 15, 1977, or first marketed before January 1, 1978, is exempt from this requirement.

(e) The mean power of any spurious emission from a station transmitter or external RF power amplifier transmitting on a frequency between 30-225 MHz must be at least 60 dB below the mean power of the fundamental. For a transmitter having a mean power of 25 W or less, the mean power of any spurious emission supplied to the antenna transmission line must not exceed 25 µW and must be at least 40 dB below the mean power of the fundamental emission, but need not be reduced below the power of 10 µW. A transmitter built before April 15, 1977, or first marketed before January 1, 1978, is exempt from this requirement.

radio-broadcast systems, and other power-line communications devices.

PART 15 SUMMARY

FCC's Part 15 rules pertain to unlicensed devices and cover a lot of territory. Although reading and understanding Part 15 can appear rather formidable — especially at first glance — the rules pertaining to RFI can be roughly summarized as follows:

• Part 15 devices operate under an unconditional requirement to not cause harmful interference to a licensed radio service, such as Amateur Radio. If such interference occurs, the operator of the Part 15 device is responsible for eliminating the interference.

• Part 15 devices receive no protection from interference from a licensed radio service. There are no FCC rules or limits with regard to Part 15 device RFI immunity.

When is the operator of a licensed transmitter responsible for interference to a Part 15 device?

• The rules hold the transmitter operator responsible if interference is caused by spurious emissions such as a harmonic. An example would be a harmonic from an amateur's transmitter interfering with a cordless telephone. In this case, the transmitter is generating harmful RF energy beyond its permitted bandwidth. A cure must be installed at the transmitter.

• The transmitter operator is not responsible when a Part 15 device is improperly responding to a legal and intentional output of the transmitter. An example of this case would be interference to a cordless telephone operation by the strong-but-legal signal from a nearby amateur transmitter. In this case, the Part 15 device is at fault and the cure must be installed there. It is important to note that this situation is typical of most interference to Part 15 devices.

Even though the causes and cures for these situations are different, the common element for all three situations is the need for personal diplomacy in resolving the problem.

PART 15 MANUFACTURER REQUIREMENTS

Under FCC rules, both device manufactures and operators of those devices share responsibility for addressing an RFI problem. The rules for manufacturers are primarily designed to reduce the possibility of harmful interference. They do not however completely eliminate the possibility of an RFI problem. If and when interference does occur, the rules are designed to minimize and confine the scope of problems such that they can be addressed on a case by case basis. Responsibility then falls on the device operator to correct the problem or cease using the device.

Manufacturers are subject to requirements that they use good engineering practice to help minimize the potential for interference. In addition, they must meet certain absolute conducted and radiated emissions limits for intentional and unintentional emitters. (See the sidebar for limits on conducted and radiated emissions.) These limits are high enough that S9+ interference levels can occur nearby, depending on frequency, distance and other factors. In fact, most reported Part 15 consumer products causing harmful interference to Amateur Radio are legal and meet these required limits. Therefore, the fact that a particular device is causing harmful interference is not in itself evidence or proof of a rules violation with regard to emissions limits.

With the exception of intentional emitters and carrier-current devices, there are no absolute radiated emissions limits below 30 MHz. The size of a Part 15 device is usually small relative to the wavelength at these frequencies. It is typically too small to be an effective antenna at these longer wavelengths. Therefore, under the FCC rules, only conducted emissions are specified below 30 MHz. (Note that cables and wiring connected to the devices are often effective at radiating signals and are frequent sources of radiated RFI.)

In general, radiated emissions limits are specified only at frequencies above 30 MHz. At the shorter wavelengths above 30 MHz, the device itself is large enough to be a radiator. Wiring connected to it can also be an effective antenna for radiating noise.

Although incidental radiators do not have any absolute emissions limits, as for all Part 15 devices, manufacturers must still employ good engineering practice to minimize the potential for interference.

The FCC also requires manufacturers to add information as a label to most Part 15

Part 15 Absolute Emissions Limits for Unintentional Emitters

§15.107 Conducted limits

(a) Except for Class A digital devices, for equipment that is designed to be connected to the public utility (ac) power line, the radio frequency voltage that is conducted back onto the ac power line on any frequency or frequencies within the band 150 kHz to 30 MHz shall not exceed the limits in the following table, as measured using a 50 µH/50 ohms line impedance stabilization network (LISN). Compliance with the provisions of this paragraph shall be based on the measurement of the radio frequency voltage between each power line and ground at the power terminal. The lower limit applies at the band edges.

Conducted Limits — Non Class-A Digital Devices

Frequency of emission (MHz)	*Conducted limit (dBµV) Quasi-peak*	*Average*
0.15–0.5	66 to 56*	56 to 46*
0.5–5	56	46
5–30	60	50

*Decreases with the logarithm of the frequency.

(b) For a Class A digital device that is designed to be connected to the public utility (ac) power line, the radio frequency voltage that is conducted back onto the ac power line on any frequency or frequencies within the band 150 kHz to 30 MHz shall not exceed the limits in the following table, as measured using a 50 µH/50 ohms LISN. Compliance with the provisions of this paragraph shall be based on the measurement of the radio frequency voltage between each power line and ground at the power terminal. The lower limit applies at the boundary between the frequency ranges.

Conducted Limits — Class-A Digital Devices

Frequency of emission (MHz)	*Conducted limit (dBµV) Quasi-peak*	*Average*
0.15–0.5	79	66
0.5–30	73	60

(c) The limits shown in paragraphs (a) and (b) of this section shall not apply to carrier current systems operating as unintentional radiators on frequencies below 30 MHz. In lieu thereof, these carrier current systems shall be subject to the following standards:

(1) For carrier current systems containing their fundamental emission within the frequency band 535-1705 kHz and intended to be received using a standard AM broadcast receiver: no limit on conducted emissions.

(2) For all other carrier current systems: 1000 µV within the frequency band 535–1705 kHz, as measured using a 50 µH/50 ohms LISN.

(3) Carrier current systems operating below 30 MHz are also subject to the radiated emission limits in §15.109(e).

(d) Measurements to demonstrate compliance with the conducted limits are not required for devices which only employ battery power for operation and which do not operate from the ac power lines or contain provisions for operation while connected to the ac power lines. Devices that include, or make provision for, the use of battery chargers which permit operating while charging, ac adaptors or battery eliminators or that connect to the ac power lines indirectly, obtaining their power through another device which is connected to the ac power lines, shall be tested to demonstrate compliance with the conducted limits.

§ 15.109 Radiated emission limits

(a) Except for Class A digital devices, the field strength of radiated emissions from unintentional radiators at a distance of 3 meters shall not exceed the following values:

Radiated Limits — Non Class-A Digital Devices

Frequency of emission (MHz)	*Field Strength (µV/meter)*
30–88	100
88–216	150
216–960	200
Above 960	500

(b) The field strength of radiated emissions from a Class A digital device, as determined at a distance of 10 meters, shall not exceed the following:

Radiated Limits — Class-A Digital Devices

Frequency of emission (MHz)	*Field Strength (µV/meter)*
30–88	90
88–216	150
216–960	210
Above 960	300

(c) In the emission tables above, the tighter limit applies at the band edges. Sections 15.33 and 15.35 which specify the frequency range over which radiated emissions are to be measured and the detector functions and other measurement standards apply.

(d) For CB receivers, the field strength of radiated emissions within the frequency range of 25–30 MHz shall not exceed 40 microvolts/meter at a distance of 3 meters. The field strength of radiated emissions above 30 MHz from such devices shall comply with the limits in paragraph (a) of this section.

(e) Carrier current systems used as unintentional radiators or other unintentional radiators that are designed to conduct their radio frequency emissions via connecting wires or cables and that operate in the frequency range of 9 kHz to 30 MHz, including devices that deliver the radio frequency energy to transducers, such as ultrasonic devices not covered under part 18 of this chapter, shall comply with the radiated emission limits for intentional radiators provided in §15.209 for the frequency range of 9 kHz to 30 MHz. As an alternative, carrier current systems used as unintentional radiators and operating in the frequency range of 525 kHz to 1705 kHz may comply with the radiated emission limits provided in §15.221(a). At frequencies above 30 MHz, the limits in paragraph (a), (b), or (g) of this section, as appropriate, apply.

RFI-related Part 15 FCC Rules and Definitions

The FCC's Part 15 rules are found in Title 47 section of the Code of Federal Regulations (CFR). They pertain to unlicensed devices. Here are some of the more important Part 15 rules and definitions pertaining to RFI.

§15.3 Definitions.

(m) ***Harmful interference.*** Any emission, radiation or induction that endangers the functioning of a radionavigation service or of other safety services or seriously degrades, obstructs or repeatedly interrupts a radio communications service operating in accordance with this chapter.

(n) ***Incidental radiator.*** A device that generates radio frequency energy during the course of its operation although the device is not intentionally designed to generate or emit radio frequency energy.

(o) ***Intentional radiator***. A device that intentionally generates and emits radio frequency energy by radiation or induction.

(z) ***Unintentional radiator.*** A device that intentionally generates radio frequency energy for use within the device, or that sends radio frequency signals by conduction to associated equipment via connecting wiring, but which is not intended to emit RF energy by radiation or induction.

(t) ***Power line carrier systems.*** An unintentional radiator employed as a carrier current system used by an electric power utility entity on transmission lines for protective relaying, telemetry, etc. for general supervision of the power system. The system operates by the transmission of radio frequency energy by conduction over the electric power transmission lines of the system. The system does not include those electric lines which connect the distribution substation to the customer or house wiring.

(ff) ***Access Broadband over Power Line (Access BPL).*** A carrier current system installed and operated on an electric utility service as an unintentional radiator that sends radio frequency energy on frequencies between 1.705 MHz and 80 MHz over medium voltage lines or over low voltage lines to provide broadband communications and is located on the supply side of the utility service's points of interconnection with customer premises. Access BPL does not include power line carrier systems as defined in §15.3(t) or In-House BPL as defined in §15.3(gg).

(gg) ***In-House Broadband over Power Line (In-House BPL)***. A carrier current system, operating as an unintentional radiator, that sends radio frequency energy by conduction over electric power lines that are not owned, operated or controlled by an electric service provider. The electric power lines may be aerial (overhead), underground, or inside the walls, floors or ceilings of user premises. In-House BPL devices may establish closed networks within a user's premises or provide connections to Access BPL networks, or both.

Some of the most important Part 15 rules pertaining to radio and television interference from unintentional and incidental radiators include:

§15.5 General conditions of operation.

(b) Operation of an intentional, unintentional, or incidental radiator is subject to the conditions that no harmful interference is caused and that interference must be accepted that may be caused by the operation of an authorized radio station, by another intentional or unintentional radiator, by industrial, scientific and medical (ISM) equipment, or by an incidental radiator.

(c) The operator of the radio frequency device shall be required to cease operating the device upon notification by a Commission representative that the device is causing harmful interference. Operation shall not resume until the condition causing the harmful interference has been corrected.

§15.13 Incidental radiators.

Manufacturers of these devices shall employ good engineering practices to minimize the risk of harmful interference.

§15.15 General technical requirements.

(c) Parties responsible for equipment compliance should note that the limits specified in this part will not prevent harmful interference under all circumstances. Since the operators of Part 15 devices are required to cease operation should harmful interference occur to authorized users of the radio frequency spectrum, the parties responsible for equipment compliance are encouraged to employ the minimum field strength necessary for communications, to provide greater attenuation of unwanted emissions than required by these regulations, and to advise the user as to how to resolve harmful interference problems (for example, see Sec. 15.105(b)).

§15.19 Labeling requirements.

(a) In addition to the requirements in part 2 of this chapter, a device subject to certification, notification, or verification shall be labeled as follows:

(3) All other devices shall bear the following statement in a conspicuous location on the device:

This device complies with part 15 of the FCC Rules. Operation is subject to the following two conditions: (1) This device may not cause harmful interference, and (2) this device must accept any interference received, including interference that may cause undesired operation.

And the following requirements apply for consumer and residential Class B digital devices. Different requirements apply for Class A digital devices which can only be used in industrial and similar environments:

§15.105 Information to the user.

(b) For a Class B digital device or peripheral, the instructions furnished the user shall include the following or similar statement, placed in a prominent location in the text of the manual:

This equipment has been tested and found to comply with the limits for a Class B digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference in a residential installation. This equipment generates, uses and can radiate radio frequency energy and, if not installed and used in accordance with the instructions, may cause harmful interference to radio communications. However, there is no guarantee that interference will not occur in a particular installation. If this equipment does cause harmful interference to radio or television reception, which can be determined by turning the equipment off and on, the user is encouraged to try to correct the interference by one or more of the following measures:

Reorient or relocate the receiving antenna.

Increase the separation between the equipment and receiver.

Connect the equipment into an outlet on a circuit different from that to which the receiver is connected.

Consult the dealer or an experienced radio/TV technician for help.

devices or as text in the device's operating manual. This information attests to the potential for interference and to the responsibility of the device operator. It must be placed in a conspicuous location on the device or in the manual and contain the following statement:

This device complies with part 15 of the FCC Rules. Operation is subject to the following two conditions: (1) This device may not cause harmful interference, and (2) this device must accept any interference received, including interference that may cause undesired operation.

Owners of Part 15 devices are frequently unaware of this information and surprised to find it on the device or in its manual. Reading this label can be an important step in resolving RFI issues. Additional details regarding labeling requirements can be found in the sidebar on Part 15 Rules.

EQUIPMENT AUTHORIZATION

FCC regulations do not require Part 15 devices to be tested by the FCC. In fact, very few devices must actually undergo FCC testing. In most cases, the requirements are met by the manufacturer testing the device and the test results either kept on file or sent to the FCC, depending on the type of device involved. Here is some general information concerning various FCC approval processes for RF devices:

• *Certification:* Requires submittal of an application that includes a complete technical description of the product and a measurement report showing compliance with the FCC technical standards. Certification procedures have now largely replaced the once familiar Type Acceptance, which is no longer used by the FCC. Devices subject to certification include: low-power transmitters such as cordless telephones, security alarm systems, scanning receivers, super-regenerative receivers, Amateur Radio external HF amplifiers and amplifier kits, and TV interface devices such as DVD players.

• *Declaration of Conformity (DoC)*: Is a declaration that the equipment complies with FCC requirements. A DoC is an alternative to certification since no application to FCC is required, but the applicant must have the device tested at an accredited laboratory. A Declaration of Conformity is the usual approval procedure for Class B personal computers and personal computer peripherals.

• *Notification*: Requires submittal to the FCC of an abbreviated application for equipment authorization which does not include a measurement report. However, a measurement report showing compliance of the product with the FCC technical standards must be retained by the applicant and must be submitted upon request by the Commission. Devices subject to notification include: point-to-point microwave transmitters, AM, FM and TV broadcast transmitters and other receivers (except as noted elsewhere).

• *Verification*: Verification is a self-approval process where the applicant performs the necessary tests and verifies that they have been done on the device to be authorized and that the device is in compliance with the technical standards. Verified equipment requires that a compliance label be affixed to the device as well as information included in the operating manual regarding the interference potential of the device. Devices subject to verification include: business computer equipment (Class A); TV and FM receivers; and non-consumer Industrial, Scientific and Medical Equipment.

PART 15 OPERATOR REQUIREMENTS

All Part 15 devices are prohibited from causing harmful interference to a licensed radio service — including the Amateur Radio Service. This is an absolute requirement without regard to the emitter type or a manufacturer's conformance to emissions limits or other FCC technical standards. It is important to note that the manufacturer's requirements are not sufficient to prevent harmful interference from occurring under all circumstances. If and when a Part 15 device generates harmful interference, it becomes the responsibility of the device operator to correct the problem. Upon notice from the FCC, the device operator may also be required to cease using the device until such time as the interference has been corrected.

27.3 Elements of RFI

27.3.1 Source-Path-Victim

All cases of RFI involve a *source* of radio frequency energy, a device that responds to the electromagnetic energy (*victim*), and a transmission *path* that allows energy to flow from the source to the victim. Sources include radio transmitters, receiver local oscillators, computing devices, electrical noise, lightning and other natural sources. Note that receiving unwanted electromagnetic energy does not necessarily cause the victim to function improperly.

A device is said to be *immune* to a specific source if it functions properly in the presence of electromagnetic energy from the source. In fact, designing devices for various levels of immunity is one aspect of electromagnetic compatibility engineering. Only when the victim experiences a *disturbance* in its function as a consequence of the received electromagnetic energy does RFI exist. In this case, the victim device is *susceptible* to RFI from that source.

There are several ways that RFI can travel from the source to the victim: *radiation*, *conduction*, *inductive coupling* and *capacitive coupling*. *Radiated RFI* propagates by electromagnetic radiation from the source through space to the victim. *Conducted RFI* travels over a physical conducting path between the source and the victim, such as wires, enclosures, ground planes, and so forth. Inductive coupling occurs when two circuits are magnetically coupled. Capacitive coupling occurs when two circuits are coupled electrically through capacitance. Typical RFI problems you are likely to encounter often include multiple paths, such as conduction and radiation. (See the section Shields and Filters, also Ott, sections 2.1-2.3.)

27.3.2 Differential-Mode vs Common-Mode Signals

The path from source to victim almost always includes some conducting portion, such as wires or cables. RF energy can be conducted directly from source to victim, be conducted onto a wire or cable that acts as an antenna where it is radiated, or be picked up by a conductor connected to the victim that acts like an antenna. When the noise signal is traveling along the conducted portion of the path, it is important to understand the differences between *differential-mode* and *common-mode* conducted signals (see **Fig 27.3**).

Differential-mode currents usually have two easily identified conductors. In a two-wire transmission line, for example, the signal leaves the generator on one wire and returns on the other. When the two conductors are in close proximity, they form a transmission line and the two signals have opposite polarities as shown in Fig 27.3A. Most desired signals, such as the TV signal inside a coaxial cable or an Ethernet signal carried on CAT5 network cable, are conducted as differential-mode signals.

A common-mode circuit consists of several wires in a multi-wire cable acting as if they were a single current path as in Fig 27.3B. Common-mode circuits also exist when the outside surface of a cable's shield acts as a conductor as in Figs 27.3C and 27.3D. (See the chapter on **Transmission Lines** for a discussion about isolation between the shield's inner and outer surfaces for RF signals.) The return path for a common-mode signal often involves Earth ground.

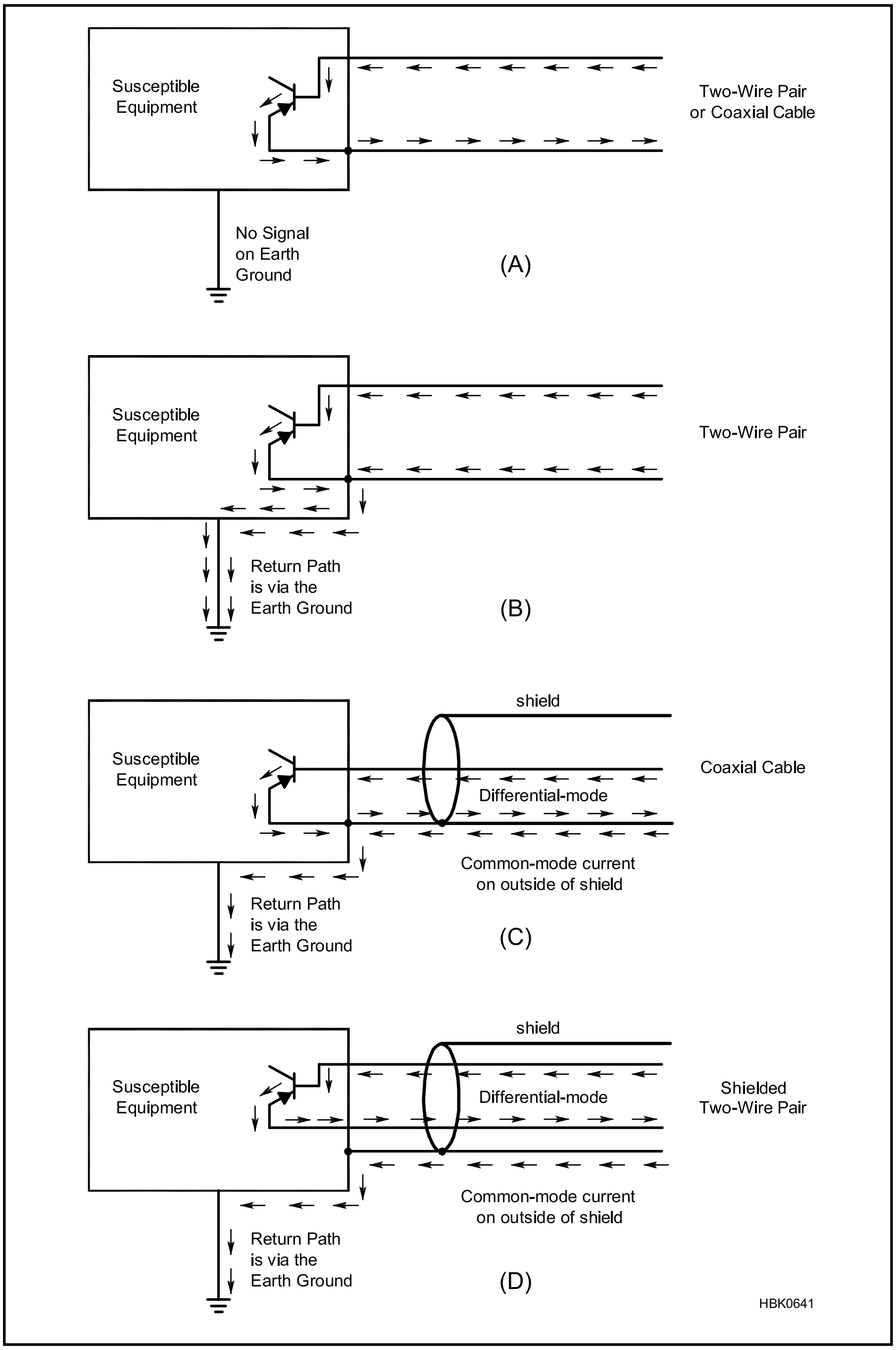


Fig 27.3 — Typical configurations of common-mode and differential-mode current. The drawing in A shows the currents of a differential-mode signal while B shows a common-mode signal with currents flowing equally on all of the source wires. In C, a common-mode signal flows on the outside of a coaxial cable shield with a differential-mode signal inside the cable. In D, the differential-mode signal flows on the internal wires while a common-mode signal flows on the outside of the cable shield.

27.3.3 Types of RFI

There are four basic types of RFI that apply to Amateur Radio. The first two occur in the following order of likelihood when the interfering source is an amateur transmitter intentionally generating a radio signal:

1) Fundamental Overload — Disruption or degradation of a device's function in the presence of a transmitter's fundamental signal (the intended signal from the transmitter).

2) Spurious Emissions — Reception of a radio signal interfered with by spurious emissions from the transmitter as defined in the previous section on Part 97 definitions and Fig 27.1.

The second two types of RFI occur, again in order of likelihood, when the reception of a desired signal is interfered with by RF energy received along with the desired signal.

3) External Noise Sources — Reception of a radio signal interfered with by RF energy transmitted incidentally or unintentionally by a device that is not a licensed transmitter

4) Intermodulation — Reception of a radio signal interfered with by intermodulation distortion (IMD) products generated inside or outside of the receiver

As an RFI troubleshooter, start by determining which of these is involved in your interference problem. Once you know the type of RFI, selecting the most appropriate cure for the problem becomes much easier.

27.3.4 Spurious Emissions

All transmitters generate some (hopefully few) RF signals that are outside their intended transmission bandwidth — out-of-band emissions and spurious emissions as illustrated in Fig 27.1. Out-of-band signals result from distortion in the modulation process or consist of broadband noise generated by the transmitter's oscillators that is added to the intended signal. Harmonics, the most common spurious emissions, are signals at integer multiples of the operating (or fundamental) frequency.

Transmitters may also produce broadband noise and/or parasitic oscillations as spurious emissions. (Parasitic oscillations are discussed in the **RF Power Amplifiers** chapter.) Overdriving an amplifier often creates spurious emissions. Amplifiers not meeting FCC certification standards but sold illegally are frequent sources of spurious emissions.

Regardless of how the unwanted signals are created, if they cause interference, FCC regulations require the operator of the transmitter to correct the problem. The usual cure is to adjust or repair the transmitter or use filters at the transmitter output to block the spurious emissions from being radiated by the antenna.

27.3.5 Fundamental Overload

Most cases of interference caused by an amateur transmission are due to *fundamental overload*. (See the sidebar "Fundamental Overload of Radio Receivers.") The world is filled with RF signals. Properly designed radio receivers of any sort should be able to select the desired signal, while rejecting all others. Unfortunately, because of design deficiencies such as inadequate shields or filters, some radio receivers are unable to reject strong out-of-band signals. Electronic equipment that is not a radio receiver can also suffer from fundamental overload from similar design shortcomings. Both types of fundamental overload are common in consumer electronics.

Fundamental Overload of Radio Receivers

When used in a discussion of radio (and TV) receiver performance, "fundamental overload" specifically refers to the effects of a signal at the receiver input that is too strong for the receiver circuits to process properly. In other words, the term means "overload of a radio receiver due to the strength of a transmitted signal's fundamental or intended component." For example, in a superheterodyne receiver, fundamental overload would be caused by a signal that drives an input amplifier stage into clipping or cutoff or both.

Reducing the level of the offending strong signal returns the receiver to normal operation and causes the undesirable effects to disappear. An attenuator is often a weapon of choice when encountering this type of problem. This type of fundamental overload is discussed in the **Receivers** chapter.

A strong signal can enter equipment in several different ways. Most commonly, it is conducted into the equipment by connecting wires and cables. Possible RFI conductors include antennas and feed lines, interconnecting cables, power cords, and ground wires. TV antennas and feed lines, telephone or speaker wiring and ac power cords are the most common points of entry.

If the problem is a case of fundamental overload, significant improvement can often be observed just by moving the victim equipment and the signal source farther away from each other. The effect of an interfering signal is directly related to its strength, diminishing with the square of the distance from the source. If the distance from the source doubles, the strength of the electromagnetic field decreases to one-fourth of its power density at the original distance from the source. This characteristic can often be used to help identify an RFI problem as fundamental overload. If reducing the strength of the signal source causes the same effect that is also a signature of fundamental overload.

27.3.6 External Noise Sources

Most cases of interference to the Amateur Service reported to the FCC are eventually determined to involve some sort of external noise source, rather than signals from a radio transmitter. Noise in this sense means an RF signal that is not essential to the generating device's operation. The most common external noise sources are electrical, primarily power lines. Motors and switching equipment can also generate electrical noise.

External noise can also come from unlicensed Part 15 RF sources such as computers and networking equipment, video games, appliances, and other types of consumer electronics. Regardless of the source, if you determine the problem to be caused by external noise, elimination of the noise must take place at the source. As an alternative, several manufacturers also make noise canceling devices that can help in some circumstances.

27.3.7 Intermodulation Distortion

As discussed in the chapter on **Receivers**, intermodulation distortion (IMD) is caused by two signals combining in such a way as to create *intermodulation products* — signals at various combinations of the two original frequencies. The two original signals may be perfectly legal, but the resulting *intermodulation distortion products* may occur on the frequencies used by other signals and cause interference in the same way as a spurious signal from a transmitter. Depending on the nature of the generating signals, "intermod" can be intermittent or continuous. IMD can be generated inside a receiver by large signals or externally by signals mixing together in non-linear junctions or connections.

27.3.8 Ground Connections

An electrical ground is not a huge sink that somehow swallows noise and unwanted signals. Ground is a *circuit* concept, whether the circuit is small, like a radio receiver, or large, like the propagation path between a transmitter and cable-TV installation. Ground forms a universal reference point between circuits.

While grounding is not a cure-all for RFI problems, ground is an important safety component of any electronics installation. It is part of the lightning protection system in your station and a critical safety component of your house wiring. Any changes made to a grounding system must not compromise these important safety considerations. Refer to the **Safety** chapter for important information about grounding.

Many amateur stations have several connections referred to as "grounds"; the required safety ground that is part of the ac wiring system, another required connection to the Earth for lightning protection, and perhaps another shared connection between equipment for RFI control. These connections can interact with each other in ways that are difficult to predict.

Rearranging the station ground connections may cure some RFI problems in the station by changing the RF current distribution so that the affected equipment is at a low-impedance point and away from RF "hot spots." Creating a low-impedance connection between your station's equipment is easy to do and will help reduce voltage differences (and current flow) between pieces of equipment. However, a station ground is not always the cure-all that some literature has suggested.

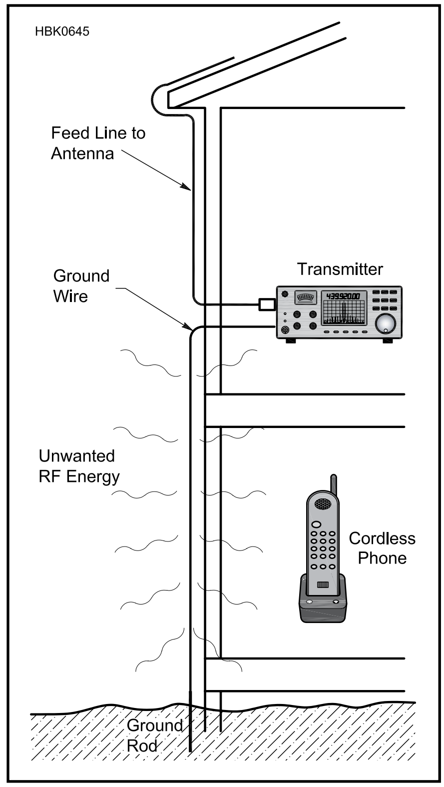


Fig 27.4 — An Earth ground connection can radiate signals that might cause RFI to nearby equipment. This can happen if the ground connection is part of an antenna system or if it is connected to a coaxial feed line carrying RF current on the outside of the shield.

LENGTH OF GROUND CONNECTIONS

The required ground connection for lightning protection between the station equipment and an outside ground rod is at least several feet long in most practical installations. (See the **Safety** chapter for safety and lightning protection ground requirements.)

In general, however, a long connection to Earth should be considered as part of an RFI problem only to the extent that it is part of the antenna system. For example, should a long-wire HF antenna end in the station, a ground connection of *any* length is a necessary and useful part of that antenna and will radiate RF.

At VHF a ground wire can be several wavelengths long — a very effective antenna for any harmonics that could cause RFI! For example, in **Fig 27.4**, signals radiated from the required safety ground wire could very easily create an interference problem in the downstairs electronic equipment.

GROUND LOOPS

A *ground loop* is created by a continuous conductive path around a series of equipment enclosures. While this does create an opportunity for lightning and RFI susceptibility, the ground loop itself is rarely a cause of problems at RF. Ground loops are usually associated with problems of audio hum or buzz caused by coupling to power-frequency magnetic fields and currents. To avoid low-frequency ground-loop issues, use short, properly-shielded cables that are the minimum length required to connect the equipment and bundle them together to minimize the area of any enclosed loop. Ground-loop problems at RF are minimized by the use of a single-point or star ground system as shown in **Fig 27.5**.

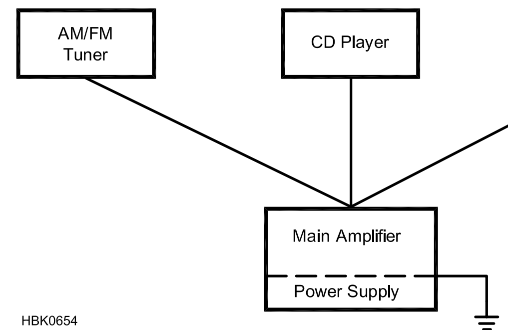


Fig 27.5 — A single-point or star ground eliminates ground loops in a multiple-component system.

27.4 Identifying the Type of RFI Source

It is useful to place an offending noise source into one of several broad categories at the early stages of any RFI investigation. Since locating and resolution techniques can vary somewhat for each type, the process of locating and resolving RFI problems should begin with identifying the general type of RFI source.

It is often impossible to identify the exact type of device generating the RFI from the sound of the interference. Because there are many potential sources of RFI, it is often more important to obtain and interpret clues from the general noise characteristics and the patterns in which it appears.

A source that exhibits a repeatable pattern during the course of a day or week, for example, suggests something associated with human activity. A sound that varies with or is affected by weather suggests an outdoor source. Noise that occurs in a regular and repeating pattern of peaks and nulls as you tune across the spectrum, every 50 kHz for example, is often associated with switchmode power supply or similar pulsed-current devices. A source that exhibits fading or other sky wave characteristics suggests something that is not local. A good ear and careful attention to detail will often turn up some important clues. A detailed RFI log can often help, especially if maintained over time.

Noise can be characterized as broadband or narrowband — another important clue. *Broadband noise* is defined as noise having a bandwidth much greater than the affected receiver's operating bandwidth and is reasonably uniform across a wide frequency range. Noise from arcs and sparks, such as power-line noise, tend to be broadband. *Narrowband noise* is defined as noise having a bandwidth less than the affected receiver's bandwidth. Narrowband noise is present on specific, discrete frequencies or groups of frequencies, with or without additional modulation. In other words, if you listened to the noise on an SSB receiver, tuning would cause its sound to vary, just like a regular signal. Narrowband noise often sounds like an unmodulated carrier with a frequency that may drift or suddenly change. Microprocessor clock harmonics, oscillators and transmitter harmonics are all examples of narrowband noise.

27.4.1 Identifying Noise from Part 15 Devices

The most common RFI problem reported to the ARRL comes from an unknown and unidentified source. Part 15 devices and other consumer equipment noise sources are ubiquitous. Although the absolute signal level from an individual noise source may be small, their increasing numbers makes this type of noise a serious problem in many suburban and urban areas. The following paragraphs describe several common types of electronic noise sources.

Electronic devices containing oscillators, microprocessors, or digital circuitry produce RF signals as a byproduct of their operation. The RF noise they produce may be radiated from internal wiring as a result of poor shielding. The noise may also be conducted to external, unshielded or improperly shielded wiring as a common-mode signal where it radiates noise. Noise from these devices is usually narrowband that changes characteristics (frequency, modulation, on-off pattern) as the device is used in different ways.

Another major class of noise source is equipment or systems that control or switch large currents. Among them are variable-speed motors in products as diverse as washing machines, elevators, and heating and cooling systems. Charging regulators and control circuitry for battery and solar power systems are a prolific source of RF noise. So are switchmode power supplies for computers and low-voltage lighting. This type of noise is only present when the equipment is operating.

Switchmode supplies, solar controllers and inverters often produce noise signals every N kHz, with N typically being from 5 to 50 or more kHz, the frequency at which current is switched. This is different from noise produced by spark or arc sources that is uniform across a wide bandwidth. This pattern is often an important clue in distinguishing switching noise from power-line or electrical noise.

Wired computer networks radiate noise directly from their unshielded circuitry and from network and power supply cables. The noise takes two forms — broadband noise and modulated carriers at multiple frequencies within the amateur bands. As an example, Ethernet network interfaces often radiate signals heard on a receiver in CW mode. 10.120, 14.030, 21.052 and 28.016 MHz have been reported as frequencies of RFI from Ethernet networks. Each network interface uses its own clock, so if you have neighbors with networks you'll hear a cluster of carriers around these frequencies, ±500 Hz or so.

In cable TV systems video signals are converted to RF across a wide spectrum and distributed by coaxial cable into the home. Some cable channels overlap with amateur bands, but the signals should be confined within the cable system. No system is perfect, and it is common for a defective coax connection to allow leakage to and from the cable. When this happens, a receiver outside the cable will hear RF from the cable and the TV receiver may experience interference from local transmissions. Interference to and from cable TV signals is discussed in detail later in this chapter.

27.4.2 Identifying Power-line and Electrical Noise

POWER-LINE NOISE

Next to external noise from an unknown source, the most frequent cause of an RFI problem reported to the ARRL involving a known source is power-line noise. (For more information on power-line noise, see the book *AC Power Interference Handbook*, by Marv Loftness KB7KK.) Virtually all power-line noise originating from utility equipment is caused by spark or arcing across some hardware connected to or near a power line. A breakdown and ionization of air occurs and current flows across a gap between two conductors, creating RF noise as shown in **Fig 27.6**. Such noise is often referred to as “gap noise” in the utility power industry. The gap may be caused by broken, improperly installed or loose hardware. Typical culprits include insufficient and inadequate hardware spacing such as a gap between a ground wire and a staple. Contrary to common misconception, corona discharge is rarely, if ever, a source of power-line noise.

While there may not be one single conclusive test for power-line noise, there are a number of important tell-tale signs. On an AM or SSB receiver, the characteristic raspy buzz or frying sound, sometimes changing in intensity as the arc or spark sputters a bit, is often the first and most obvious clue.

Power-line noise is typically a broadband type of interference, relatively constant across a wide spectrum. Since it is broadband noise, you simply can’t change frequency to eliminate it. Power-line noise is usually, but not always, stronger on lower frequencies. It occurs continuously across each band and up through the spectrum. It can cause interference from the AM broadcast band through UHF, gradually tapering off as frequency increases. If the noise is not continuous across all of an amateur band, exhibits a pattern of peaks and nulls at different frequencies, or repeats at some frequency interval, you probably do not have power-line noise.

The frequency at which power-line noise diminishes can also provide an important clue as to its proximity. The closer the source, the higher the frequency at which it can be received. If it affects VHF and UHF, the source is relatively close by. If it drops off just above or within the AM broadcast band, it may be located some distance away — up to several miles.

Power-line noise is often affected by weather if the source is outdoors. It frequently changes during rain or humid conditions, for example, either increasing or decreasing in response to moisture. Wind may also create fluctuations or interruptions as a result of line and hardware movement. Temperature effects can also result from thermal expansion and contraction.

Another good test for power-line noise requires an oscilloscope. Remember that power-line noise occurs in bursts and usually at a rate of 120 bursts per second. Observe the suspect noise from your radio’s audio output. (Note: The record output jack works best if available). Use the AM mode with wide filter settings and tune to a frequency without a station so the noise can be heard clearly. Use the LINE setting of the oscilloscope’s trigger subsystem to synchronize the sweep to the line. Power-line noise bursts will remain stable on the display and should repeat every 8.33 ms (a 120-Hz repetition rate) or less commonly, 16.67 ms (60 Hz), if the gap is only arcing once per cycle. (This assumes the North American power-line frequency of 60 Hz.) See **Fig 27.7** for an explanation. If a noise does not exhibit either of these characteristics, it is probably

> ### Keeping an RFI Log
>
> The importance of maintaining a good and accurate RFI log cannot be overstated. Be sure to record time and weather conditions. Correlating the presence of the noise with periods of human activity and weather often provide very important clues when trying to identify power-line noise. It can also be helpful in identifying noise that is being propagated to your station via sky wave. A log showing the history of the noise can also be of great value should professional services or FCC involvement become necessary at some point.

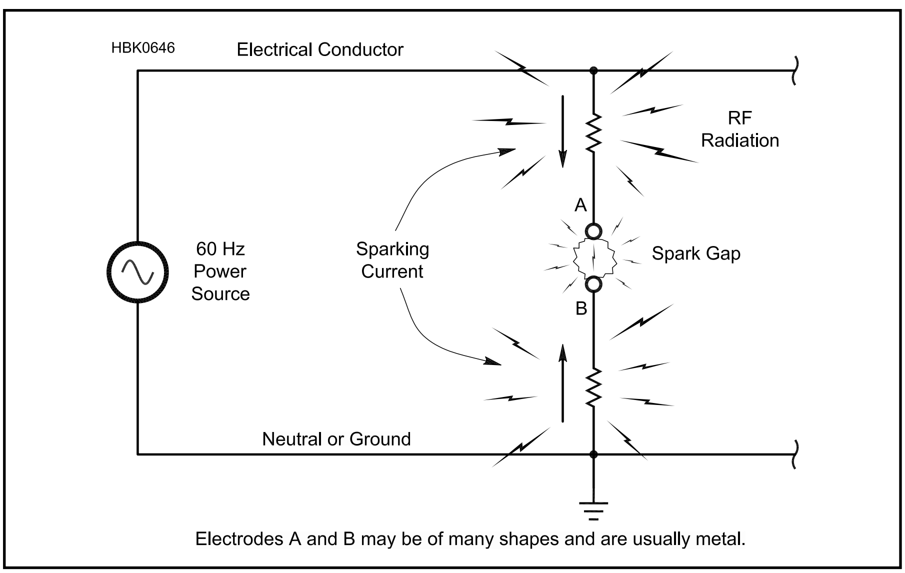


Fig 27.6 — The gap noise circuit on a power line — simplified. (From Loftness, *AC Power Interference Handbook*)

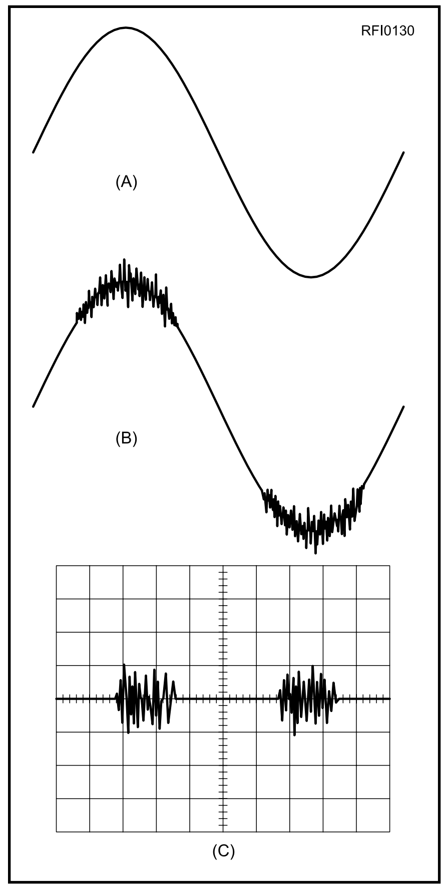


Fig 27.7 — The 60-Hz signal found on quiet power lines is almost a pure sine wave, as shown in A. If the line, or a device connected to it, is noisy, this will often add visible noise to the power-line signal, as shown in B. This noise is usually strongest at the positive and negative peaks of the sine wave where line voltage is highest. If the radiated noise is observed on an oscilloscope, the noise will be present during the peaks, as shown in C.

not power-line noise.

If a local TV station is transmitting analog TV signals on a lower VHF channel (very few remain as of mid-2010), additional clues may be obtained by viewing the noise pattern on an analog TV set using an antenna (not a cable TV connection). Power-line noise usually appears as two horizontal bars that drift slowly upward on the screen through the picture. (This is due to the difference between the NTSC signal's 59.94 Hz field rate and the 60 Hz power-line frequency.) As one bar rolls off the screen at the top of the display, a new one simultaneously forms at the bottom. In cases where the noise is occurring at 60 bursts per second, there will be only one bar on the display. In addition, the power-line noise bursts may have slightly different characteristics at the positive and negative peaks. This can cause each half of the cycle to have a slightly different pattern on the screen.

ELECTRICAL NOISE

Electrical noise sounds like power-line noise, but is generally only present in short bursts or during periods when the generating equipment or machinery is in use. Noise that varies with the time of day, such as daytime-only or weekends-only, usually indicates some electrical device or appliance being used on a regular basis and not power-line noise. Unless it is associated with climate control or HVAC system, an indoor RFI source of electrical noise less likely to be affected by weather than power-line noise.

ELECTRIC FENCES

A special type of electrical noise that is easy to identify is the "pop…pop…pop" of an electric fence. High voltage is applied to the fence about once a second by a charging unit. Arcs will occur at corroded connections in the fence, such as at a gate hook or splice. If brush or weeds touch the fence, the high-voltage will cause an arc at those points until the vegetation burns away (the arc will return when the vegetation re-grows). Each arc results in a short burst of broadband noise, received as a "tick" or "pop" in an HF receiver.

27.4.3 Identifying Intermodulation Distortion

Intermodulation distortion (IMD) often occurs within a receiver when two strong signals combine to produce intermodulation products that can interfere with a desired signal. Since the products are generated internally to the receiver, the strong signals must be filtered out or attenuated before they can enter the receiver circuits in which IMD products are generated.

Mixing of signals can also occur in any non-linear junction where the original signals are both strong enough to cause current to flow in the junction. This is a particular problem at multi-transmitter sites, such as broadcast facilities and industrial or commercial communications sites. Non-linear junctions can be formed by loose mechanical contacts in metal hardware, corroded metal junctions, and by semiconductor junctions connected to wires that act as antennas for the strong signals. Non-linear junctions also detect or demodulate RF signals to varying degrees, creating interfering audio or dc signals in some cases. IMD products generated externally cannot be filtered out at the receiver and must be eliminated where the original signals are being combined.

An intermodulation product generated externally to a receiver often appears as an intermittent transmission, similar to a spurious emission. (See the **Receivers** chapter for more information on intermodulation.) It is common for strong signals from commercial paging or dispatch transmitters sharing a common antenna installation to combine and generate short bursts of voice or data signals. AM broadcast transmissions can combine to produce AM signals with the modulation from both stations audible.

Like external intermodulation products, those generated by a receiver acting non-linearly appear as combinations of two or more strong external signals. For example, intermodulation from two SSB or FM voice signals produces somewhat distorted signals with the modulating signals of both stations. Since the two signals are not synchronized, the intermodulation products come and go unpredictably, present only when both of the external signals are present.

Intermodulation within a receiver can often be detected simply by activating the receiver's incoming signal attenuator. If attenuating the incoming signals causes the intermodulation product to by reduced in strength by a greater amount than that of the applied attenuation, intermodulation in the receiver is a strong possibility. Since receivers vary in their IMD performance, differences in the interfering signal strength between receivers is also an indication of intermodulation.

The following simple "attenuator test" can be used to identify an IMD product, even in cases where it appears similarly in multiple receivers:

- If your receiver does not have one, install a step attenuator at its RF input. If you use an attenuator internal to your receiver, it must attenuate the RF at the receiver's input.
- Tune the receiver to the suspected intermod product with the step attenuator set to 0 dB. Note the signal level.
- Add a known amount of attenuation to the signal. Typically 10 or 20 dB makes a good starting point for this test.
- If the suspect signal drops by more than the amount of added attenuation, the suspect signal is an IMD product. For example, if you add 10 dB of attenuation, and the signal drops by 30 dB, you have identified an IMD product.
- You can also compare the reduction in signal level between the suspect IMD product and a known genuine signal with and without the added attenuation. Use a known genuine signal that is about the same strength as the suspect signal with no added attenuation. If the suspect signal drops by the same as the added attenuation, it is not an IMD product.

Intermodulation distortion can be cured in a number of ways. The goal is to reduce the strength of the signals causing IMD so that the receiver circuits can process them linearly and without distortion.

If IMD is occurring in your receiver, filters that remove the strong unwanted signals causing the IMD while passing the desired signal are generally the best approach since they do not compromise receiver sensitivity. (The chapter on **Receivers** discusses how to add additional filtering to your receiver.) Turning off preamplifiers, adding or increasing the receiver's attenuation, and reducing its RF gain will reduce the signal strength in your receiver. Antenna tuners and external band-pass filters can also act as a filter to reduce IMD from out-of-band signals. Directional beams and antennas with a narrower bandwidth can also help, depending on the circumstances of your particular problem.

IMD can also be created in a broadcast FM or TV receiver or preamplifier. The solutions are the same — add suitable filters or reduce overall signal levels and gain so that the strong interfering signal can be processed linearly.

27.5 Locating Sources of RFI

Locating an offending device or noise source might sometimes seem like trying to find a needle in a haystack. With a little patience and know-how, it is often possible to find the source of a problem in relatively short order. RF detective work is often required and some cases require a little more perseverance than others. In any case, armed with some background and technique, it is often easier to find an offending source than the first-time RFI investigator might expect.

Whenever an unknown source of interference becomes an issue, begin the process of identifying the source by verifying that the problem is external to your radio. Start by removing the antenna connection. If the noise disappears, the source is external to your radio and you are ready to begin hunting for the noise source.

27.5.1 Noise Sources Inside Your Home

Professional RFI investigators and the experiences of the ARRL RFI desk confirm that most RFI sources are ultimately found to be in the complainant's home. Furthermore, locating an in-house source of RFI is so simple it that it makes sense to start an investigation by simply turning off your home's main circuit breaker while listening to the noise with a battery-powered portable radio. (Don't forget that battery-powered equipment may also be a noise source — remove the batteries from consumer devices, as well.) If the noise goes away, you know the source is in your residence. After resetting the breaker, you can further isolate the source by turning off individual breakers one at a time. Once you know the source circuit, you can then unplug devices on that circuit to find it.

CAUTION: ***Do not attempt to remove cartridge fuses or operate exposed or open-type disconnects if it is possible to make physical contact with exposed electrical circuits.***

27.5.2 Noise Sources Outside Your Home

It is often possible to locate a noise source outside your home with a minimum of equipment and effort. Because of Part 15's absolute emissions limits, most Part 15 noise sources are within a few hundred feet of the complainant's antenna. They are also often on the same power transformer secondary system as the complainant. This typically reduces the number of possible residences to relatively few. If the noise source is not compliant with Part 15 limits, it may be blocks or even thousands of feet from your station.

Electrical noise sources in a home, such as an arcing thermostat or a noisy washing machine controller, can also be tracked down in the same way as noise from consumer electronic devices. Electrical noise from an incidental emitter, such as a power line, can propagate much farther than noise from an otherwise legal unintentional emitter. Some Part 15 devices, battery chargers for electric scooters and wheelchairs, for example, are notorious for exceeding Part 15 absolute emissions limits on conducted noise.

The following procedure can be used to trace a noise source to a private home, town house, apartment, or condominium. The number of homes that could be host to a source generating noise could make searching house by house impractical. In such cases, use noise tracking techniques discussed in the following sections to narrow the search to a more reasonable area.

1) Verify that the noise is active before attempting to locate it. Don't forget this all-important first step. You cannot find the source when it's not present.

2) If possible, use a beam to record bearings to the noise before leaving your residence. Walk or drive through the neighborhood with particular emphasis in the direction of the noise, if known. Try to determine the rough geographic area over which the noise can be heard. If the geographic area over which you can hear the noise is confined to a radius of several hundred feet or less, or it diminishes quickly as you leave your neighborhood, this confirms you are most likely dealing with a Part 15 consumer device.

3) Since the noise will be strongest at an electrical device connected to the residence containing the source, you want to measure the noise at a device common to the exterior of all the potential homes. Suitable devices include electric meters, main service breakers (whether outside or in a utility room), front porch lights, electric lamp posts, outside air conditioner units, or doorbell buttons. Whatever radiator you choose, it should be accessible at each home. The device you select to test as the noise radiator will be referred to in these instructions as the "radiator." Using the same type of device as a test point at each home helps obtain consistent results.

4) You are now ready to compare the relative signal strengths at the radiator on each of the potential source residences. Use a detector suitable to receive the noise, typically a battery-powered receiver. Preferably, the receiver should have a variable RF gain control. An external step attenuator will also work if the antenna is external to the radio. If the antenna can be removed, a probe can also be made from a small piece of wire or paper clip to reduce the receiver's sensitivity. Start by holding the detector about two inches from the radiator at the residence where the noise source may be located. Turn the detector's RF gain control down to a point where you can just barely hear the noise. Alternately, increase the attenuation if using an external step attenuator. Record the RF gain or attenuator setting for each test.

5) Proceed to the next residence. Again hold the detector approximately two inches from the radiator. (The detector should be placed at the same location at each residence, as much as is practical.) Since you had previously set the detector to just barely hear the noise at the residence having the interference problem, you can move on to the next residence if you do not hear the noise. Remember, in order for your detector to hear the noise at then next house, the noise level will have to be the same or higher than the previous location. If you need to increase the detector's sensitivity to be able to hear the noise, you are moving away from the noise source.

6) When you reach the next residence, if the level is lower or not heard, you're moving further from the source. Continue your search to residences in other directions or across the street. If the level is higher, then you're headed in the right direction. Be sure to turn the gain control down to the point of just barely hearing the noise as its strength increases.

7) Continue on to the next house, repeating the previous steps as necessary. The residence with the source will be the one with the strongest noise at the radiator.

Depending on the circumstances of a particular situation, it may be possible to first isolate the power pole to which the source residence is connected. Walk or drive along the power lines in the affected area while listening to the noise with a battery-powered radio. Continue to decrease the receiver's RF gain as the noise gets louder, thus reducing the area over which you can hear it. Finally, isolate the loudest pole by reducing the RF gain to a point at which you can hear it at only one pole. Once the pole has been isolated, look to see which houses are connected to its transformer. Typically this will reduce the number of potential residences to a very small number.

CAUTION: ***Always observe good safety practices! Only qualified people familiar with the hazards of working around energized electrical equipment should inspect power-line or other energized circuitry.***

When attempting to isolate the pole, it is often best to use the highest frequency at which you can hear the noise. Noise can exhibit peaks and nulls along a power line that are a function of its wavelength. Longer wavelengths can therefore make it difficult to pinpoint a particular point along a line. Furthermore, longer wavelength signals typically propagate further along power lines. You can often reduce your search area by simply increasing the frequency at which you look for the noise.

In some cases, tuning upward in frequency can also be used to attenuate noise. This can be especially helpful in cases where your receiver does not have an RF gain control. As mentioned previously, switchmode power supplies typically generate noise that exhibits a regular and repeating pattern of peaks and nulls across the spectrum. While a typical interval might be every 50 kHz or so, the noise will often start to diminish at the highest frequencies. The peaks in some cases might drift over time, but tuning to the highest frequency at which you can hear the noise will often attenuate it enough to help locate it. If the peak drifts however, be sure to keep your receiver set on the peak as you attempt to locate the source.

Under FCC rules, the involved utility is responsible for finding and correcting harmful interference that is being generated by its own equipment. In cases where a utility customer is using an appliance or device that generates noise, the operator of the device is responsible for fixing it — even if the noise is conducted and radiated by the power company's power lines.

27.5.3 Approaching Your Neighbor

Once you identify the source residence and approach your neighbor, the importance of personal diplomacy simply cannot be overstated. The first contact regarding an RFI problem between a ham and a neighbor is often the most important; it is the start of all future relations between the parties. The way you react and behave when you first discuss the problem can set the tone for everything that follows. It is important, therefore, to use a diplomatic path from the very start. A successful outcome can depend upon it!

A self-help guide for the consumer published jointly by the ARRL and the Consumer Electronics Association (CEA) often proves helpful when discussing an interference problem with a neighbor. Entitled *What To Do if You Have an Electronic Interference Problem*, it may be printed and distributed freely. It is available on the ARRL Web site at **www.arrl.org/information-for-the-neighbors-of-hams** and also on the CD-ROM accompanying this book. Be sure to download and print a copy for your neighbor before you approach him or her.

With the noise active and with a copy of the pamphlet handy, approach your neighbor with a radio in hand, preferably an ordinary AM broadcast or short-wave receiver. Let them hear it but not so loud that it will be offensive. Tell them this is the problem you are experiencing and you believe the source may be in their home. Don't suggest what you think the cause is. If you're wrong, it often makes matters worse. Give them the pamphlet and tell them it will only take a minute to determine whether the source is in their home. Most neighbors will agree to help find the source, and if they agree to turn off circuit breakers, it can be found very quickly. Start with the main breaker to verify you have the correct residence, then the individual breakers to find the circuit. The procedure then becomes the same as described for your own residence.

27.5.4 Radio Direction Finding

Radio direction finding (RDF) can be a highly effective method to locate an RFI source although it requires more specialized equipment than other methods. Professional interference investigators almost always use radio direction finding techniques to locate power-line noise sources. See the **Antennas** chapter for more information on direction finding antennas.

A good place to start, whenever possible, is at the affected station. Use an AM receiver, preferably one with a wide IF bandwidth. An RF gain control is particularly helpful but an outboard step attenuator can be a good substitute. If there is a directional beam capable of receiving the noise, use it on highest frequency band at which the noise can be heard using the antenna. If you can hear the noise at VHF or UHF, you'll typically want to use those frequencies for RDF.

Select a frequency at which no other stations or signals are present and the antenna can discern a directional peak in the noise. Rotate the beam as required to get a bearing on the noise, keeping the RF gain at a minimum. Repeat with a complete 360° sweep using the minimum RF gain possible to hear the noise in its loudest direction. Try to decrease the RF gain to a point at which the noise clearly comes from one and only one direction. You can simultaneously increase the AF gain as desired to hear the noise.

Distant sources, including power-line noise, are generally easier to RDF at HF than nearby sources. Whenever possible, it's almost always better to use VHF or UHF when in close proximity to a source. Tracking a source to a specific residence by RDF at HF is sometimes possible. Such factors as balance and geometry of a home's internal wiring, open switch circuits and distance, may cause the residence to appear somewhat as a point source.

If the search is being conducted while mobile or portable, VHF and UHF are t ypically the easiest and most practical antennas. Small handheld Yagi antennas for 2 meters and 440 MHz are readily available and can serve double duty when operating portable. Many handheld receivers can be configured to receive AM on the VHF bands. Be sure to check your manual for this feature. VHF Aircraft band or "Air band" receivers are also a popular choice since they receive AM signals.

Using RDF to locate an HF noise source while in motion presents significant challenges. Conducted emissions are typical from a consumer device or appliance. In this case, the emissions can be conducted outside the residence and on to the power line. The noise can then propagate along neighborhood distribution lines, which in turn acts as an antenna. The noise can often exhibit confusing peaks and nulls along the line, and if in the vicinity of a power line radiating it, RDF can be extremely difficult, if not impossible. Depending on the circumstances, you could literally be surrounded by the near field of an antenna! You would generally want to stay away from power lines and other potential radiators when searching at HF.

Antennas for HF RDF while walking typically include small loops and ferrite rod antennas. In some cases, a portable AM broadcast radio with a ferrite rod antenna can be used for direction finding. An HF dipole made from a pair of whip antennas may be able to be used to get an approximate bearing toward the noise. Mount the dipole about 12 feet above ground (remembering to watch out for overhead conductors!) and rotate to null out the noise. For all three types of antenna, there will be two nulls in opposite directions. Note the direction of the null. Repeat this procedure from another location then triangulate to determine the bearing to the noise.

27.6 Power-line Noise

This chapter's section "Identifying RFI Source Types" describes power-line noise, its causes, and methods to identify it. Power-line noise is a unique problem in several respects. First and foremost, the offending source is never under your direct control. You can't just simply "turn it off" or unplug the offending device. Nor will the source be under the direct control of a neighbor or someone you are likely to know. In the case of power-line noise, the source is usually operated by a company, municipality, or in some cases, a cooperative. Furthermore, shutting down a power line is obviously not a practical option.

Another unique aspect of power-line noise is that it almost always involves a defect of some sort. The cure for power-line noise is to fix the defect. This is almost always a utility implemented repair and one over which you do not have any direct control.

FCC rules specify that that the operator of a device causing interference is responsible for fixing it. Whenever encountering a power-line noise problem, you will be dealing with a utility and won't have the option of applying a relatively simple technical solution to facilitate a cure, as you would if the device were located in your home. Utilities have a mixed record when it comes to dealing with power-line noise complaints. In some cases, a utility will have a budget, well-trained personnel, and equipment to quickly locate and address the problem. In other cases, however, the utility is simply unable to effectively deal with power-line noise complaints or even denies their equipment can cause RFI.

What does this mean for an amateur with a power-line noise complaint? Utilities can be of any size from large corporations to local cooperatives or city-owned systems. Regardless of the category in which your utility may fall, it must follow Part 15 of the FCC rules. Dealing with a company, coop or municipality, however, as opposed to a device in your home, or a nearby neighbor that you know personally, can present its own set of unique challenges. Multiple parties and individuals are often involved, including an RFI investigator, a line crew and associated management. In some cases, the utility may never have received an RFI complaint before yours.

27.6.1 Before Filing a Complaint

Obviously, before filing a complaint with your local utility, it is important to verify the problem as power-line noise as best as possible and verify that it is not caused by a problem with electrical equipment in your home. Other sources, such as lighting devices and motors, can mimic power-line noise, especially to an untrained ear. Don't overlook these important steps. Attempting to engage your utility in the resolution of an RFI problem can not only waste time but can be embarrassing if the source is right in your own home!

Utilities are not responsible for noise generated by customer-operated devices — *even if the noise is being radiated by the power lines.* They are responsible for fixing only that noise which is being generated by their equipment.

27.6.2 Filing a Complaint

Once you have verified the problem to be power-line noise (see this chapter's section on Identifying Power-line and Electrical Noise) and that it is not coming from a source in your home or a nearby residence, contact your utility's customer service department. In addition to your local phone book, customer service phone numbers are included on most power company Web sites.

It is important to maintain a log during this part of the process. Be sure to record any "help ticket" numbers that may be assigned to your complaint as well as names, dates and a brief description of each conversation you have with electric company personnel. If you identify specific equipment or power poles as a possible noise source, record the address and any identifying numbers on it.

Hopefully, your complaint will be addressed in a timely and professional manner. Once a noise source has been identified, it is up to the utility to repair it within a reasonable period. You and the utility may not agree on what constitutes a reasonable period, but attempt to be patient. If no action is taken after repeated requests, reporting the complaint to the ARRL and requesting assistance may be in order. (Before contacting the ARRL review The Cooperative Agreement, a section of this chapter.)

It is also important to cooperate with utility personnel and treat them with respect. Hostile and inappropriate behavior is almost always counter-productive in these situations. Remember, you want utility and other related personnel to help you — not avoid you. Even if the utility personnel working on your case seem unqualified, hostile behavior has historically never been a particularly good motivator in these situations. In fact, most protracted power-line noise cases reported to the ARRL began with an altercation in the early stages of the resolution process. In no case did it help or expedite correction of the problem.

27.6.3 Techniques for Locating Power-line Noise Sources

Radio direction finding (RDF) techniques typically offer the best and most efficient approach to locating most power-line noise sources. It is the primary method of choice used by professionals. While RDF is usually the most effective method, it also requires some specialized equipment, such as a handheld beam antenna. Although specialized professional equipment is available for RDF, hams can also use readily available amateur and homebrew equipment successfully. The CD-ROM accompanying this *Handbook* includes some power-line noise locating equipment projects you can build.

Although it is the utility's responsibility to locate a source of noise emanating from its equipment, many companies simply do not possess the necessary expertise or equipment to do so. As a practical matter, many hams have assisted their utility in locating noise sources. In some cases, this can help expedite a speedy resolution.

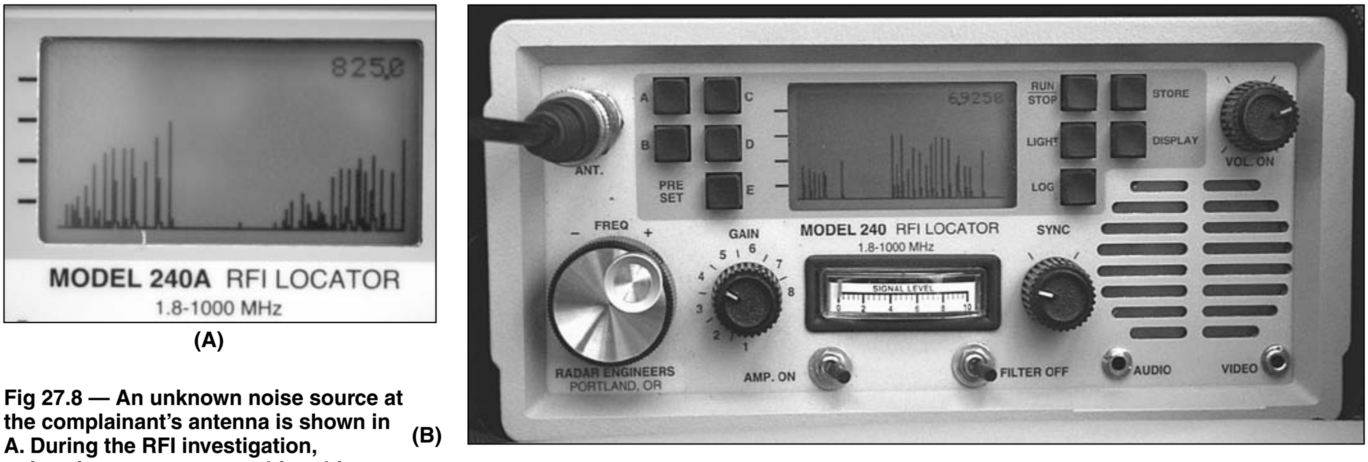
There is a significant caveat to this approach however. Should you mislead the power company into making unnecessary repairs, they will become frustrated. This expense and time will be added to their repair list. Do not make a guess or suggestions if you don't know what is causing the noise. While some power companies might know less about the locating process than the affected ham, indiscriminate replacement of hardware almost always makes the problem worse. Nonetheless, depending on your level of expertise and the specifics of your situation, you may be able to facilitate a speedy resolution by locating the RFI source for the utility.

27.6.4 Amateur Power-line Noise Locating Equipment

Much of the equipment that an amateur would use to locate power-line noise has previously been described in the "Radio Direction Finding" section. Before discussing how to locate power-line noise sources, here are a few additional equipment guidelines:

Receiver — You'll need a battery-operated portable radio capable of receiving VHF or UHF in the AM mode. Ideally, it should also be capable of receiving HF frequencies, especially if the interference is a problem at HF and not VHF. Some amateurs also use the aircraft band from 108 to 137 MHz. The lower frequencies of this band can sometimes enable an RFI investigator to hear the noise at greater distances than on 2 meters or 70 cm. An RF gain control is essential but an outboard step attenuator can be used as a substitute. A good S-meter is also required.

Attenuator — Even if your receiver has an RF gain control, an additional outboard step attenuator can often be helpful. It can not only minimize the area of a noise search



(A)

(B)

Fig 27.8 — An unknown noise source at the complainant's antenna is shown in A. During the RFI investigation, noise signatures not matching this pattern can be ignored, such as shown in B. Once the matching signature originally shown in A is found, the offending noise source has been located.

but also provide added range for the RF gain control. As with other RFI sources — you'll need to add more and more attenuation as you approach the source.

VHF/UHF Antennas — You'll need a hand-held directional beam antenna. A popular professional noise-locating antenna is an eight-element Yagi tuned for 400 MHz. Since power-line noise is a broadband phenomenon, the exact frequency is not important. Either a 2 meter or 70 cm Yagi are capable of locating a power-line noise source on a specific power pole.

Although professional grade antennas can cost several hundred dollars, some hams can build their own for a lot less. See the CD-ROM accompanying this book for the article, "Adapting a Three-Element Tape Measure Beam for Power-line Noise Hunting," by Jim Hanson, W1TRC. This low cost and easy to build antenna for locating power-line noise can be adapted for a variety of frequencies and receivers. Commercial 2 meter and 70 cm antennas for portable use are also suitable if a handle is added, such as a short length of PVC pipe.

Before using an antenna for power-line noise locating, determine its peak response frequency. Start by aiming the antenna at a known power-line noise source. Tune across its range and just beyond. Using minimum RF gain control, find its peak response. Label the antenna with this frequency using a piece of tape or marking pen. When using this antenna for noise locating, tune the receiver to this peak response frequency.

If you don't have a VHF or UHF receiver that can receive AM signals, see the CD-ROM accompanying this book for the article, "A Simple TRF Receiver for Tracking RFI," by Rick Littlefield, K1BQT. It describes the combination of a simple 136 MHz beam and receiver for portable RFI tracking.

HF Antennas — Depending on the circumstances of a particular case, a mobile HF whip such as a 7 or 14 MHz model can be helpful. Magnet-mount models are acceptable for temporary use. An RFI investigator can typically get within VHF range by observing the relative strength of the noise from different locations. Driving in a circle centered on the affected station will typically indicate the general direction in which the noise is strongest. As with beam antennas, determine the peak response frequency for best results.

Ultrasonic Pinpointer — Although an ultrasonic pinpointer is not necessary to locate the pole or structure containing the source, some hams prefer to go one more step by finding the offending noise source on that structure. Guidelines for the use of an ultrasonic device are described later in this section.

Professional-grade ultrasonic locators are often beyond the budget of the average ham. Home brewing options however, can make a practical ultrasonic locator affordable in most situations — and make a great weekend project too. See the CD-ROM accompanying this book for "A Home-made Ultrasonic Power Line Arc Detector" by Jim Hanson, W1TRC.

Oscilloscope — A battery-powered portable oscilloscope is only required for signature analysis. See the next section, Signature or Fingerprint Method, for details.

Thermal/Infrared Detectors and Corona Cameras — This equipment is not recommended for the sole purpose of locating power-line noise sources. It is rare that an RFI source is even detectable using infrared techniques. Although these are not useful tools for locating noise sources, many utilities still use them for such purposes with minimal or no results. Not surprisingly, ARRL experience has shown that these utilities are typically unable to resolve interference complaints in a timely fashion.

27.6.5 Signature or Fingerprint Method

Each sparking interference source exhibits a unique pattern. By comparing the characteristics between the patterns taken at the affected station with those observed in the field, it becomes possible to conclusively identify the offending source or sources from the many that one might encounter. It therefore isn't surprising that a pattern's unique characteristic is often called its "fingerprint" or "signature." See **Fig 27.8** for an example.

This is a very powerful technique and a real money saver for the utility. Even though there may be several different noise sources in the field, this method helps identify only those sources that are actually causing the interference problem. The utility need only correct the problem(s) matching the pattern of noise affecting your equipment.

You as a ham can use the signature method by observing the noise from your radio's audio output with an oscilloscope. Record the pattern by drawing it on a notepad or taking a photograph of the screen. Take the sketch or photograph with you as you hunt for the source and compare it to signatures you might observe in the field.

Professional interference-locating receivers, such as the Radar Engineers Model 240A shown in Fig 27.8B, have a built in oscilloscope display and waveform memory. This is the preferred method used by professional interference investigators. These receivers provide the ability to switch between the patterns saved at the affected station and those from sources located in the field.

Once armed with the noise fingerprint taken at the affected station, you are ready to begin the hunt. If you have a directional beam, use it to obtain a bearing to the noise. If multiple sources are involved, you'll need to record the bearings to each one. Knowing how high in frequency a particular noise can be heard also provides a clue to its proximity. If the noise can be heard at 440 MHz, for example, the source will typically be within walking distance. If it diminishes beginning 75 or 40 meters, it can be up to several miles away.

Since each noise source will exhibit unique characteristics, you can now match this noise "signature" with one from the many sources you may encounter in the investigation. Compare such characteristics as the duration of each noise burst, pulse shape, and number of pulses.

If you have a non-portable oscilloscope, you may still be able to perform signature matching by using an audio recorder. Make a high quality recording of the noise source at your station and at each suspected noise source in the field, using the same receiver if possible. Replay the sounds for signature analysis.

27.6.6 Locating the Source's Power Pole or Structure

Start your search in front of the affected station. If you can hear the noise at VHF or UHF, begin with a handheld beam suitable for these frequencies. As discussed previously, the longer wavelengths associated with the AM broadcast band and even HF, can create misleading "hotspots" along a line when searching for a noise source as shown in **Fig 27.9**.

As a general rule, only use lower frequencies when you are too far away from the source to hear it at VHF or UHF. Generally work with the highest frequency at which the noise can be heard. As you approach the source, keep increasing the frequency to VHF or UHF, depending on your available antennas. Typically, 2 meters and 70 cm are both suitable for isolating a source down to the pole level.

If you do not have an initial bearing to the noise and are unable to hear it with your portable or mobile equipment, start traveling in a circular pattern around the affected station, block-by-block, street-by-street, until you find the noise pattern matching the one recorded at the affected station.

Once in range of the noise at VHF or UHF, start using a handheld beam. You're well on your way to locating the structure containing the source. In many cases, you can now continue your search on foot. *Again, maintain minimum RF gain to just barely hear the noise over a minimum area.* This is important step is crucial for success. If the RF gain is too high, it will be difficult to obtain accurate bearings with the beam.

Power-line noise will often be neither vertically nor horizontally polarized but somewhere in between. Be sure to rotate the beam's polarization for maximum noise response. Maintain this same polarization when comparing poles and other hardware.

27.6.7 Pinpointing the Source on a Pole or Structure

Once the source pole has been identified, the next step becomes pinpointing the offending hardware on that pole. A pair of binoculars on a dark night may reveal visible signs of arcing and in some cases you may be able to see other evidence of the problem from the ground. These cases are rare. More than likely, a better approach will be required. Professional and utility interference investigators typically have two types of specialized equipment for this purpose:

• An ultrasonic dish or pinpointer. The RFI investigator, even if not a lineman, can pinpoint sources on the structure down to a component level from the ground using this instrument. See **Fig 27.10**.

• An investigator can instruct the lineman on the use of a hot stick-mounted device used to find the source. This method is restricted to only qualified utility personnel, typically from a bucket truck. See **Fig 27.11**.

Both methods are similar but hams only have one option — the ultrasonic pinpointer.

Caution — Hot sticks and hot stick mounted devices are not for hams! Do not use them. Proper and safe use of a hot stick requires specialized training. In most localities, it is generally unlawful for anyone unqualified by a utility to come within 10 feet of an energized line or hardware. This includes hot sticks.

ULTRASONIC PINPOINTER TIPS

An ultrasonic dish is the tool of choice for pinpointing the source of an arc from the ground. While no hot stick is required, an unobstructed direct line-of-sight path is re-

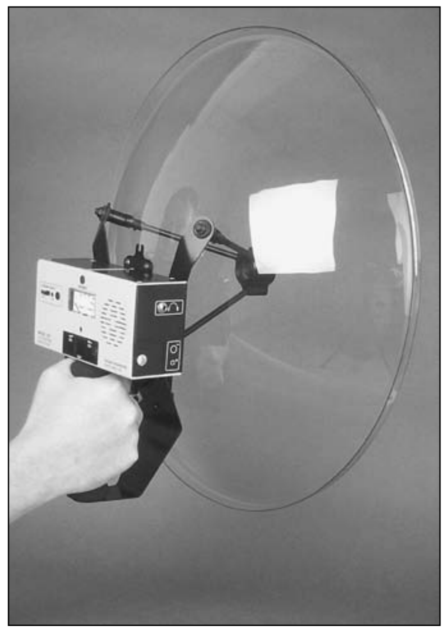


Fig 27.10 — The clear plastic parabolic dish is an "ear" connected to an ultrasonic detector that lets utility personnel listen for the sound of arcs.

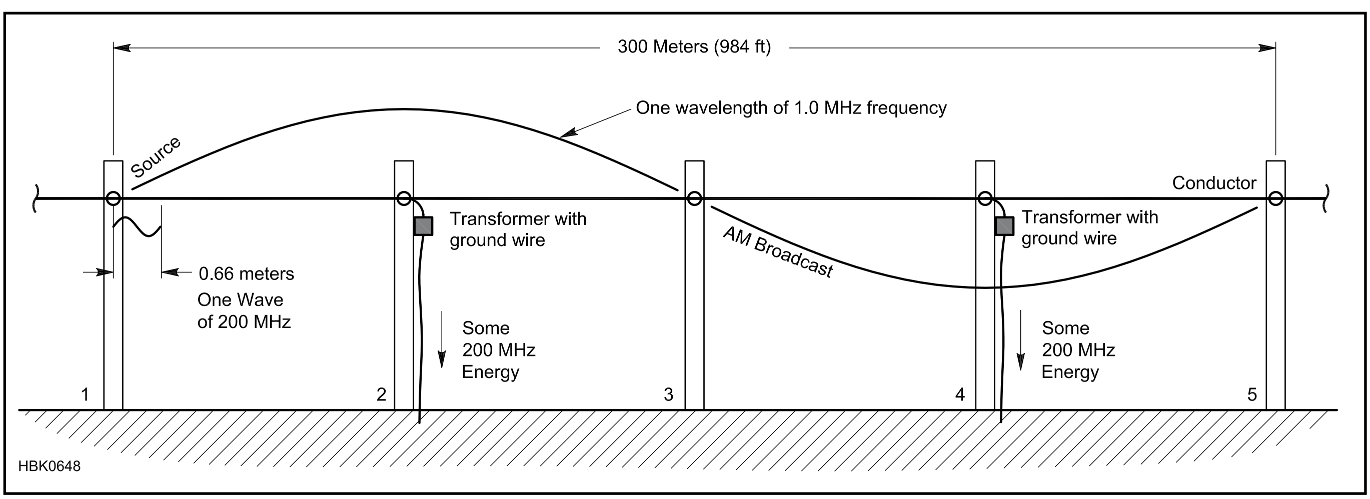


Fig 27.9 — Listening for noise signals on a power distribution line at 1 MHz vs 200 MHz can result in identification of the wrong power pole as the noise source. (From Loftness, *AC Power Interference Handbook*)

Fig 27.11 — The Radar Engineers Model 247 Hotstick Line Sniffer is an RF and ultrasonic locator. It is used by utility workers to pinpoint the exact piece of hardware causing a noise problem. Mounted on a hotstick, the sniffer is used from the pole or from a bucket.

quired between the arc and the dish. This is not a suitable tool for locating the structure containing the source. It is only useful for pinpointing a source once its pole or structure has been determined.

Caveat: Corona discharge, while typically not a source of RF power-line noise, can and often is a significant source of ultrasonic sound. It can often be difficult to distinguish between the sound created by an arc and corona discharge. This can lead to mistakes when trying to pinpoint the source of an RFI problem with an ultrasonic device.

The key to success, just as with locating the structure, is using gain control effectively. Use minimum gain after initially detecting the noise. If the source appears to be at more than one location on the structure, reduce the gain. In part, this will eliminate any weaker noise signals from hardware not causing the problem.

27.6.8 Common Causes of Power-line Noise

The following are some of the more common power-line noise sources. They're listed in order from most common to least common. Note that some of the most common sources are not connected to a primary conductor. This in part is due to the care most utilities take to ensure sufficient primary conductor clearance from surrounding hardware. Note, too, that power transformers do not appear on this list:

- Loose staples on ground conductor
- Loose pole-top pin
- Ground conductor touching nearby hardware
- Corroded slack span insulators
- Guy wire touching neutral
- Loose hardware
- Bare tie wire used with insulated conductor
- Insulated tie wire on bare conductor
- Loose cross-arm braces
- Lightning arrestors

27.6.9 The Cooperative Agreement

While some cases of power-line noise are resolved in a timely fashion, the reality is that many cases can linger for an extended period of time. Many utilities simply do not have the expertise, equipment or motivation to properly address a power-line noise complaint. There are often no quick solutions. Patience can often be at a premium in these situations. Fortunately, the ARRL has a Cooperative Agreement with the FCC that can help. While the program is not a quick or easy solution, it does offer an opportunity and step-by-step course of action for relief. It emphasizes and provides for voluntary cooperation without FCC intervention.

Under the terms of the Cooperative Agreement, the ARRL provides technical help and information to utilities in order to help them resolve power-line noise complaints. It must be emphasized that the ARRL's role in this process is strictly a technical one — it is not in the enforcement business. In order to participate, complainants are required to treat utility personnel with respect, refrain from hostile behavior, and reasonably cooperate with any reasonable utility request. This includes making his or her station available for purposes of observing and recording noise signatures. The intent of the Cooperative Agreement is to solve as many cases as possible before they go to the FCC. In this way, the FCC's limited resources can be allocated where they are needed the most — enforcement.

As the first step in the process, the ARRL sends the utility a letter advising of pertinent Part 15 rules and offering assistance. The FCC then requires a 60-day waiting period before the next step. If by the end of 60 days the utility has failed to demonstrate a good faith effort to correct the problem, the FCC then issues an advisory letter. This letter allows the utility another 60-day window to correct the problem.

A second FCC advisory letter, if necessary, is the next step. Typically, this letter provides another 20- or 30-day window for the utility to respond. If the problem still persists, a field investigation would follow. At the discretion of the Field Investigator, he or she may issue an FCC Citation or Notice of Apparent Liability (NAL). In the case of an NAL, a forfeiture or fine can result.

It is important to emphasize that the ARRL Cooperative Agreement Program does not offer a quick fix. There are several built-in waiting periods and a number of requirements that a ham must follow precisely. It does however provide a step-by-step and systematic course of action under the auspices of the FCC in cases where a utility does not comply with Part 15. Look for complete details, including how to file a complaint, in the ARRL's Power-line Noise FAQ Web page at **www.arrl.org/power-line-noise-faq-page**.

27.7 Elements of RFI Control

27.7.1 Differential- and Common-Mode Signal Control

The path from source to victim almost always includes some conducting portion, such as wires or cables. RF energy can be conducted directly from source to victim, be conducted onto a wire or cable that acts as an antenna where it is radiated, or be picked up by a conductor connected to the victim that acts like an antenna. When the energy is traveling along the conducting portion of its path, it is important to understand whether it is as a differential- or common-mode signal.

Removing unwanted signals that cause RFI is different for each of these conduction modes. Differential-mode cures (a high-pass filter, low-pass filter, or a capacitor across the ac power line, for example) do not attenuate common-mode signals. Similarly, a common-mode choke will not affect interference resulting from a differential-mode signal.

It's relatively simple to build a differential-mode filter that passes desired signals and blocks unwanted signals with a high series impedance or presents a low-impedance to a signal return line or path. The return path for common-mode signals often involves Earth ground, or even the chassis of equipment if it is large enough to form part of an antenna at the frequency of the RFI. A differential-mode filter is not part of this current path, so it can have no effect on common-mode RFI.

In either case, an exposed shield surface is a potential antenna for RFI, either radiating or receiving unwanted energy, regardless of the shield's quality. In this way, a coaxial cable can act as an antenna for RFI if the victim device is unable to reject common-mode signals on the cable's shield. This is why it is important to connect cable shields in such a way that common-mode currents flowing on the shields are not allowed to enter the victim device.

27.7.2 Shields and Filters

Breaking the path between source and victim is often an attractive option, especially if either is a consumer electronics device. Remember, the path will involve one or more of three possibilities — radiation, conduction, and inductive or capacitive coupling. Breaking the path of an RFI problem can require analysis and experimentation in some cases. Obviously you must know what the path is before you can break it. While the path may be readily apparent in some cases, more complex situations may not be so clear. Multiple attempts at finding a solution may be required.

SHIELDS

Shielding can be used to control radiated emissions — that is, signals radiated by wiring inside the device — or to prevent radiated signals from being picked up by signal leads in cables or inside a piece of equipment. Shielding can also be used to reduce inductive or capacitive coupling, usually by acting as an intervening conductor between the source and victim.

Shields are used to set boundaries for radiated energy and to contain electric and magnetic fields. Thin conductive films, copper braid and sheet metal are the most common shield materials for the electric field (capacitive coupling), and for electromagnetic fields (radio waves). At RF, the small skin depth allows thin shields to be effective at these frequencies. Thicker shielding material is needed for magnetic field (inductive coupling) to minimize the voltage caused by induced current. At audio frequencies and below, the higher skin depth of common shield materials is large enough (at 60 Hz, the skin depth for aluminum is 0.43 inches) that high-permeability materials such as steel or mumetal are required.

Maximum shield effectiveness usually requires solid sheet metal that completely encloses the source or susceptible circuitry or equipment. Small discontinuities, such as holes or seams, decrease shield effectiveness. In addition, mating surfaces between different parts of a shield must be conductive. To ensure conductivity, file or sand off paint or other nonconductive coatings on mating surfaces.

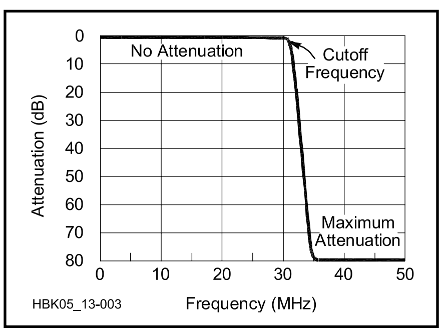


Fig 27.12 — An example of a low-pass filter's response curve.

The effectiveness of a shield is determined by its ability to reflect or absorb the undesired energy. Reflection occurs at a shield's surface. In this case, the shield's effectiveness is independent of its thickness. Reflection is typically the dominant means of shielding for radio waves and capacitive coupling, but is ineffective against magnetic coupling. Most RFI shielding works, therefore, by reflection. Any good conductor will serve in this case, even thin plating.

Magnetic material is required when attempting to break a low-frequency inductive coupling path by shielding. A thick layer of high permeability material is ideal in this case. Low frequency magnetic fields are typically a very short range phenomenon. Simply increasing the distance between the source and victim may help avoid the expense and difficulty of implementing a shield.

Adding shielding may not be practical in many situations, especially with many consumer products, such as a television. Adding a shield to a cable can minimize capacitive coupling and RF pickup, but it has no effect on magnetic coupling. Replacing parallel-conductor cables (such as zip cord) with twisted-pair is quite effective against magnetic coupling and also reduces electromagnetic coupling.

Additional material on shielding may be found in Chapter 2 of Ott.

FILTERS

Filters and chokes can be very effective in dealing with a conducted emissions problem. Fortunately, filters and chokes are simple, economical and easy to try. As we'll see, use of common-mode chokes alone can often solve many RFI problems, especially at HF when common-mode current is more likely to be the culprit.

A primary means of separating signals

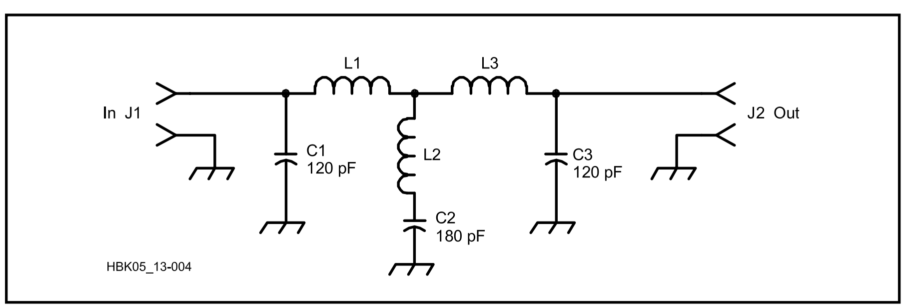


Fig 27.13 — A low-pass filter for amateur transmitting use. Complete construction information appears in the Transmitters chapter of *The ARRL RFI Book*. A high-performance 1.8-54 MHz filter project can be found in the RF and AF Filters chapter of this *Handbook*.

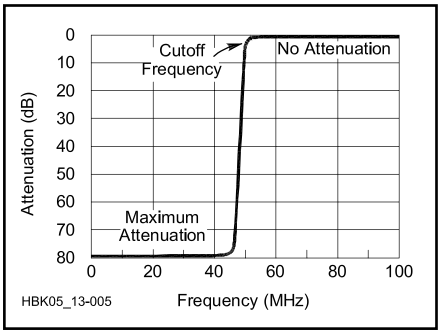


Fig 27.14 — An example of a high-pass filter's response curve.

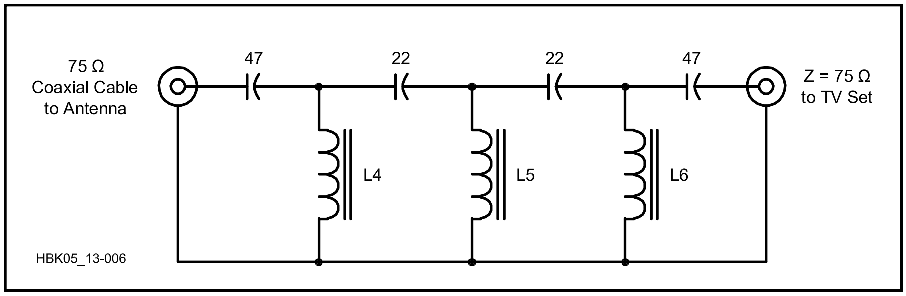


Fig 27.15 — A differential-mode high-pass filter for 75-Ω coaxial cable. It rejects HF signals picked up by a TV antenna or that leak into a cable-TV system. All capacitors are high-stability, low-loss, NP0 ceramic disc components. Values are in pF. The inductors are all #24 AWG enameled wire on T-44-0 toroid cores. L4 and L6 are each 12 turns (0.157 µH) and L5 is 11 turns (0.135 µH).

relies on their frequency difference. Filters offer little opposition to signals with certain frequencies while blocking or shunting others. Filters vary in attenuation characteristics, frequency characteristics and power-handling capabilities. The names given to various filters are based on their uses. (More information on filters may be found in the **RF and AF Filters** chapter.)

Low-pass filters pass frequencies below some cutoff frequency, while attenuating frequencies above that cutoff frequency. A typical low-pass filter curve is shown in **Fig 27.12**. A schematic is shown in **Fig 27.13**. These filters are difficult to construct properly so you should buy one. Many retail Amateur Radio stores that advertise in *QST* stock low-pass filters.

High-pass filters pass frequencies above some cutoff frequency while attenuating frequencies below that cutoff frequency. A typical high-pass filter curve is shown in **Fig 27.14**. **Fig 27.15** shows a schematic of a typical high-pass filter. Again, it is best to buy one of the commercially available filters.

Bypass capacitors can be used to cure differential-mode RFI problems by providing a low-impedance path for RF signals away from the affected lead or cable. A bypass capacitor is usually placed between a signal or power lead and the equipment chassis. If the bypass capacitor is attached to a shielded cable, the shield should also be connected to the chassis. Bypass capacitors for HF signals are usually 0.01 µF, while VHF bypass capacitors are usually 0.001 µF. Leads of bypass capacitors should be kept short, particularly when dealing with VHF or UHF signals.

AC-line filters, sometimes called "brute-force" filters, are used to remove RF energy from ac power lines. Both common-mode and differential-mode noise can be attenuated by a commercially built line filter. A typical schematic is shown in **Fig 27.16**. Products from Corcom, (**www.corcom.com**) and Delta Electronics, (**www.delta.com.tw**) are widely available and well documented on their Web sites. Industrial Communications Engineers (**www.iceradioproducts.com**) sells stand-alone AC-line filters with ac plugs and sockets.

AC-line filters come in a wide variety of sizes, current ratings, and attenuation. In general, a filter must be physically larger to handle higher currents at lower frequencies. The Corcom 1VB1, a compact filter small enough to fit in the junction box for many low voltage lighting fixtures, provides good common mode attenuation at MF and HF and its 1 A at 250 V ac rating is sufficient for many LV lighting fixtures. In general, you will get more performance from a filter that is physically small if you choose the filter with the lowest current rating sufficient for your application. (Section 13.3 of Ott covers ac-line filters.)

Any wiring between a filter and the equipment being filtered acts as an antenna and forms an inductive loop that degrades the performance of the filter. All such wiring should be as short as possible, and should be twisted. Always bond the enclosure of the filter to the enclosure of the equipment by the shortest possible path. Some commercial filters are built with an integral IEC power socket, and can replace a standard IEC connector if there is sufficient space behind the panel. (IEC is the International Electrotechnical Commission, an international standards organization that has created specifications for power plugs and sockets.) Such a filter is bonded to the chassis and interconnecting leads are shielded by the chassis, optimizing its performance.

A capacitor between line and neutral or between line and ground at the noise source or at victim equipment can solve some RFI problems. ("Chassis ground" in this sense is not "Earth," it is the power system equipment ground — the green wire — at the equipment.) Power lines, cords, and cables are often subjected to short-duration spikes of very high voltage (4 kV). Ordinary capacitors are likely to fail when subjected to these voltages, and the failure could cause a fire. Only Type X1, X2, Y1 and Y2 capacitors should be used on power wiring. AC-rated capacitors can safely handle the current that flows through them when they are placed across an ac line along with the typical voltage surges that occur from time to time. Type X1 and X2 capacitors are rated for use between line and neutral, and are available in values between 0.1 µF and 1 µF. Type X2 capacitors are tested to withstand 2.5 kV, type X1 capacitors are tested to 4 kV. Type Y1 and Y2 capacitors are rated for use between line and ground; Y1 capacitors are impulse tested to 8 kV; Type Y2 to 5 kV. Note that 4700 pF is the largest value permitted to be used between line and ground — larger values can result in excessive leakage currents.

Warning: Bypassing Speaker Leads

Older amateur literature might suggest connecting a 0.01-µ*F capacitor across an amplifier's speaker output terminals to cure RFI from common-mode signals on speaker cables. Don't do this!* Doing so can cause some modern solid-state amplifiers to break into a destructive, full-power, sometimes ultrasonic oscillation if they are connected to a highly capacitive load. Use common-mode chokes and twisted-pair speaker cables instead.

27.7.3 Common-Mode Chokes

Common-mode chokes on ferrite cores are the most effective answer to RFI from

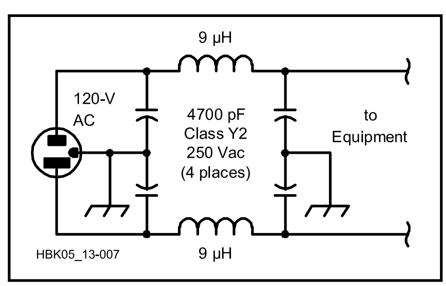


Fig 27.16 — A "brute-force" ac-line filter.

Fig 27.17 — A common-mode RF choke wound on a toroid core is shown at top left. Several styles of ferrite cores for common-mode chokes are also shown.

a common-mode signal. Differential-mode filters are *not* effective against common-mode signals. (AC-line filters often perform both common- and differential-mode filtering.) Common-mode chokes work differently, but equally well, with coaxial cable and paired conductors. (Additional material on common-mode chokes is found in sections 3.5 and 3.6 of Ott.)

The most common form of common-mode choke is multiple turns of cable wound on a magnetic toroid core, usually ferrite, as shown in **Fig 27.17**. The following explanation applies to chokes wound on rods as well as toroids, but avoid rod cores since they may couple to nearby circuits at HF.

Most of the time, a common-mode signal on a coaxial cable or a shielded, multi-wire cable is a current flowing on the outside of the cable's shield. By wrapping the cable around a magnetic core the current creates a flux in the core, creating a high impedance in series with the outside of the shield. (An impedance of a few hundred to several thousand ohms are required for an effective choke.) The impedance then blocks or reduces the common-mode current. Because equal-and-opposite fields are coupled to the core from each of the differential-mode currents, the common-mode choke has no effect on differential-mode signals inside the cable.

When the cable consists of two-wire, unshielded conductors such as zip cord or twisted-pair, the equal-and-opposite differential currents each create a magnetic flux in the core. The equal-and-opposite fluxes cancel each other and the differential-mode signal experiences zero net effect. To common-mode signals, however, the choke appears as a high impedance in series with the signal: the higher the impedance, the lower the common-mode current.

It is important to note that common-mode currents on a transmission line will result in radiation of a signal from the feed line. (See the sidebar for an explanation of balanced vs unbalanced transmission lines.) The radiated

Feed Line Radiation from Balanced vs Unbalanced Transmission Lines

Q. What is meant by the terms "balanced" and "unbalanced" when referring to transmission lines?

A. The physical differences between balanced and unbalanced feed lines are obvious. Balanced lines are parallel-type transmission lines, such as ladder line or twin lead. The two conductors that make up a balanced line run side-by-side, separated by an insulating material (plastic, air, whatever). Unbalanced lines, on the other hand, are coaxial-type feed lines. One of the conductors (the shield) completely surrounds the other (the center).

In an ideal world, both types of transmission lines would deliver RF power to the load (typically your antenna) without radiating any energy along the way. It is important to understand, however, that both types of transmission lines require a balanced condition in order to accomplish this feat. That is, the currents in each conductor must be equal in magnitude, but opposite in polarity.

The classic definition of a balanced transmission line tells us that both conductors must be symmetrical (same length and separation distance) relative to a common reference point, usually ground. It's fairly easy to imagine the equal and opposite currents flowing through this type of feeder. When such a condition occurs, the fields generated by the currents cancel each other-hence, no radiation. An imbalance occurs when one of the conductors carries more current than the other. This additional "imbalance current" causes the feed line to radiate.

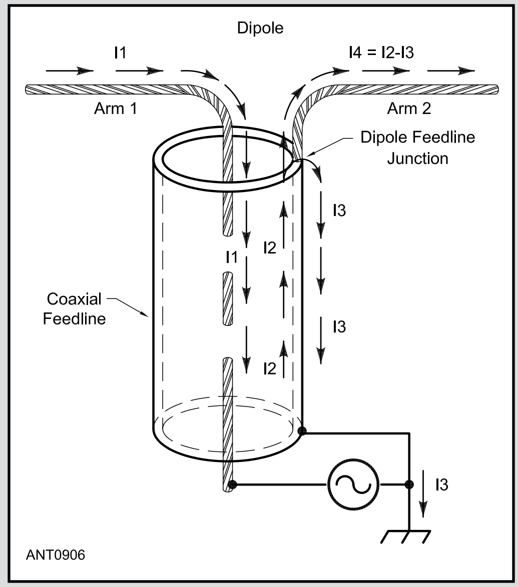


Fig 27.A — Various current paths are present at the feed point of a balanced dipole fed with unbalanced coaxial cable. The diameter of the coax is exaggerated to show the currents clearly.

Things are a bit different when we consider a coaxial cable. Instead of its being a symmetrical line, one of its conductors (usually the shield), is grounded. In addition, the currents flowing in the coax are confined to the outside portion of the center conductor and the inside portion of the shield.

When a balanced load, such as a resonant dipole antenna, is connected to unbalanced coax, the outside of the shield can act as an electrical third conductor (see **Fig 27.A**). This phantom third conductor can provide an alternate path for the imbalance current to flow. Whether the small amount of stray radiation that occurs is important or not is subject to debate. In fact, one of the purposes of a balun (a contraction of balanced to unbalanced) is to reduce or eliminate imbalance current flowing on the outside of the shield.

Warning: Surplus Ferrite Cores

Don't use a core to make a common-mode choke if you don't know what type of material it is made of. Such cores may not be effective in the frequency range you are working with. This may lead to the erroneous conclusion that a common-mode choke doesn't work when a core with the correct material would have done the job.

signal can then cause RFI in nearby circuits. This is most common when using coaxial cable as a feed line to a balanced load, such as the dipole in the sidebar. Using a common-mode choke to reduce common-mode feed line currents can reduce RFI caused by signals radiated from the feed line's shield.

The optimum core size and ferrite material is determined by the application and frequency. For example, an ac cord with a plug attached cannot be easily wrapped on a small ferrite core. The characteristics of ferrite materials vary with frequency, as shown by the graph in **Fig 27.18**. Type 31 material is a good all-purpose material for HF and low-VHF applications, especially at low HF frequencies. Type 43 is widely used for HF through VHF and UHF. (See the **Component Data and References** chapter for a table of ferrite materials and characteristics.)

Ferrite beads and clamp-on split cores are also used for EMI control at VHF and UHF, both as common-mode chokes and low-pass filters. (These are essentially single-turn chokes as the cable passes just once through the bead or core.) Multi-turn chokes are required for effective suppression at HF. It is usually more effective to form a common-mode choke by wrapping about multiple turns of wire or coaxial cable around a 1- to 2-inch OD core of the correct material.

Common-mode chokes can be used on single conductors unless the desired signal is in the RF spectrum. A common-mode choke creates a high resistive impedance at radio frequencies. At audio frequencies, however, it looks like a relatively small inductance, and is unlikely to have any effect on audio-frequency signals.

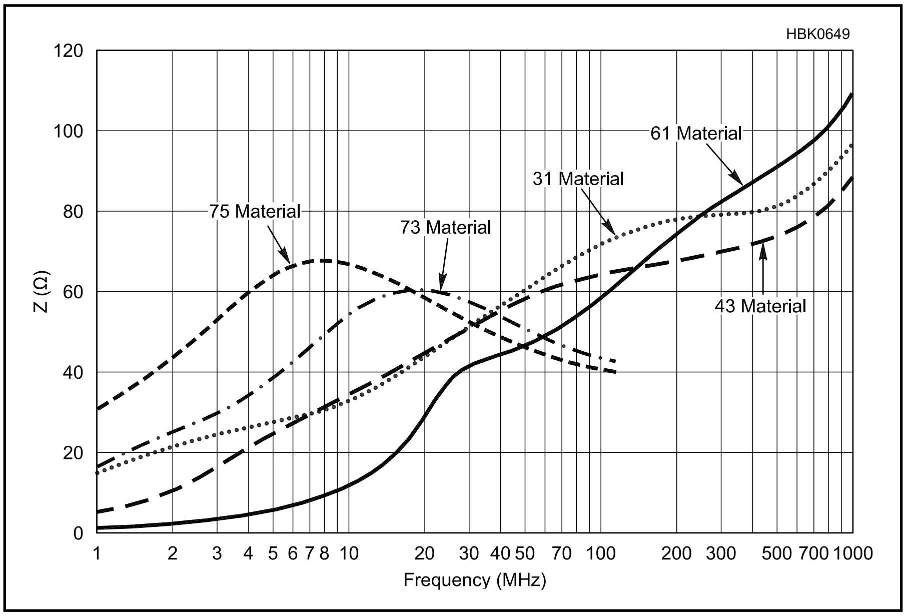


Fig 27.18 — Impedance vs. frequency plots for "101" size ferrite beads illustrate the effect of various ferrite materials across different frequency ranges. A 3.50 mm × 1.30 mm × 6.00 mm bead (Fair-Rite 301 size) was used for the above curve for material comparison, however all materials are not available in all shapes and sizes. Type 73 material is only available in smaller cores, type 31 is only available in larger cores, and type 75 is currently only available as a toroid core. (Graph provided courtesy of the Fair-Rite Corporation)

27.8 Troubleshooting RFI

Troubleshooting an RFI problem is a multi-step process, and all steps are equally important. First you must determine the type(s) of noise source(s) that are involved. Next, diagnose the problem by locating the noise source and the means by which it creates the noise. The final step is to identify the path by which the noise or signals reach the victim device. Only then can you cure the problem by breaking the path from source to victim.

Each step in troubleshooting an RFI problem involves asking and answering several questions: Is the problem caused by harmonics, fundamental overload, conducted emissions, radiated emissions or a combination of all of these factors? Should it be fixed with a low-pass filter, high-pass filter, common-mode chokes or ac-line filter? How about shielding, isolation transformers, a different ground or antenna configuration? By the time you finish with these questions, the possibilities could number in the millions. You probably will not see your exact problem and cure listed in this book or any other. You must not only diagnose the problem but find a cure as well!

Now that you have learned some RFI fundamentals, you can work on specific technical solutions. A systematic approach will identify the problem and suggest a cure. Most RFI problems can be solved in this way by the application of standard techniques. The following sections suggest specific approaches for different types of common interference problems. This advice is based on the experience of the ARRL RFI Desk, but is not guaranteed to provide a solution to your particular problem. Armed with your RFI knowledge, a kit of filters and tools, your local TC and a determination to solve the problem, it is time to begin. You should also get a copy of the *ARRL RFI Book*. It's comprehensive and picks up where this chapter leaves off.

27.8.1 General RFI Troubleshooting Guidelines

Before diving into the problem, take a step back and consider some of these "pre-troubleshooting steps."

Is It Really EMI? — Before trying to solve a suspected case of EMI, verify that the symptoms actually result from external causes. A variety of equipment malfunctions or external noise can look like interference.

Is It Your Station? — "Your" EMI problem might be caused by another ham or a radio transmitter of another radio service, such as a local CB or police transmitter. If it appears that your station is involved, operate your station on each band, mode and power level that you use. Note all conditions that produce interference. If no transmissions produce the problem, your station *may* not be the cause. (Although some contributing factor may have been missing in the test.) Have your neighbor keep notes of when and how the interference appears: what time of day, what station, what other appliances were in use, what was the weather? You should do the same whenever you operate. If you can readily reproduce the problem with your station, you can start to troubleshoot the problem.

Take One Away — Can you remove the source or victim entirely? The best cure for an RFI problem is often removing the source of the noise. If the source is something broken, for example, the usual solution is to repair it.

Power-line noise and an arcing electric fence usually fall into this category. If a switchmode power supply is radiating noise, replace it with a linear supply. Victim devices can sometimes be replaced with a more robust piece of equipment, as well.

Look Around — Aside from the brain, the eyes are a troubleshooter's best tool. Installation defects contribute to many RFI problems. Look for loose connections, shield breaks in a cable-TV installation or corroded contacts in a telephone installation. Have these fixed these first. Look for wiring connected to the victim equipment that might be long enough to be resonant on one or more amateur bands. If so, a common-mode choke may be an easy cure. Ideally you'll generally want place the choke as close to the victim device as practical. If this placement proves too difficult or additional suppression is required, chokes placed at the middle of the wiring may help break up resonances. These are just a few of the possible deficiencies in a home installation.

At Your Station — Make sure that your own station and consumer equipment are clean. This cuts the size of a possible interference problem from your station in half! Once this is done, you won't need to diagnose or troubleshoot your station later. Also, any cures successful at your house may work at your neighbor's as well. If you do have problems in your own home, continue through the troubleshooting steps and specific cures and take care of your own problem first.

Simplify the Problem — Don't tackle a complex system — such as a telephone system in which there are two lines running to 14 rooms — all at once. You could spend the rest of your life running in circles and never find the true cause of the problem.

There's a better way. In our hypothetical telephone system, first locate the telephone jack closest to the telephone service entrance. Disconnect the lines to more remote jacks and connect one RFI-resistant telephone at the remaining jack. (Old-style rotary-dial phones are often quite immune to RF.) If the interference remains, try cures until the problem is solved, then start adding lines and equipment back one at a time, fixing the problems as you go along. If you are lucky, you will solve all of the problems in one pass. If not, at least you can point to one piece of equipment as the source of the problem.

Multiple Causes — Many RFI problems have multiple causes. These are usually the ones that give new RFI troubleshooters the most trouble. For example, consider a TVI problem caused by the combination of harmonics from the transmitter due to an arc in the transmitting antenna, an overloaded TV preamplifier, fundamental overload generating harmonics in the TV tuner, induced and conducted RF on the ac-power connections, and a common-mode signal picked up on the shield of the TV's coaxial feed line. You would never find a cure for this multiple-cause problem by trying only one cure at a time.

In this case, the solution requires that all of the cures be present at the same time. When troubleshooting, if you try a cure, leave it in place even if it doesn't solve the problem. When you add a cure that finally solves the problem entirely, start removing the "temporary" attempts one at a time. If the interference returns, you know that there were multiple causes.

Take Notes — In the process of troubleshooting an RFI problem, it's easy to lose track of what remedies were applied, to what equipment, and in what order. Configurations of equipment can change rapidly when you're experimenting. To minimize the chances of going around in circles or getting confused,

Table 27.1
RFI Survival Kit

Quantity	*Item*
(2)	300-Ω high-pass filter
(2)	75-Ω high-pass filter
(2)	Commercially available clamp-on ferrite cores: #31 and #43 material, 0.3" ID
(12)	Assorted ferrite cores: #31 and #43 material, FT-140 and FT-240 size
(3)	Telephone RFI filters
(2)	Brute-force ac line filters
(6)	0.01-µF ceramic capacitors
(6)	0.001-µF ceramic capacitors

Miscellaneous:
- Hand tools, assorted screwdrivers, wire cutters, pliers
- Hookup wire
- Electrical tape
- Soldering iron and solder (use with caution!)
- Assorted lengths 75-Ω coaxial cable with connectors
- Spare F connectors, male, and crimping tool
- F-connector female-female "barrel"
- Clip leads
- Notebook and pencil
- Portable multimeter

"Keeping It Simple"

Filters and chokes are the number one weapons of choice for many RFI problems whether the device is the source or the victim. They are relatively inexpensive, easy to install, and do not require permanently modifying the device.

Common-mode choke — Making a common-mode choke is simple. Select the type of core and ferrite material for the frequency range of the interference. (Type 31 is a good HF/low-VHF material, type #43 from 5 MHz through VHF) Wrap several turns of the cable or wire pairs around the toroid. Six to 8 turns is a good start at 10-30 MHz and 10 to 15 turns from 1.8 to 7 MHz. (Ten to 15 turns is probably the practical limit for most cables.) Ferrite clamp-on split cores and beads that slide over the cable or wire are not as effective as toroid-core chokes at HF but are the right solution at VHF and higher frequencies. For a clamp-on core, the cable doesn't even need to be disconnected from its end. Use type 31 or type 43 material at VHF, type 61 at UHF. At 50 MHz, use two turns through type 31 or 43 cores.

"Brute-Force" ac-line filters — RF signals often enter and exit a device via an ac power connection. "Brute-force" ac-line filters are simple and easy to install. Most ac filters provide both common- and differential-mode suppression. It is essential to use a filter rated to handle the device's required current.

General installation guidelines for using chokes and filters

1. If you have a brute-force ac-line filter, put one on the device or power cord. If RFI persists, add a common-mode choke to the power cord at the device.
2. Simplify the problem by removing cables one at a time until you no longer detect RFI. Start with cables longer than 1/10th-wavelength at the highest frequency of concern. If the equipment can't operate without a particular cable, add common-mode chokes at the affected or source device.
3. Add a common-mode choke to the last cable removed and verify its effect on the RFI. Some cables may require several chokes in difficult cases.
4. Begin reconnecting cables one at a time. If RFI reappears, add a common-mode choke to that cable. Repeat for each cable.
5. Once the RFI goes away, remove the common-mode chokes you added one at a time. If the RFI does not return, you do not need to reinstall the choke. If the RFI returns after removing a choke, reinstall it. Keep only those chokes required to fix the problem.

take lots of notes as you proceed. Sketches and drawings can be very useful. When you do find the cause of a problem and a cure for it, be sure to write all that down so you can refer to it in the future.

RFI Survival Kit — **Table 27.1** is a list of the material needed to troubleshoot and solve most RFI problems. Having all of these materials in one container, such as a small tackle or craft box, makes the troubleshooting process go a lot smoother.

27.8.2 Transmitters

We start with transmitters not because most interference comes from transmitters, but because your station transmitter is under your direct control. Many of the troubleshooting steps in other parts of this chapter assume that your transmitter is "clean" (free of unwanted RF output).

Start by looking for patterns in the interference. Problems that occur only on harmonics of a fundamental signal usually indicate the transmitter is the source of the interference. Harmonics can also be generated in nearby semiconductors, such as an unpowered VHF receiver left connected to an antenna, rectifiers in a rotator control box, or a corroded connection in a tower guy wire. Harmonics can also be generated in the front-end components of the TV or radio experiencing interference.

If HF transmitter spurs at VHF are causing interference, a low-pass filter at the transmitter output will usually cure the problem. Install the filter after the amplifier (if used) and before the antenna tuner. (A second filter between the transmitter and amplifier may occasionally help as well.) Install a low-pass filter as your first step in any interference problem that involves another radio service.

Interference from non-harmonic spurious emissions is extremely rare in commercial radios. Any such problem indicates a malfunction that should be repaired.

27.8.3 Television Interference (TVI)

An analog TV signal must have about a 45 to 50 dB signal-to-noise ratio to be classified as good-quality viewing. If interference is present due to a single, discrete signal (for example, a CW signal) the signal-to-interference ratio must be 57 dB or greater, depending on the frequency of the interference within the affected channel. Digital TV has somewhat better immunity but for both formats, clear reception requires a strong signal at the TV antenna-input connector so the receiver must be in what is known as a *strong-signal area*.

TVI to a TV receiver (or a video monitor) normally has one of the following causes:

• Spurious signals within the TV channel coming from your transmitter or station.

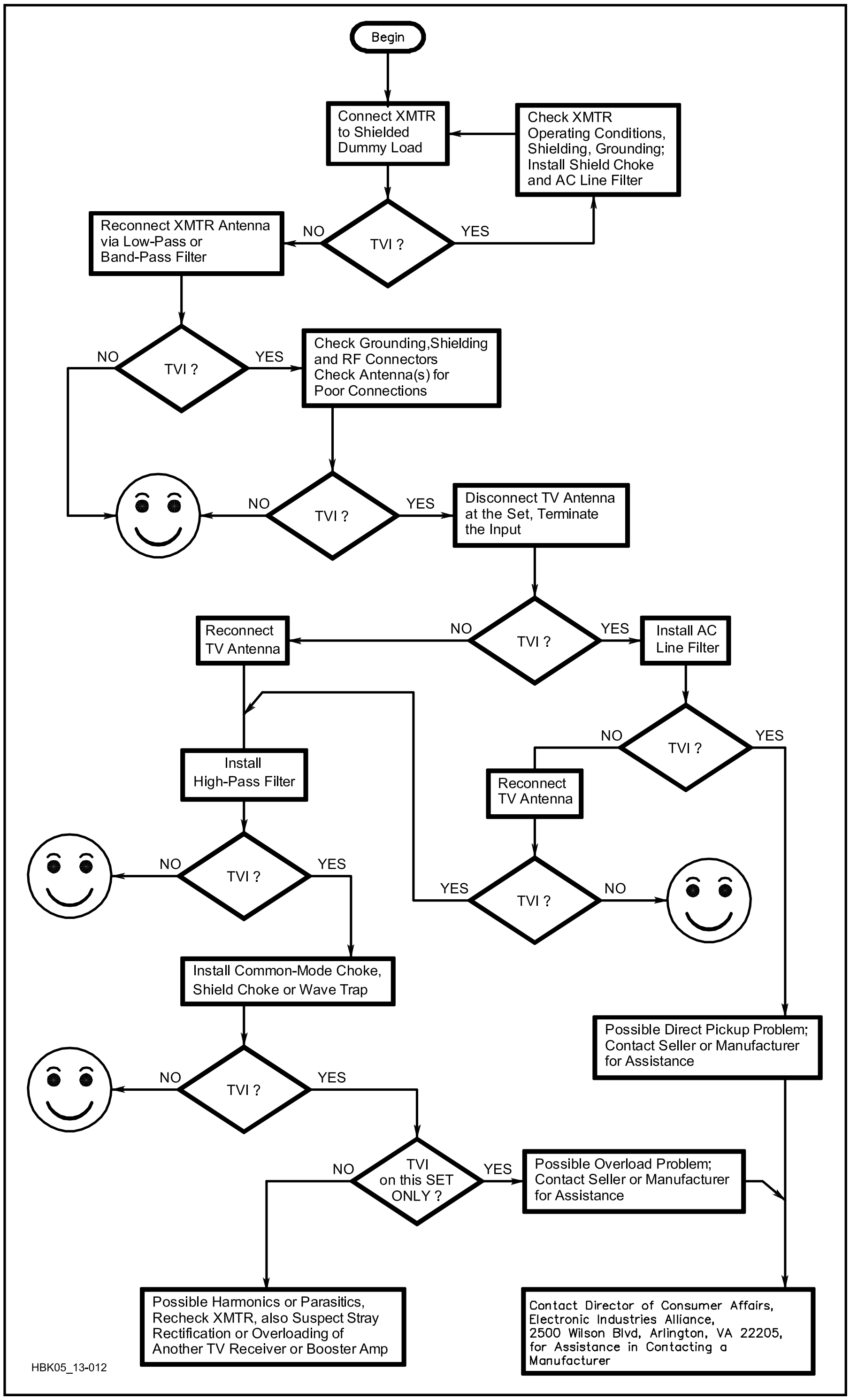


Fig 27.19 — TVI troubleshooting flowchart.

• The TV set may be overloaded by your transmitter's fundamental signal.

• Signals within the TV channel from some source other than your station, such as electrical noise, an overloaded mast-mounted TV preamplifier or a transmitter in another service.

• The TV set might be defective or misadjusted, making it look like there is an interference problem.

All of these problems are made potentially more severe because TV receiving equipment is hooked up to *two* antenna systems: (1) the incoming antenna or cable feed line and (2) the ac power line and interconnecting cables. These two antenna systems can couple significant levels of fundamental or harmonic energy into the TV set or video display! The

TVI Troubleshooting Flowchart in **Fig 27.19** is a good starting point.

The problem could also be caused by direct pickup of the transmitted signal by an unshielded TV or device connected to the TV.

Certain types of television receivers and video monitors are reported to cause broadband RF interference *to* amateur signals — large-screen plasma display models seem to be the most frequent offender — and this may be difficult to cure due to the nature of the display technology. Fortunately, less-expensive, more power-efficient, and RF-quieter LCD technology seems to be displacing plasma technology.

The manufacturer of the TV or video equipment can sometimes help with an interference problem. The Electronic Industries Alliance (EIA) can also help you contact equipment manufacturers. Contact them directly for assistance in locating help at **www.eia.org**.

COMMON SOURCES OF TVI

HF transmitters — A nearby HF transmitter is most likely to cause fundamental overload. This is usually indicated by interference to all channels, or at least all VHF channels. To cure fundamental overload from an HF transmitter to an antenna-connected TV, install a high-pass filter directly at the TV set's antenna input. (Do not use a high-pass filter on a cable-TV input because the HF range is used for data and other system signals.)

A strong HF signal can also result in a strong common-mode signal on the TV's feed line. A common-mode choke will block signals on the outside of the feed line shield, leaving the desired signals inside the feed line unaffected. **Fig 27.20** shows how a common-mode choke is constructed for a coaxial feed line.

These two filters can probably cure most cases of TVI! **Fig 27.21** shows a "bulletproof" installation for both over-the-air and cable TV receivers. If one of these methods doesn't cure the problem, the problem is likely direct pickup in which a signal is received by the TV set's circuitry without any conducting path being required. In that case, don't try to fix it yourself — it is a problem for the TV manufacturer.

High-pass filters *should not* be used in a cable TV feed line (Fig 27.21A) with two-way cable devices such as cable modems, set-top boxes, and newer two-way CableCARD-equipped TVs. The high-pass filter may prevent the device from communicating via the cable network's upstream signal path.

VHF Transmitters —Most TV tuners are not very selective and a strong VHF signal, including those from nearby FM and TV transmitters, can overload the tuner easily, particularly when receiving channels 2-13 over the air and not by cable TV. In this case, a VHF notch or stop-band filter at the TV can help by attenuating the VHF fundamental signal that gets to the TV tuner. Winegard (**www.winegard.com**) and Scannermaster (**www.scannermaster.com**) sell tunable notch filters. A common-mode choke may also be necessary if the TV is responding to the common-mode VHF signal present on the TV's feed line.

TV Preamplifiers — Preamplifiers are only needed in weak-signal areas and they often cause trouble, particularly when used unnecessarily in strong-signal areas. They are subject to the same overload problems as TVs and when located on the antenna mast it can be difficult to install the appropriate cures. You may need to install a high-pass or notch filter at the input of the preamplifier, as well as a common-mode choke on the input, output and power-supply wiring (if separate) to effect a complete cure. All filters, connections, and chokes must be weatherproofed. Secure the coax tightly to a metal mast to minimize common-mode current. (Do not secure twin-lead to a metal support.) Use two 1-inch long type 43 clamp-on ferrite cores if VHF signals are causing the interference and type 61 mate-

Fig 27.20 — To eliminate HF and VHF signals on the outside of a coaxial cable, use an 1- to 2-inch OD toroid core and wind as many turns of the cable on the core as practical.

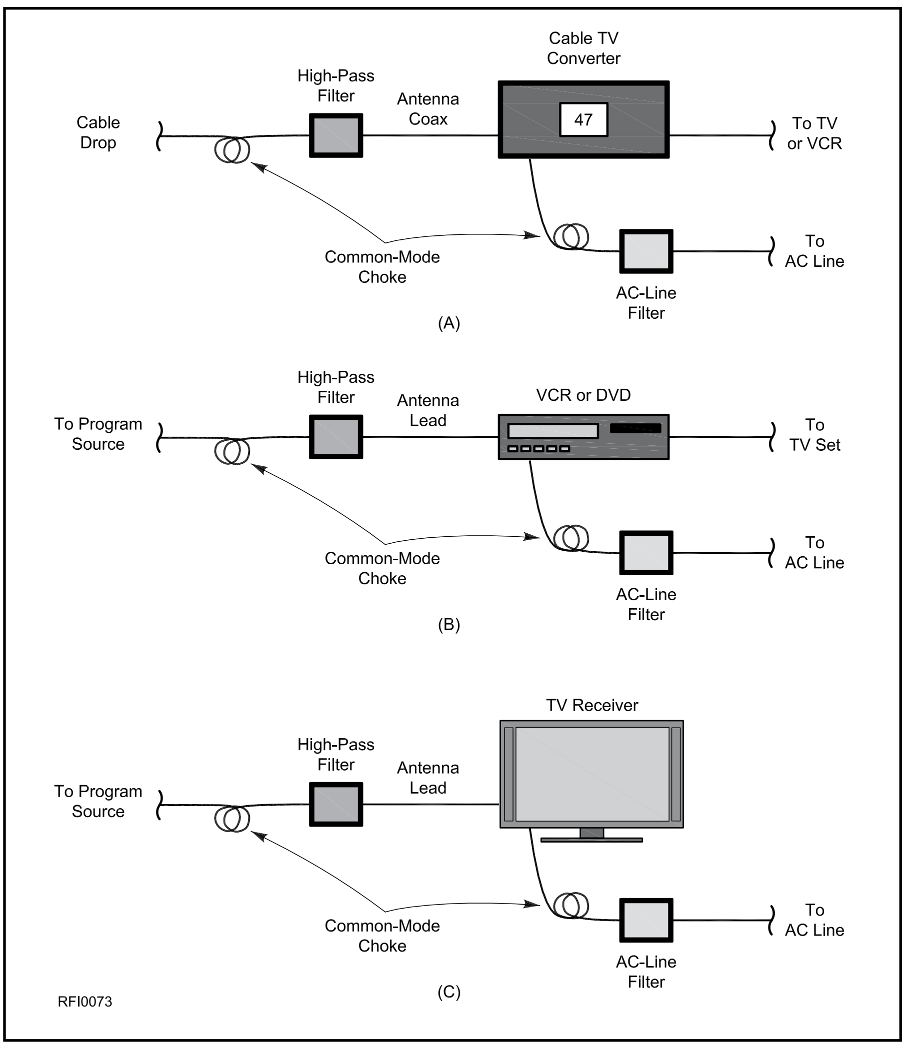


Fig 27.21 — Installing common-mode chokes and high-pass filters will cure most fundamental overload interference from HF sources. This technique does not address direct pickup or spurious emission problems.

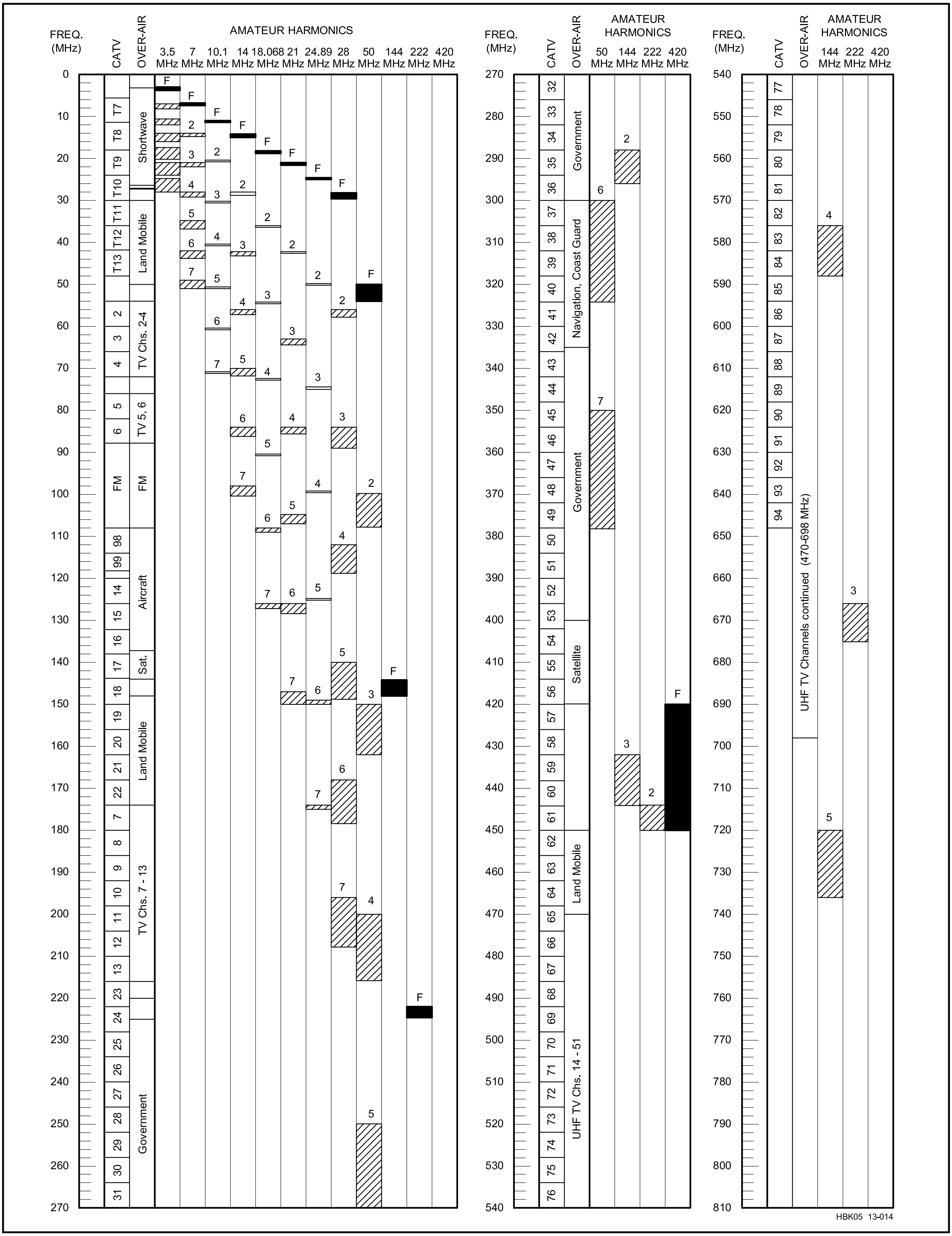


Fig 27.22 — This chart shows CATV and broadcast channels used in the United States and their relationship to the harmonics of MF, HF, VHF and UHF amateur bands. Over-the-air UHF TV channels 52-69 (698-890 MHz) have been reallocated to other services. (F denotes a fundamental frequency for amateur signals.)

rial for UHF. HF choke design is discussed in the section on Common-Mode Chokes.

Spurious Emissions — You are responsible for spurious emissions produced by your station. If your station is generating any interfering spurious signals, the problem must be cured there. Start by analyzing which TV channels are affected. The TV Channel Chart in **Fig 27.22** shows the relationship of the amateur allocations and their harmonics to over-the-air and cable channels. Each channel is 6 MHz wide. If the interference is only on channels that are multiples of your transmitting frequency, you probably have interference caused by harmonics of your transmitted signal.

It is not certain that these harmonics are coming from your station, however. Harmonics can be generated by overloaded preamplifiers or tuner input circuits. Harmonics can also be generated by non-linear junctions near your station transmitter or very near the TV receiver antenna. (See the section on Intermodulation Distortion.) If your transmitter and station check "clean" — check to see if you have interference on a TV set in your own home — then you must look elsewhere for the source of the harmonics.

Electrical Noise — Electrical noise on an analog TV screen generally appears as shown in **Fig 27.23**. Because the noise is nearly synchronized with the ac line frequency, noise artifacts move upward slowly on the screen. Digital TV signals are fairly resistant to electrical noise, but in extreme cases can cause the picture to freeze or fail to be displayed as discussed in the following section on Digital TV.

On an AM receiver (including SSB or CW receivers), electrical noise usually sounds like a buzz, sometimes changing in intensity as the arc or spark sputters a bit. If you have a problem with electrical noise, refer to the section on Electrical Noise.

ANALOG TV RECEIVERS

Even though over-the-air TV broadcasting largely switched to a digital format in 2009, millions of analog TV receivers are still in use for cable TV, satellite TV, with converter boxes for digital broadcast signals, and for displaying video from DVDs and other video sources. Older VCR and DVD players may also include an analog TV tuner to receive analog TV signals.

Interference to video displays and monitors that do not receive RF signals from an antenna or RF modulator should be assumed to be common-mode interference or direct pickup. The same applies to interference to a TV set displaying video signals (not through the antenna input). Interference that is present only on the audio is probably a case of common-mode RFI. (See the Stereos and Home Entertainment Systems section of this chapter.)

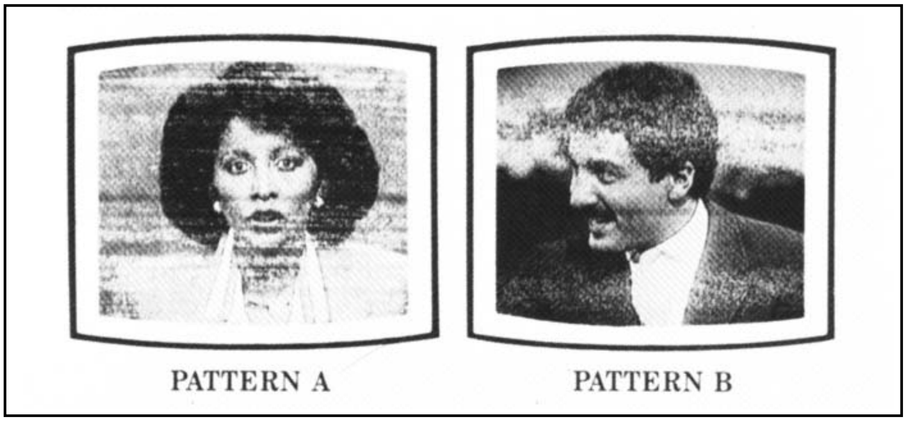


Fig 27.23 — Two examples of TVI from electrical noise to analog TV receivers.

Digital TV Basics

DTV operates on the same 6 MHz-wide channels used for analog TV. However, instead of each channel slot carrying an analog NTSC television signal (visual carrier, color subcarrier, & aural carrier), the channel slot carries an 8-VSB digitally modulated signal. The 6 MHz-wide over-the-air channel slots themselves didn't change, just the signals carried in them! So, Ch. 2 is still 54-60 MHz, Ch. 3 is 60-66 MHz, and so forth, up to channel 51. Ch. 2-6 have largely been abandoned in the US as stations moved to broadcast digital TV on UHF channels. UHF channels 52-69 will be reallocated to other uses.

The designation "8-VSB" refers to 8-level vestigial sideband modulation. This is similar to 256-QAM, which means 256-state *quadrature amplitude modulation* — the 256 "states" are 256 combinations of signal phase and amplitude values that represent the 256 different transmitted symbols — a digital format used in cable TV networks (64-QAM is also used by cable companies). In the case of 8-VSB, the "8" refers to the eight-level baseband DTV signal that amplitude modulates an IF signal. For more info about 8-VSB modulation, see the online article, "What Exactly Is 8-VSB Anyway?" at **www.broadcast.net/~sbe1/8vsb/8vsb.htm**.

Digitally modulated signals used to transport video — whether 8-VSB for over-the-air or 64-QAM or 256-QAM in cable networks — are noise-like signals over their 6 MHz bandwidth. If a digital TV signal interferes with analog radio communications such as FM or SSB, the effect is similar to degraded signal-to-noise ratio. Indeed, a digital TV signal can be thought of as a 6 MHz wide "pile of noise." On a spectrum analyzer, it looks like a "haystack" as shown in **Fig 27.B** Of course, the IF bandwidth of the amateur receiver is quite narrow relative to the 6 MHz-wide digital TV channel, so the actual noise level seen by the receiver (assuming no overload or IMD problems) will in part be determined by the receiver's IF bandwidth. Still, the effect on the receiver is what amounts to an elevated noise floor, similar to the effects of wide-spectrum broadband noise.

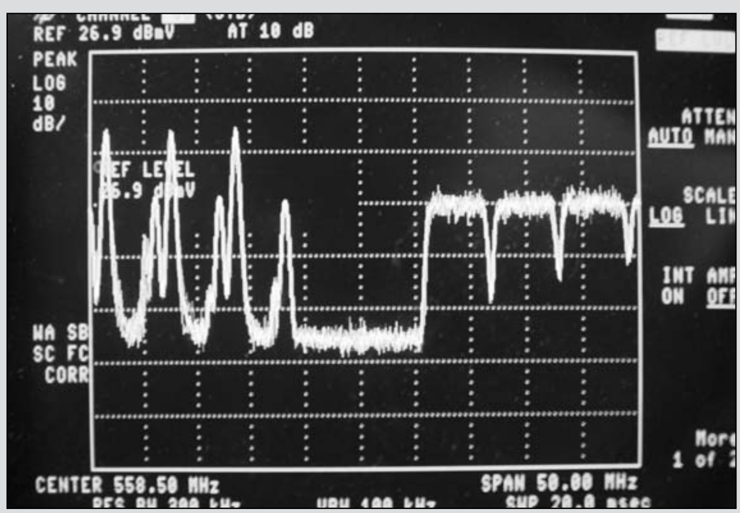


Fig 27.B — The spectrum of three analog NTSC TV channels (left of center) and three QAM signals (right of center). The digital channel power of the QAM "haystacks" is about 6 dB below the analog visual carrier PEP.

DIGITAL TV (DTV) RECEIVERS

In 2009, nearly all over-the-air TV broadcasters in the US, with the exception of low-power TV stations and translators, switched from the older NTSC analog format to a new digital format called DTV. The FCC's Digital TV Transition Web page (**www.dtv.gov**) has more information on this transition, including an FAQ page. Digital TV signals can operate with much lower signal-to-noise ratios, but are still susceptible to interference.

Interference to digital TV signals from amateur signals — narrowband interference, for instance, a CW carrier — to a 6 MHz-wide digital TV signal generally has two effects. If the interfering signal is strong enough, it will cause degraded *modulation error ratio* (MER) and degraded *bit error rate* (BER) in the digital video signal. If the amplitude of the interference is sufficient, the digital receiver's *forward error correction* (FEC) circuitry will be unable to fix the broken bits, and the digital video signal will "crash." (See the **Digital Modes** chapter for more information on coding and error correction in digital protocols.)

TV viewers watching any of the multiple video streams that may be contained within the digital video signal won't see any problems in the picture (or hear anything wrong in the sound), until the so-called "crash point" is reached. At that point, the picture will begin to show intermittent "tiling" (the picture breaking up into small squares) or blocking (freezing) in the image. As the amplitude of the interfering signal increases perhaps another 0.5 dB to 1 dB, the crash point or "digital cliff" is reached, and the picture and sound are gone! As you can see, there is a tiny window between receiving a perfect picture and receiving no picture. The same effect is produced by signal fading and may be difficult to distinguish from RFI.

Interference to the digital signal does not make its presence known through visual or audible artifacts such as streaks, lines, or tearing in the picture, or garbled audio. This means that a viewer experiencing interference may not be able to identify its source, but troubleshooting interference may also become more difficult. Nevertheless, the more robust digital modulation is often less susceptible to interference from narrowband amateur signals. (See the sidebar "Report from the ARRL Lab Regarding Amateur Radio Operation and Converter Boxes.") A clue to the source of the interference is that interference caused by an amateur signal will occur in sync with the amateur's transmissions while other types of interference will have no correlation.

The techniques for curing interference between amateur and digital TV signals are largely the same as for analog TV. Fundamental overload generally responds well to filters in the antenna or RF inputs. Interference caused by spurious emissions from the amateur station can be eliminated by filtering at the amateur transmitter. Common-mode problems in which RF signals are conducted into the television receiver's circuitry by external audio, video, and power cables are no more or less likely than for analog TV sets and can be addressed as described elsewhere in this chapter.

Report from the ARRL Lab Regarding Amateur Radio Operation and Converter Boxes

Upon receiving an email from a concerned member, I thought I would test out a digital TV to analog TV converter box that one of our Lab staffers had. It is a Zenith brand, identical to an Insignia brand I have at home.

To test the box by itself, I took the RF output from the converter box and fed it directly via coax to the analog TV RF input, using broadcast channel 3 on the TV.

Fed directly to the antenna input of the converter box, I combined an off-air digital signal with an analog RF signal representing a very strong nearby ham transmitter (CW and amplitude modulation). Watching and listening to the television, I varied my signal generator's frequency through the MF, HF, VHF and UHF spectrum at 0 dBm (equivalent to a signal stronger than 70 dB over S9 on some S meters) with no signal break-up or other problems. The TV signal strength meter was typically about 2/3 scale on all channels, just enough for the off-air TV signal to come in. The test was repeated watching both VHF and UHF DTV channels.

Problems occurred when interfering signals reached the +10 dBm range (extremely strong), where you would expect any receiver to have blocking issues. Another Lab staff member and I both concluded the box we tested was very good at rejecting strong signals.

For a real life situation, we observed digital TV signals when W1AW was fired up on 20 m, with 1500 W on SSB, right across the parking lot! This was a good, real-life overload test. No pixelation or loss of picture occurred. Please note our TV receiving antenna was a multiband HF vertical on the roof of ARRL HQ.

While this limited test may not be representative of all converter boxes, TVI from radio amateurs is still possible, but not likely, through the TV antenna. Many DTV problems occur with RF getting into interconnecting cables or power lines and can be solved on an as needed basis, by trying the same methods used with analog TVs. Solutions to such problems are described in this chapter and in more detail in The ARRL *RFI Book.*

Off-air DTV needs a good signal to be seen. Either you have it, or you don't, period. There is no in-between like analog. Your neighbor may not understand that DTV signal breakup may have nothing to do with your transmissions. As described at the beginning of this chapter, try to be a good neighbor and ambassador of ham radio by working to help with your neighbor to improve reception.

Note: I have not had any interference to Amateur Radio from my converter box at my home. — *Bob Allison, WB1GCM, ARRL Test Engineer*

27.8.4 Cable TV

Cable TV has generally benefited Amateur Radio with respect to TVI. The cable system delivers a strong, consistent signal to the TV receiver, reducing susceptibility to interference from amateur signals. It is also a shielded system so an external signal shouldn't be able to cause interference. Most cable companies are responsible about keeping signal leakage (*egress*) and *ingress* — the opposite of leakage — under control, but problems do happen. Cable companies are not responsible for direct pickup or common-mode interference problems, but are responsible for leakage, ingress, and any noise radiated by common-mode currents from their equipment.

Cable companies are able to take advantage of something known as frequency reuse. That is, all radio frequencies higher than 5 MHz are used to transmit TV signals. The latter is possible because the cables and components used to transport signals to and from paying subscribers comprise what is known as a closed network. In other words, a cable company can use frequencies inside of its cables that may be used for entirely different purposes in the over-the-air environment. As long as the shielding integrity of the cable network is maintained, the cable company's signals won't interfere with over-the-air services, and vice-versa.

The reality is that the shielding integrity of a cable network *is* sometimes compromised, perhaps because of a loose or damaged connector, a cracked cable shield, rodent damage, poorly shielded customer premises equipment (CPE) such as cable-ready TVs and VCRs, and problems that may happen when someone tries to steal cable service! §76.605(a)(12) of the FCC Rules defines the maximum allowable signal leakage (*egress*) field strength at specified measurement distances, and §76.613 covers harmful interference. FCC Rules also mandate that cable

Table 27.2
Amateur Radio Bands Relative to Cable TV Downstream Channels

Amateur Band	*Over-The-Air Frequency Range*	*Cable Channel*	*Cable Frequency Range*
6 meters	50-54 MHz	Below Ch. 2	50-54 MHz, sometimes used for narrowband telemetry carriers
2 meters	144-148 MHz	Ch. 18	144-150 MHz
1.25 meters	222-225 MHz	Ch. 24	222-228 MHz
70 cm	420-450 MHz	Ch. 57	420-426 MHz
		Ch. 58	426-432 MHz
		Ch. 59	432-438 MHz
		Ch. 60	438-444 MHz
		Ch. 61	444-450 MHz
33 cm	902-928 MHz	Ch. 142	900-906 MHz
		Ch. 143	906-912 MHz
		Ch. 144	912-918 MHz
		Ch. 145	918-924 MHz
		Ch. 146	924-930 MHz

operators "…shall provide for a program of regular monitoring for signal leakage by substantially covering the plant every three months," and leaks greater than 20 microvolts per meter (μV/m) at a 10 ft. measurement distance repaired in a reasonable period of time. As well, an annual "snapshot" of leakage performance must be characterized via a flyover measurement of the cable system, or a ground-based measurement of 75% of the network.

CABLE TV FREQUENCY USAGE

A typical modern North American cable network is designed to use frequencies in the 5 to 1002 MHz spectrum. Signals that travel from the cable company to the subscriber occupy frequencies from just above 50 MHz to as high as 1002 MHz range (this is the downstream or forward spectrum), and signals that travel from the subscriber to the cable company are carried in the 5 to as high as 42 MHz range, known as the upstream or return spectrum. The downstream is divided into 6 MHz-wide channel slots, which may carry analog NTSC television signals or 64- or 256-QAM digitally modulated signals used for digital video, high-speed data, and telephone services. Upstream signals from cable modems and two-way set-top boxes are generally carried on specific frequencies chosen by the cable company. **Table 27.2** summarizes cable downstream channel allocations that overlap Amateur Radio bands. The complete North American channel plan is shown in Fig 27.22.

Cable channels below about 550 MHz may carry analog NTSC signals or digital signals. Cable channels above 550 MHz generally carry digital signals, although there are exceptions. Cable channels above 870 MHz almost always carry only digital signals.

COMMON MECHANISMS FOR LEAKAGE AND INGRESS

As noted previously, cable TV leakage and ingress occur when the shielding integrity of the cable network is compromised. A large cable system that serves a major metropolitan area has literally millions of connectors, tens of thousands of miles of coaxial cable, thousands of amplifiers, hundreds of thousands of passives (splitters, directional couplers, and similar devices), and uncountable customer premises equipment connected to the cable network! Any of these may be a source of leakage and ingress.

ANALOG TV CHANNEL LEAKAGE SYMPTOMS

When signal leakage does happen, interference to the Amateur Radio service may occur. And where there is leakage, there is probably ingress. That compounds the problem, because not only are you experiencing interference, but when you transmit you may interfere with cable service in the area. One of the most common signs of possible leakage is interference to the 2 meter amateur band, especially in the vicinity of standard (STD) cable channel 18's visual carrier on 145.25 MHz. If you suspect cable leakage, listen for the telltale buzz from the video signal on or near 145.25 MHz (sometimes buzz may not be heard), and check other STD, incrementally related carrier (IRC), and harmonically related carrier (HRC) visual carrier frequencies on nearby channels listed in **Table 27.3** using a wide range receiver or scanner. (Leakage of a digital TV signal on cable channel 18 sounds like broadband noise over the 144-150 MHz range.) Also listen for TV channel sound on the FM aural carriers 4.5 MHz above the visual carriers.

DIGITAL SIGNAL LEAKAGE?

The digitally modulated signals carried in a cable TV network use 64-QAM or 256-QAM, the latter more common. If a QAM signal were to leak from a cable TV network, it is possible for interference to an over-the-air service to occur, but very unlikely to be identified as from a digital TV signal. The reason for this is that a QAM signal is noise-like, and sounds like normal background noise or hiss on a typical amateur receiver. The QAM signal's digital channel power — its average power over the entire occupied bandwidth — is typically 6 to 10 dB lower than what an analog TV signal's visual carrier peak envelope power (PEP) would be on the same channel. As well, a QAM signal occupies most of the 6 MHz channel slot, and there are no carriers per se within that channel bandwidth. Note that over-the-air 8-VSB digital TV broadcast signals transmit a pilot carrier near the lower end of the digital "haystack," but the QAM format used by cable operators has no comparable pilot carrier.

What makes the likelihood of interference occurring (or not occurring) has in large part to do with the behavior of a receiver in the presence of broadband noise. While each downstream cable TV QAM signal occupies close to 6 MHz of RF bandwidth, the IF

Table 27.3
VHF Midband Cable Channels

Cable Channel	*Visual Carrier Frequency, MHz (STD)*	*Visual Carrier Frequency, MHz (IRC)*	*Visual Carrier Frequency, MHz (HRC)*
98	109.2750	109.2750	108.0250*
99	115.2750	115.2750	114.0250*
14	121.2625	121.2625	120.0060
15	127.2625	127.2625	126.0063
16	133.2625	133.2625	132.0066
17	139.25	139.2625	138.0069
18	145.25	145.2625	144.0072
19	151.25	151.2625	150.0075
20	157.25	157.2625	156.0078
21	163.25	163.2625	162.0081
22	169.25	169.2625	168.0084

*Excluded from HRC channel set because of FCC frequency offset requirements bandwidth of a typical amateur FM receiver might be approximately 20 kHz. Thus, the noise power in the receiver will be reduced by $10\log_{10}(6{,}000{,}000/20{,}000) = 24.77$ dB because of the receiver's much narrower IF bandwidth compared to the QAM signal's occupied bandwidth. In addition, there is the 6 to 10 dB reduction of the digital signal's average signal PEP.

Field tests during 2009 confirmed this behavior, finding that a leaking QAM signal would not budge the S-meter of a Yaesu FT-736R at low to moderate field strength leaks, even when the receiver's antenna — a resonant half-wave dipole — was located just 10 feet from a calibrated leak. In contrast, a CW carrier that produced a 20 μV/m leak resulted in an S-meter reading of S9+15 dB, definitely harmful interference! When the CW carrier was replaced by a QAM signal whose digital channel power was equal to the CW carrier's PEP and which produced the same leakage field strength (the latter integrated over the full 6 MHz channel bandwidth), the S-meter read <S1. When the leakage field strength was increased to 100 μV/m, the CW carrier pegged the S-meter at S9+60 dB, while the QAM signal was S3 in FM mode and between S1 and S2 in USB mode. It wasn't until the leaking QAM signal's field strength reached several hundred μV/m that the "noise" (and it literally sounded like typical white noise) could be construed to be harmful interference.

LOCATING LEAKAGE SOURCES

When a cable company technician troubleshoots signal leakage, the process is similar to Amateur Radio fox hunting. The technician uses radio direction finding techniques that may include equipment such as handheld dipole or Yagi antennas, Doppler antenna arrays on vehicles, near-field probes, and commercially manufactured signal leakage detectors. Many leakage detectors incorporate what is known as "tagging" technology to differentiate a leaking cable signal from an over-the-air signal or electrical noise that may exist on or near the same frequency. Most leakage detection is done on a dedicated cable channel in the 108-138 MHz frequency range.

ELIMINATING LEAKAGE

A large percentage of leakage and ingress problems are not the result of a single shielding defect, although this does happen. For example, a squirrel might chew a hardline feeder cable, or a radial crack might develop in the shield as a consequence of environmental or mechanical damage. Most often, leakage and ingress are caused by several small shielding defects in an area: loose or corroded hardline connectors and splices, old copper braid subscriber drop cabling, improperly installed F connectors, subscriber-installed substandard "do-it-yourself" components, and the previously mentioned poorly shielded cable-ready TVs and other *customer premises equipment* (*CPE*).

After the cable technician locates the source(s) of the leakage, it is necessary to repair or replace the culprit components or cabling. In the case of poorly shielded TVs or VCRs, the cable technician cannot repair those devices, only recommend that they be fixed by a qualified service shop. Often the installation of a set-top box will take care of a cable-ready CPE problem because the subscriber drop cabling is no longer connected directly to the offending device. The latter usually resolves direct pickup problems, too, because the cable-ready TV must be tuned to channel 3 or 4 to receive the set-top signals.

VERIFYING AN RFI SOURCE TO BE LEAKAGE

Spurious signals, birdies, harmonics, intermodulation, electrical noise, and even interference from Part 15 devices are sometimes mistaken for cable signal leakage. One of the most common is emissions from Part 15 devices that become coupled to the cable TV coax shield in some way. Non-leakage noise or spurious signals may radiate from the cable TV lines or an amplifier location, but only because the outer surface of the cable shield is carrying the coupled interference as a common-mode current.

When interference from what sounds like a discrete carrier in the downstream spectrum is received, note the frequency and compare it to known analog TV channel visual and aural carrier frequencies. Consider the following example in which an interfering signal is being heard in the 70 cm Amateur band and it falls within cable channel 60 (438-444 MHz). When a cable operator carries an analog TV channel that complies with the STD channel frequency plan (Table 27.3), the visual carrier is at 439.25 MHz. The aural carrier falls 4.5 MHz above the visual carrier, or 443.75 MHz. If the cable operator were using HRC channelization rather than STD channelization, channel 60's visual carrier would be at 438.0219 MHz and its aural carrier at 442.5219 MHz. Can you hear anything at either visual carrier frequency? What about the aural carrier frequencies? Since the visual carrier is the strongest part of an analog TV channel, that's the best place to listen for leakage.

The color subcarrier of STD channel 60 falls at 439.25 + 3.58 = 442.83 MHz, but this is a double sideband suppressed carrier. There are horizontal sidebands spaced every 15.734 kHz from the visual carrier (and also from the color subcarrier), but these are generally very low level. Analog TV channel visual carriers use AM, and the aural carriers use FM. If the interference is from the aural carrier of an analog TV channel, you may be able to hear the channel's audio. If the interfering carrier does not fall on expected cable frequencies, it may not be leakage.

A common non-leakage interference that may radiate from a cable network is broadband electrical interference or other noise in the MF and lower end of the HF spectrum. A common misconception is that since cable companies carry digital signals on frequencies that overlap portions of the over-the-air spectrum below 30 MHz, any "noise" that radiates from the cable plant must be leaking digital signals. This type of interference is almost always power-line electrical interference or other noise that is coupled to the cable network's shield as a common-mode signal.

Upstream digital signals from cable modems, which have channel bandwidths of 1.6, 3.2 or 6.4 MHz, are typically transmitted in the roughly 20 to 40 MHz range, and are bursty in nature rather than continuous like downstream digital signals. Set-top box upstream telemetry carriers are narrowband frequency shift keying (FSK) or quadrature phase shift keying (QPSK) carriers usually in the approximately 8 to 11 MHz range. This type of interference may respond to common-mode chokes. Radiated non-leakage noise-like interference from the outside of the hardline coaxial cables that happens outdoors, affecting MF and/or HF reception in the neighborhood, cannot be fixed using chokes. The source of the interference must be identified and repaired. A little RFI detective work may be necessary. Refer to the various RFI troubleshooting sections of this chapter.

If normal leakage troubleshooting techniques do not clearly identify the source of the interference, sometimes the cable company may temporarily shut off its network in the affected neighborhood. If the interference remains after the cable network is turned off, it is not leakage, and the cable company is not responsible for that type of interference. If the interference disappears when the cable network is turned off, then it most likely is leakage or something related to the cable network. Turning off even a small portion of the cable network is a last resort and may not be practical because of the service disruption to subscribers. It may be easier for the cable company to temporarily shut off a suspect cable channel briefly. Here, too, if the interference remains after the channel is turned off, the interference is not leakage.

HOW TO REPORT LEAKAGE

If you suspect cable signal leakage is causing interference to your Amateur station, *never attempt your own repairs to any part of the cable network, even the cabling in your own home*! Document what you have observed. For instance, note the frequency or frequencies involved, the nature of the interference, any changes to the interference with time of day, how long it has been occurring, and so forth. If you have fox-hunting skills and equipment, you might note the probable source(s) of the interference or at least the direction from which it appears to be originating.

Next, contact the cable company. You will most likely reach the cable company's customer service department, but ask to speak with the local cable system's Plant Manager (may also be called Chief Engineer, Director of Engineering, Chief Tech, VP of Engineering, or similar), and explain to him or her that you are experiencing what you believe to be signal leakage-related interference. If you cannot reach this individual, ask that a service ticket be created, and a technician familiar with leakage and ingress issues be dispatched. Share the information you have gathered about the interference. And as with all RFI issues, remember diplomacy!

In the vast majority of cases when cable leakage interference to Amateur Radio occurs, it is able to be taken care of by working with local cable system personnel. Every now and then for whatever reason, the affected ham is unable to get the interference resolved locally. Contact the ARRL for help in these cases.

27.8.5 DVD and Video Players

A DVD or similar video player usually contains a television tuner or has a TV channel output. It is also connected to an antenna or cable system and the ac line, so it is subject to all of the interference problems of a TV receiver. Start by proving that the video player is the susceptible device. Temporarily disconnect the device from the television or video monitor. If there is no interference to the TV, then the video player is the most likely culprit.

Next, find out how the interfering signal is getting into the video player. Temporarily disconnect the antenna or cable feed line from the video player. If the interference goes away, then the antenna line is involved. In this case, you can probably fix the problem with a common-mode choke or high-pass filter.

Fig 27.21 shows a bulletproof video player installation. If you have tried all of the cures shown and still have a problem, the player is probably subject to direct pickup. In this case, contact the manufacturer through the EIA.

Some analog-type VCRs are quite susceptible to RFI from HF signals. The video baseband signal extends from 30 Hz to 3.5 MHz, with color information centered around 3.5 MHz and the FM sound subcarrier at 4.5 MHz. The entire video baseband is frequency modulated onto the tape at frequencies up to 10 MHz. Direct pickup of strong signals by VCRs is a common problem and may not be easily solved, short of replacing the VCR with a better-shielded model.

27.8.6 Non-radio Devices

Interference to non-radio devices is not the fault of the transmitter. (A portion of the *FCC Interference Handbook,* 1990 Edition, is shown in **Fig 27.24**. Although the FCC no longer offers this *Handbook*, an electronic version is available from ARRL at **www.arrl.org/files/file/Technology/FCC RFI Information/tvibook.pdf**.) In essence, the FCC views non-radio devices that pick up nearby radio signals as improperly functioning; contact the manufacturer and return the equipment. The FCC does not require that non-radio devices include RFI protection and they don't offer legal protection to users of these devices that are susceptible to interference.

TELEPHONES

Telephones have probably become the number one, non-TVI interference problem of Amateur Radio. However, most cases of telephone interference can be cured by correcting any installation defects and installing telephone RFI filters where needed.

Telephones can improperly function as radio receivers. Semiconductor devices inside many telephones act like diodes. When such a telephone is connected to the telephone wiring (a large antenna) an AM radio receiver can be formed. When a nearby transmitter goes on the air, these telephones can be affected.

Troubleshooting techniques were discussed earlier in the chapter. The suggestion to simplify the problem applies especially to telephone interference. Disconnect all telephones except one, right at the service entrance if possible, and start troubleshooting the problem there.

If any single device or bad connection in the phone system detects RF and puts the detected signal back onto the phone line as audio, that audio cannot be removed with filters. Once the RF has been detected and turned into audio, it cannot be filtered out because the interference is at the same frequency as the desired audio signal. To effect a cure, you must locate the detection point and correct the problem there.

Defective telephone company lightning arrestors can act like diodes, rectifying any nearby RF energy. Telephone-line amplifiers or other electronic equipment may also be at fault. Do not attempt to diagnose or repair any telephone company wiring or devices on the "telco" side of your service box or that were installed by the phone company. Request a service call from your phone company.

Inspect the telephone system installation. Years of exposure in damp basements, walls or crawl spaces may have caused deterioration. Be suspicious of anything that is corroded or discolored. In many cases, homeowners have installed their own telephone

PART II

INTERFERENCE TO OTHER EQUIPMENT

CHAPTER 6

TELEPHONES, ELECTRONIC ORGANS, AM/FM RADIOS, STEREO AND HI-FI EQUIPMENT

Telephones, stereos, computers, electronic organs and home intercom devices can receive interference from nearby radio transmitters. When this happens, the device improperly functions as a radio receiver. Proper shielding or filtering can eliminate such interference. The device receiving interference should be modified in your home while it is being affected by interference. This will enable the service technician to determine where the interfering signal is entering your device.

The device's response will vary according to the interference source. If, for example, your equipment is picking up the signal of a nearby two-way radio transmitter, you likely will hear the radio operator's voice. Electrical interference can cause sizzling, popping or humming sounds.

Fig 27.24 — Part of page 18 from the FCC *Interference Handbook* (1990 edition) explains the facts and places responsibility for interference to non-radio equipment.

wiring, often using substandard wiring. If you find sections of telephone wiring made from nonstandard cable, replace it with standard twisted-pair telephone or CAT5 cable. If you do use telephone cable, be sure it is high-quality twisted-pair to minimize differential-mode pickup of RF signals.

Next, evaluate each of the telephone instruments. If you find a susceptible telephone, install a telephone RFI filter on that telephone, such as those sold by K-Y Filters. (**www.ky-filters.com**) If the home uses a DSL broadband data service, be sure that the filters do not affect DSL performance by testing online data rates with and without a filter installed at the telephone instrument.

If you determine that you have interference only when you operate on one particular ham band, the telephone wiring is probably resonant on that band. Install common-mode chokes on the wiring to add a high impedance in series with the "antenna." A telephone RFI filter may also be needed. (See the section on DSL Equipment for filtering suggestions.)

Telephone Accessories — Answering machines and fax machines are also prone to interference problems. All of the troubleshooting techniques and cures that apply to telephones also apply to these telephone devices. In addition, many of these devices connect to the ac mains. Try a common-mode choke and/or ac-line filter on the power cord (which may be an ac cord set, a small transformer or power supply).

Cordless Telephones — A cordless telephone is an unlicensed *radio* device that is manufactured and used under Part 15 of the FCC regulations. The FCC does not intend Part 15 devices to be protected from interference. These devices usually have receivers with very wide front-end filters, which make them very susceptible to interference.

A likely path for interference to cordless phones is as common-mode current on the base unit's connecting cables that will respond to common-mode chokes. In addition, a telephone filter on the base unit and an ac line filter may help. The best source of help is the manufacturer but they may point out that the Part 15 device is not protected from interference.

Cordless phone systems operating at 900 MHz and higher frequencies are often less susceptible to interference than older models that use 49 MHz. It may be easiest to simply replace the system with a model less susceptible to interference.

AUDIO EQUIPMENT

Consumer and commercial audio equipment such as stereos, home entertainment systems, intercoms and public-address systems can also pick up and detect strong nearby transmitters. The FCC considers these non-radio devices and does not protect them from licensed radio transmitters that may interfere with their operation. The RFI can be caused by one of several things: pickup on speaker leads or interconnecting cables, pickup by the ac mains wiring or direct pickup. If the interference involves wiring connected to the affected device, common-mode chokes are the most likely solution.

Use the standard troubleshooting techniques discussed earlier in this chapter to isolate problems. In a multi-component home entertainment system (as in **Fig 27.25**), for example, you must determine what combination of components is involved with the problem. First, disconnect all auxiliary components to determine if there is a problem with the main receiver/amplifier. Long speaker or interconnect cables are prime suspects.

Stereos and Home Entertainment Systems — If the problem remains with the main amplifier isolated, determine if the interference level is affected by the volume control. If so, the interference is getting into the circuit *before* the volume control, usually through accessory wiring. If the volume control has no effect on the level of the interfering sound, the interference is getting in *after* the control, usually through speaker wires.

Speaker wires are often effective antennas on HF and sometimes into VHF and above. The speaker terminals are often connected directly to the output amplifier transistors. Modern amplifier designs use a negative feedback loop to improve fidelity. This loop can conduct the detected RF signal back to the high-gain stages of the amplifier. The combination of all of these factors often makes the speaker cables the dominant receiving antenna for RFI.

There is a simple test that will help determine if the interfering signal is being coupled into the amplifier by the speaker leads. Temporarily disconnect the speaker leads from the amplifier, and plug in a test set of headphones with short leads. If there is no interference with the headphones, filtering the speaker leads will likely cure the problem.

Start by applying common-mode chokes. **Fig 27.26** shows how to wrap speaker wires around an large (2-inch O.D. or larger) ferrite core to cure speaker-lead RFI. Type 31 material is preferred at HF. (See the section on Common-Mode Chokes in this chapter.)

In some cases, the speaker wires may be picking up RF as a differential-mode signal. To reduce differential-mode pickup, replace the zip cord speaker wire with twisted-pair wire. (#16 AWG will work for most systems with higher-power systems requiring #12 AWG.)

Powered Speakers — A powered speaker is one that has its own built-in power amplifier. Powered subwoofers are common in home entertainment systems and small powered speakers are often used with computer and gaming systems. If a speaker runs on batteries and/or an external power supply, or is plugged into mains power, it is a powered loudspeaker. Powered loudspeakers are notoriously susceptibility to common-mode interference from internally misconnected cable shields and poor shielding. Apply suitable common-mode chokes to all wiring, including power wiring. If the RFI persists, try an RF filter at the input to the speaker, such as the LC low-

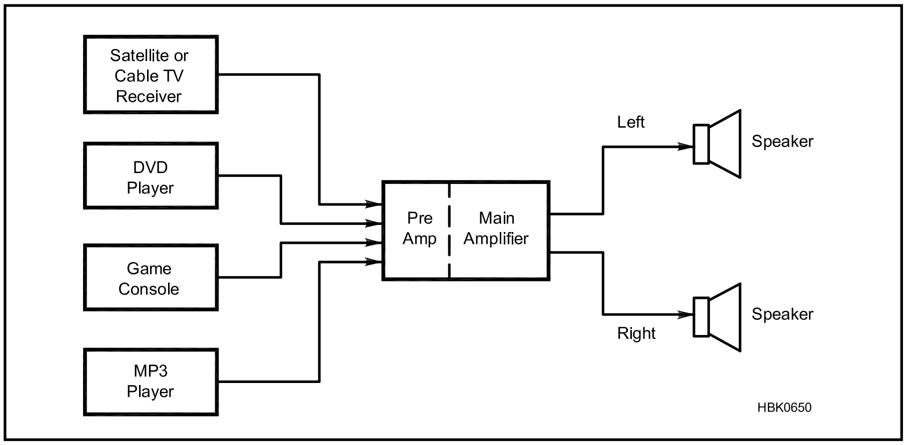


Fig 27.25 — A typical modern home-entertainment system.

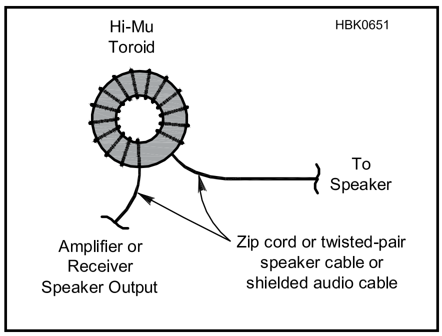


Fig 27.26 — Making a speaker-lead common-mode choke. Use ferrite material appropriate for the frequency of the RF interference.

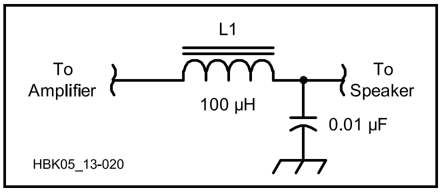


Fig 27.27 — A low-pass LC filter.

pass filter in **Fig 27.27**. Unshielded speakers may not be curable, however.

Intercoms and Public-Address Systems — RFI to these systems is nearly always caused by common-mode current on interconnect wiring. Common-mode chokes are the most likely cure, but you may also need to contact the manufacturer to see if they have any additional, specific information. Wiring can often be complex, so any work on these systems should be done by a qualified sound contractor.

COMPUTERS AND OTHER UNLICENSED RF SOURCES

Computers and microprocessor-based devices such as video games or audio players can be sources or victims of interference. These devices contain oscillators that can and do radiate RF energy. In addition, the internal functions of a computer generate different frequencies, based on the various data signals. All of these signals are digital — with fast rise and fall times that are rich in harmonics.

Computing devices are covered under Part 15 of the FCC regulations as unintentional emitters. As for any other unintentional emitter, the FCC has set absolute radiation limits for these devices. As previously discussed in this chapter, FCC regulations state that the operator or owner of Part 15 devices must take whatever steps are necessary to reduce or eliminate any interference they cause to a licensed radio service. This means that if your neighbor's video game interferes with your radio, the neighbor is responsible for correcting the problem. (Of course, your neighbor may appreciate your help in locating a solution!)

The FCC has set up two tiers of limits for computing devices. Class A is for computers used in a commercial environment. FCC Class B requirements are more stringent — for computers used in residential environments. If you buy a computer or peripheral, be sure that it is Class B certified or it will probably generate interference to your amateur station or home-electronics equipment.

If you find that your computer system is interfering with your radio (not uncommon in this digital-radio age), start by simplifying the problem. Temporarily remove power from as many peripheral devices as possible and disconnect their cables from the back of the computer. (It is necessary to physically

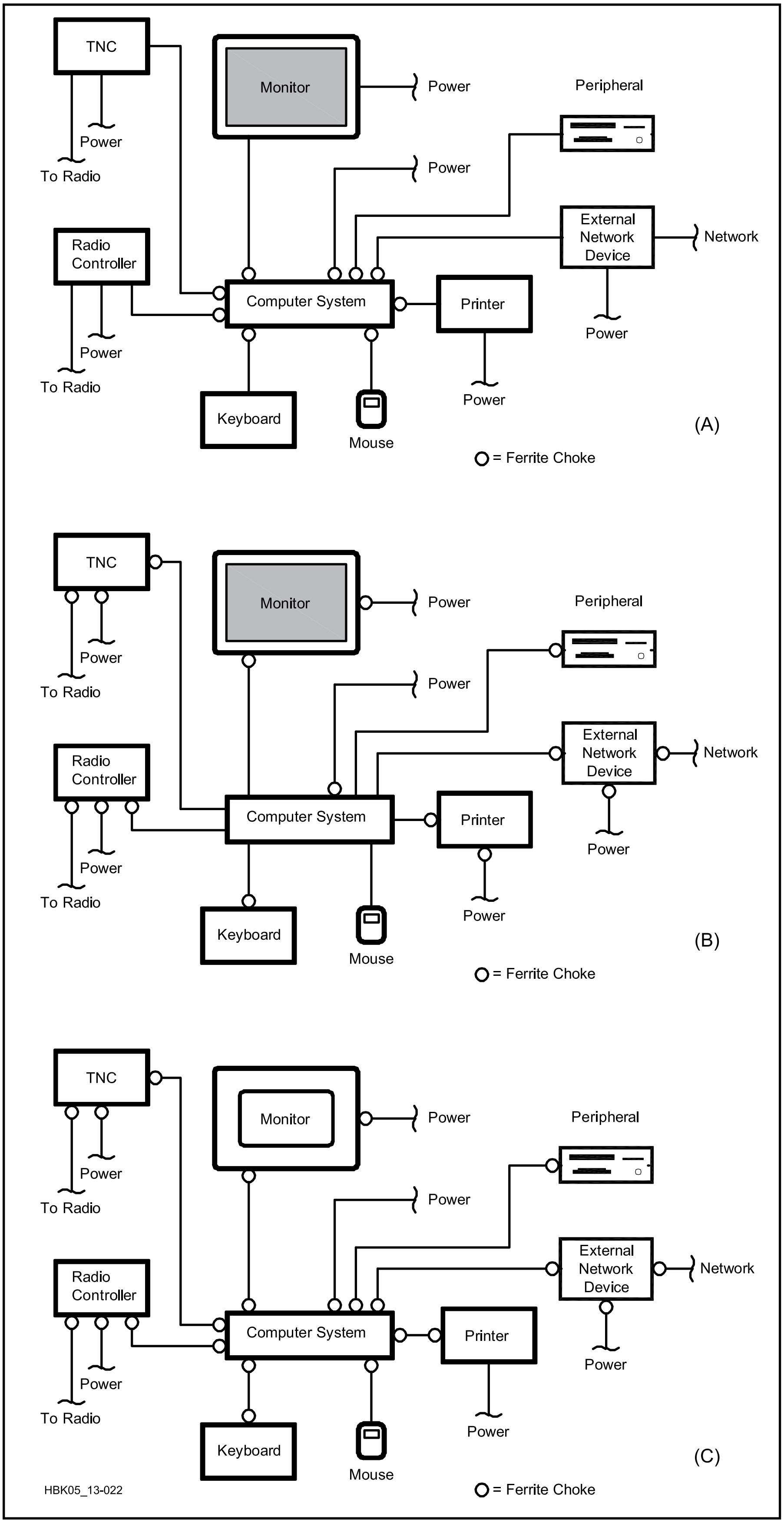


Fig 27.28 — Where to locate ferrites in a computer system. At A, the computer is noisy, but the peripherals are quiet. At B, the computer is quiet, but external devices are noisy. At C, both the computer and externals are noisy.

remove the power cable from the device, since many devices remain in a low-power state when turned off from the front panel or by a software command.) If possible, use just the computer, keyboard and monitor. This test may identify specific peripherals as the source of the interference.

Ensure that all peripheral connecting cables are shielded. Replace any unshielded cables with shielded ones; this often significantly reduces RF noise from computer systems. The second line of defense is the common-mode choke. The choke should be installed as close to the computer and/or peripheral device as practical. **Fig 27.28** shows the location of common-mode chokes in a complete computer system where both the computer and peripherals are noisy.

Switchmode power supplies in computers are often sources of interference. A common-mode choke and/or ac-line filter may cure this problem. In extreme cases of computer interference you may need to improve the shielding of the computer. (Refer to the *ARRL RFI Book* for more information about this.) Don't forget that some peripherals (such as modems) are connected to the phone line, so you may need to treat them like telephones.

27.9 Automotive RFI

Automobiles have evolved from a limited number of primitive electrical components to high technology, multi-computer systems on-wheels. Every new technology deployed can potentially interfere with amateur equipment.

Successful mobile operation depends on a multitude of factors such as choosing the right vehicle, following installation guidelines, troubleshooting and deploying the appropriate RFI fixes as needed.

A number of these factors will be covered in this section. Additionally, newly emerging electrical and hybrid-electric vehicles will be discussed, which pose unique challenges to amateur equipment installations and operation.

27.9.1 Before Purchasing a Vehicle

When shopping for a new vehicle intended for a mobile amateur installation, begin with research. A wealth of information is available on the Internet, and specifically at **www.arrl.org/automotive**, where the ARRL has compiled years of data from automotive manufacturers and other hams. Email reflectors and Web sites may provide information from hams willing to share their experiences concerning mobile communications in their own vehicles that may be the very make and model you were considering.

Armed with research, your next stop is your dealer. The manufacturer of each vehicle is the expert on how that vehicle will perform. The dealer should have good communication with the manufacturer and should be able to answer your questions. Ask about service bulletins and installation guidelines. You can also ask your dealer about fleet models of their vehicles. Some manufacturers offer special modifications for vehicles intended for sale to police, taxicabs and other users who will be installing radios (usually operating at VHF and UHF) in their cars.

When shopping for a vehicle, it is useful to take along some portable (preferably battery operated) receivers or scanners and have a friend tune through your intended operating frequencies while you drive the vehicle. This will help identify any radiated noise issues associated with that model vehicle, which can be more difficult to resolve than conducted noise. If you intend to make a permanent transceiver installation, give some consideration to how you will mount the transceiver and route the power and/or antenna cables. While looking for ways to route the wiring, keep in mind that some newer cars have the battery located in the trunk or under the rear seat, and that may make power wire routing easier.

Test the car before you buy it. A dealer expects you to take the car for a test ride; a cooperative dealer may let you test it for radio operation, too. A fair amount of checking can easily be performed without digging too deeply into the car. Check the vehicle for noise with a portable receiver on VHF, where your handheld transceiver will do the job nicely. On HF, you can usually locate noise with a portable short-wave receiver, or operate your HF transceiver with a portable antenna and cigarette-lighter plug. With the engine running, tune across the bands of interest. You may hear some noise, or a few birdies, but if the birdies don't fall on your favorite frequency, this is an encouraging sign! Check with the vehicle completely off, with the key in the ignition, and with the vehicle running — electronic subsystems operate in different ways with the vehicle running or not running.

To test the vehicle for susceptibility to your transmitted signal, you must transmit. It is important to note that without a full and complete installation, you will not be able to fully assess the effects of full-power transmissions on a vehicle. Any testing done with temporary equipment installations cannot be considered an absolute guarantee because an installed transmitter connected directly to the vehicle's power source may cause the vehicle to act differently.

To perform transmit tests, bring your radio and a separate battery (if permitted by dealer) so you can transmit at full power while in motion without having to run cables to the vehicle battery. Use a magnet-mount antenna (several *QST* advertisers sell mounts suitable for HF) for temporary testing. (Use the magnet-mount carefully; it is possible to scratch paint if any particles of dirt get on the bottom of the magnets.) Transmit on each band you will use to see if the RF has any effect on the vehicle. Lack of response to your transmissions is a good sign, but does not mean the vehicle is immune to RF as a permanent installation will result in different (likely stronger) field strengths and distributions in and around the vehicle and a permanent antenna more effectively coupled to the vehicle.

On both transmit and receive, you may want to experiment with the placement of the antenna. Antenna placement plays an important role in operation, and you may be able to find an optimal location for the antenna that predicts good performance with a permanent installation.

27.9.2 Transceiver Installation Guidelines

While most amateurs are familiar with the process of installing a transceiver, there are preferred practices that will help minimize potential problems. These include support from the automotive dealer, typical "best practices" installations, and consideration of special situations.

The first step is to ensure that your installation complies with both the vehicle manufacturer's and radio transceiver manufacturer's installation guidelines. Links to domestic automotive manufacturer installation guidelines are found at **www.arrl.org/automotive**. Automotive manufacturers that import vehicles for sale here do not publish installation guidelines because their vehicles are not typically used in police, fire and taxicab applications within the US.

The installation guidelines of different manufacturers vary as to how to install a radio transceiver's power leads. Most manufacturers recommend that the positive and negative leads from the radio be run directly to the battery. This minimizes the potential for the interaction between the radio's negative lead currents and vehicle electronics. If the manufacturer recommends that both wires be connected to the battery, they will also require that both wires be fused. This is necessary because, in the unlikely event that the connection between the battery and the engine block were to fail, excessive current could be drawn on the radio's negative lead when the vehicle starter is engaged.

Some vehicles provide a "ground block" near the battery for a negative cable to be connected. On these vehicles, run the negative power lead, un-fused, to the "ground block." When this technique is recommended by the manufacturer, the interaction between the power return currents and vehicle electronics has been evaluated by the manufacturer. In all cases, the most important rule to remember is this: If you want the manufacturer to support your installation, do it exactly the way the installation guidelines tell you to do it!

If no installation guidelines are available for your vehicle, the practices outlined below will improve compatibility between in-vehicle transceivers and vehicle electronics:

1) Transceivers

• Transceivers should be mounted in a location that does not interfere with vehicle operator controls and visibility, provides transceiver ventilation, and be securely mounted.

• Ensure all equipment and accessories are removed from the deployment path of the airbag and safety harness systems.

2) Power Leads

• The power leads should be twisted together from the back of the rig all the way to the battery. This minimizes the area formed by the power leads, reducing susceptibility to transients and RFI.

• Do not use the vehicle chassis as a power return.

• The power leads should be routed along the body structure, away from vehicle wiring harnesses and electronics.

• Any wires connected to the battery should be fused at the battery using fuses appropriate for the required current.

• Use pass-through grommets when routing wiring between passenger and engine compartments.

• Route and secure all under hood wiring away from mechanical hazards.

3) Coaxial Feed Lines

• The coaxial feed line should have at least 95% braid coverage. The cable shield should be connected to every coaxial connector for the entire circumference (no "pigtails").

• Keep antenna feed lines as short as practical and avoid routing the cables parallel to vehicle wiring.

4) Antennas

• Antenna(s) should be mounted as far from the engine and the vehicle electronics as practical. Typical locations would be the rear deck lid or roof. Metal tape can be used to provide an antenna ground plane on non-metallic body panels.

• Care should be used in mounting antennas with magnetic bases, since magnets may affect the accuracy or operation of the compass in vehicles, if equipped.

• Since the small magnet surface results in low coupling to the vehicle at HF, it is likely that the feed line shield will carry substantial RF currents. A large (2-inch OD or larger toroid) common-mode choke at the antenna will help reduce this current, but will also reduce any radiation produced by that current.

• Adjust the antenna for a low SWR.

27.9.3 Diagnosing Automotive RFI

Most VHF/UHF radio installations should result in no problems to either the vehicle systems or the transceiver, while HF installations are more likely to experience problems. In those situations where issues do occur, the vast majority are interference to the receiver from vehicle on-board sources of energy that are creating emissions within the frequency bands used by the receiver. Interference to one of the on-board electronic systems can be trivial or it can cause major problems with an engine control system.

The dealer should be the first point of contact when a problem surfaces, because the dealer should have access to information and factory help that may solve your problem. The manufacturer may have already found a fix for your problem and may be able to save your mechanic a lot of time (saving you money in the process). If the process works properly, the dealer/customer-service network can be helpful. In the event the dealer is unable to solve your problem, the next section includes general troubleshooting techniques you can perform independently.

GENERAL TROUBLESHOOTING TECHNIQUES

An important aspect is to use the source-path-victim model presented earlier in this chapter. The path from the source to the receiver may be via radiation or conduction. If the path is radiation, the electric field strength (in V/m) received is reduced as a function of the distance from the source to the receiver. In most cases, susceptible vehicle electronics is in the near-field region of the radiating source, where the electric and magnetic fields can behave in complex ways. In general, however, the strength of radiated signals falls off with distance.

The best part of all this is that with a general-coverage receiver or spectrum analyzer, a fuse puller and a shop manual, the vehicle component needing attention may be identified using a few basic techniques. The only equipment needed could be as simple as:

• A mobile rig, scanner or handheld transceiver, or

• Any other receiver with good stability and an accurate readout, and

• An oscilloscope for viewing interference waveforms

BROADBAND NOISE

Automotive broadband noise sources include:

• Electric motors such as those that operate fans, windows, sunroof, AM/FM antenna deployment, fuel pumps, etc.

• Ignition spark

If you suspect electric motor noise is the cause of the problem, obtain a portable AM or SSB receiver to check for this condition. Switch on the receiver and then activate the electric motors one at a time. When a noisy motor is switched on, the background noise increases. It may be necessary to rotate the radio, since portable AM radios use a directional ferrite rod antenna.

To check whether fuel pumps, cooling fans, and other vehicle-controlled motors are the source of noise, pull the appropriate fuse and see whether the noise disappears.

A note concerning fuel pumps: virtually every vehicle made since the 1980s has an electric fuel pump, powered by long wires. It may be located inside the fuel tank. Don't overlook this motor as a source of interference just because it may not be visible. Electric fuel-pump noise often exhibits a characteristic time pattern. When the vehicle ignition switch is first turned on, without engaging the starter, the fuel pump will run for a few seconds, and then shut off when the fuel system is pressurized. At idle, the noise will generally follow the pattern of being present for a few seconds before stopping, although in some vehicles the fuel pump will run almost continuously if the engine is running.

NARROWBAND NOISE

Automotive narrowband noise sources include:

- Microprocessor based engine control systems
- Instrument panel
- RADAR obstacle detection
- Remote keyless entry
- Key fob recognition systems
- Tire pressure monitoring systems
- Global positioning systems
- Pulse width modulating motor speed controls
- Fuel injectors
- Specialized electric traction systems found in newer hybrid/electric vehicles

Start by moving the antenna to different locations. Antenna placement is often key to resolving narrowband RFI problems. However, if antenna location is not the solution, consider pulling fuses. Tune in and stabilize the noise, then find the vehicle fuse panels and pull one fuse at a time until the noise disappears. If more than one module is fed by one fuse, locate each module and unplug it separately. Some modules may have a "keep-alive" memory that is not disabled by pulling the fuse. These modules may need to be unplugged to determine whether they are the noise source. Consult the shop manual for fuse location, module location, and any information concerning special procedures for disconnecting power.

A listening test may verify alternator noise, but if an oscilloscope is available, monitor the power line feeding the affected radio. Alternator whine appears as full-wave rectified ac ripple and rectifier switching transients superimposed on the power system's dc power voltage (see **Fig 27.29**).

Alternators rely on the low impedance of the battery for filtering. Check the wiring from the alternator output to the battery for corroded contacts and loose connectors when alternator noise is a problem.

Receivers may allow conducted harness noise to enter the RF, IF or audio sections (usually through the power leads), and interfere with desired signals. Check whether the interference is still present with the receiver powered from a battery or power supply instead of from the vehicle. If the interference is no longer present when the receiver is operating from a battery or external supply, the interference is conducted via the radio power lead. Power line filters installed at the radio may resolve this problem.

27.9.4 Eliminating Automotive RFI

The next section includes various techniques to resolve the more common RFI problems. As a caveat, performing your own RFI work, in or out of warranty, you assume the same risks as you do when you perform any other type of automotive repair. Most state laws (and common sense) say that those who work on cars should be qualified to do so. In most cases, this means that work should be done either by a licensed dealer or automotive repair facility.

CONDUCTED INTERFERENCE

To reduce common-mode current, impedance can be inserted in series with the wiring in the form of common-mode chokes. (See this chapter's section on Common-Mode Chokes.) Wire bundles may also be wound around large toroids for the same effect.

Mechanical considerations are important in mobile installations. A motor vehicle is subject to a lot of vibration. If a choke is installed on a wire, this vibration may cause the choke to flex the wire, which may ultimately fail. It is critical that any additional shielding and/or chokes placed on wiring have been installed by qualified personnel who have considered these factors. These must be properly secured, and sometimes cable extenders are required to implement this fix.

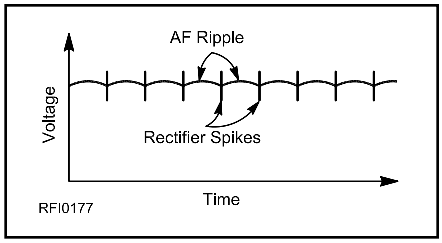


Fig 27.29 — Alternator whine consists of full-wave rectified ac, along with pulses from rectifier switching, superimposed on the vehicle's dc power voltage.

RFI TO ON-BOARD CONTROL SYSTEMS

RFI to a vehicle's on-board control and electronic modules should be treated with common-mode chokes at the connection to the module. Some success has been reported by using braid or metal foil to cover a wire bundle as a shield and connecting the shield to the vehicle chassis near the affected module. Vehicle electronic units should not be modified except by trained service personnel according to the manufacturer's recommendations. The manufacturer may also have specific information available in the form of service bulletins.

FILTERS FOR DC MOTORS

If the motor is a conventional brush- or commutator-type dc motor, the following cures shown in **Fig 27.30** are those generally used. As always, the mechanic should consult with the vehicle manufacturer. To diagnose motor noise, obtain an AM or SSB receiver to check the frequency or band of interest. Switch on the receiver, and then activate the electric motors one at a time. When a noisy motor is switched on, the background noise increases as well.

The pulses of current drawn by a brush-commutator motor generate broadband RFI that is similar to ignition noise. However, the receiver audio sounds more like bacon frying rather than popping. With an oscilloscope displaying receiver audio, the noise appears as a series of pulses with random space between the pulses. Such broadband noise generally has a more pronounced effect on AM receivers than on FM. Unfortunately, the pulses may affect FM receivers by increasing the "background noise level" and will reduce perceived receiver sensitivity because of the degraded signal-to-noise ratio.

ALTERNATOR AND GENERATOR NOISE

As mentioned previously, brush-type motors employ sliding contacts which can generate noise. The resulting spark is primarily responsible for the "hash" noise associated with these devices. Hash noise appears as overlapping pulses on an oscilloscope connected to the receiver audio output. An alternator also has brushes, but they do not interrupt current. They ride on slip rings and supply a modest current, typically 4 A to the field winding. Hence, the hash noise produced by alternators is relatively minimal.

Generators use a relay regulator to control field current and thus output voltage. The voltage regulator's continuous sparking creates broadband noise pulses that do not overlap in time. They are rarely found in modern automobiles.

Alternator or generator noise may be conducted through the vehicle wiring to the power

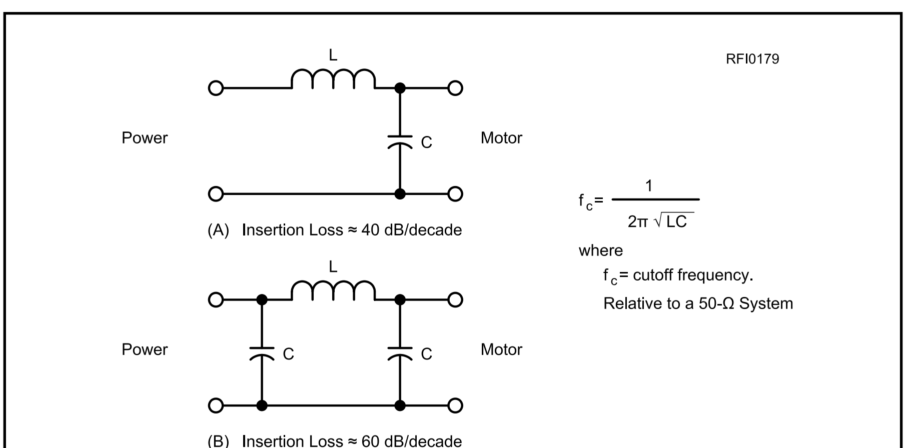


Fig 27.30 — Filters for reducing noise from dc motors

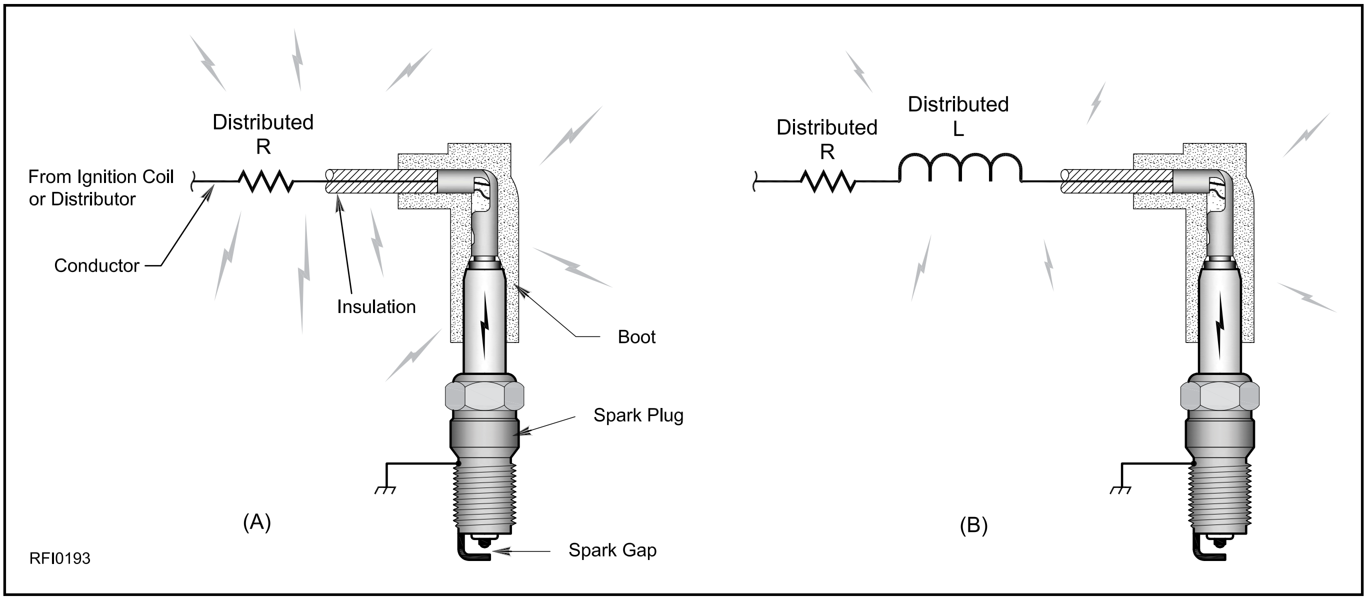


Fig 27.31 — Ignition noise suppression methods.

input of mobile receivers and transmitters and may then be heard in the audio output. If alternator or generator noise is suspected and an oscilloscope is not available, temporarily remove the alternator belt as a test. (This may not be possible in vehicles with a serpentine belt.)

IGNITION NOISE

Ignition noise is created by fast-rise-time pulses of coil current discharging across air gaps (distributor and spark plug). The theoretical models (zero rise time) of such pulses are called impulse functions in the time domain. When viewed in the frequency domain, the yield is a constant spectral energy level starting nearly at 0 Hz and theoretically extending up in frequency to infinity. In practice, real ignition pulses have a finite rise time, so the spectral-energy envelope decreases above some frequency.

It turns out that noise generated by ignition sparks and fuel injector activation manifest themselves as a regular, periodic "ticking" in the receiver audio output, which varies with engine RPM. If an oscilloscope were connected to the audio output, a series of distinct, separate pulses would appear. At higher speeds it sounds somewhat musical, like alternator whine, but with a harsher note (more harmonic content).

A distinguishing feature of ignition noise is that it increases in amplitude under acceleration. This results from the increase in the required firing voltage with higher cylinder pressure. (Noise at higher frequencies may also be reproduced better by the audio circuits.) Since ignition noise is usually radiated noise, it should disappear when the antenna element is disconnected from the antenna mount. The radiation may be from either the secondary parts of the system or it may couple from the secondary to the primary of the coil and be conducted for some distance along the primary wiring to the ignition system, then radiated from the primary wiring.

Two main methods are employed to suppress this noise — one involves adding an inductance, and the other involves adding a resistance — both in the secondary (high voltage) wiring. This is shown in **Fig 27.31**. The addition of these elements does not have a measurable effect on the engine operation, because the time constants involved in the combustion process are much longer than those associated with the suppression components. (Note that modifying your vehicle's ignition system may be considered as tampering with your vehicle's emission control system and may affect your warranty coverage — work with your dealer or limit your efforts to changing spark plug wires or possibly shielding them.)

The resistance method suppresses RFI by dissipating energy that would have been radiated and/or conducted. Even though the amount of energy dissipated is small, it is still enough to cause interference to sensitive amateur installations. The other method uses inductance and even though the energy is not dissipated, suppression occurs because the inductor will store the pulse energy for a short time. It then releases it into the ignition burn event, which is a low impedance path, reducing the RFI.

For traditional "Kettering" inductive discharge ignition systems, a value of about 5 kΩ impedance (either real and/or reactive) in the spark plug circuit provides effective suppression and, with this value, there is no detectable engine operation degradation. (Capacitor discharge systems, in comparison, are required to have very low impedance on the order of tens of ohms in order to not reduce spark energy, so they are not tolerant of series impedance). Most spark plug resistances are designed to operate with several kV across the plug gap, so a low-voltage ohmmeter may not give proper resistance measurement results.

The term "resistor wire" is somewhat misleading. High-voltage ignition wires usually contain both resistance and inductance. The resistance is usually built into suppressor spark plugs and wires, while there is some inductance and resistance in wires, rotors and connectors. The elements can be either distributed or lumped, depending on the brand, and each technique has its own merit. A side benefit of resistance in the spark plug is reduced electrode wear.

COIL-ON-PLUG IGNITION NOISE

Many newer spark-ignition systems incorporate a "coil on plug" (COP) or "coil near plug" (CNP) approach. There are advantages to this from an engine operation standpoint, and this approach may actually reduce some of the traditional sources of ignition system RFI. This is because of the very short secondary wires that are employed (or perhaps there are no wires — the coil is directly attached to the spark plug). This reduces the likelihood of coupling from the secondary circuit to other wires or vehicle/engine conductive structures.

There will always be some amount of energy from the spark event that will be conducted along the lowest impedance path. It may mean that the energy that would have been in the secondary circuit will be coupled back on the primary wiring harness attached to the coils.

This means that the problem may go from a radiated to a conducted phenomenon.

The fix for this in some cases may actually be easier or harder than one might think. Two approaches that have been used with success are ferrite cores and bypass capacitors.

Ferrite cores are recommended as the first choice, since they require no electrical modification to the vehicle. Ferrite clamp-on split cores are added to the 12-V primary harness attached to the coils. Depending on the frequency of the noise and selection of the ferrite material, there can be significant improvement (as much as 10 dB). Key to optimizing the amount of suppression is to determine where the noise "peaks" and selecting the correct ferrite material for that frequency range (see this chapter's section Using Ferrite for RFI Suppression).

The second method is to add a bypass capacitor between the primary wire of the 12-V coil and ground in the harness near the coil assemblies (there may be 2, 3 or 4 coils). This must be done carefully because it could affect the functionality of the ignition system and — perhaps most importantly — may void the vehicle warranty. This "bypass" capacitor performs the same function that bypass capacitors in any other application perform — separating the noise from the intended signal/power.

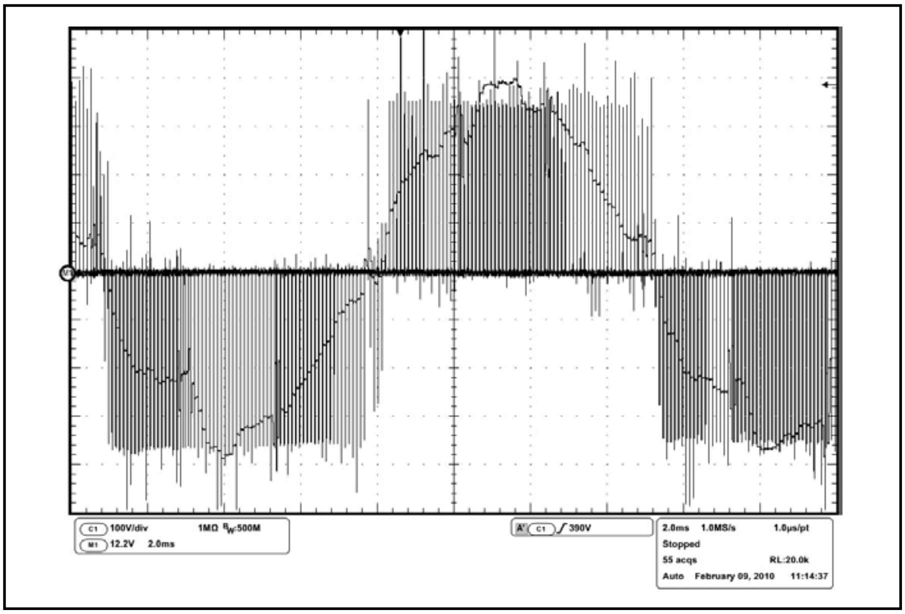


Fig 27.32 — Phase-to-phase motor terminal voltage.

27.9.5 Electric and Hybrid-Electric Vehicles

Electric vehicles (EV) and hybrid-electric vehicles (HEV) are quickly becoming a practical means of transportation. EV/HEVs are advanced vehicles that pose unique challenges for amateur equipment. While EV/HEVs provide improved emissions and fuel economy, EV/HEVs utilize switched high voltage and high current to control propulsion. The switching techniques used generate RFI within much of our frequency bands — a cause for concern, particularly for HF operation.

This section is designed to enlighten vehicle owners to the challenges and to make suggestions when installing mobile amateur equipments in an EV/HEV.

EV AND HEV ARCHITECTURE

Most EVs and HEVs have similar electrical traction system (ETS) architectures consisting of a high voltage battery supplying energy to an inverter which controls an electric motor within a transmission connected to the drive wheels. The main difference between the two is that an HEV includes an internal combustion engine to aid in propulsion and a pure EV is strictly electrically powered.

The heart of the ETS is a device called an inverter. It simply converts dc voltage from the high voltage battery (typical voltage range from 42 to 350 V dc) to an ac waveform supplying the electric motor. This dc-to-ac conversion is performed by a matrix of six transistor switches. The switches chop the dc voltage into systematically varying pulses called pulse-width-modulation (PWM) to form an adjustable frequency and RMS voltage suitable to power electric motor.

In most cases, the ac voltage from the inverter is a three-phase waveform similar to industrial applications because three-phase motors can be smaller, more efficient, and provide greater torque than single-phase motors.

IMPORTANT — Bright orange cables connect the battery pack to the inverter and the inverter to the drive motor, transferring voltage and current to and from the inverter. Because of the non-sinusoidal waveforms being transferred, these cables are shielded and terminated at each end. Under no condition should these cables be disconnected or modified, because the high voltage system depends on a delicate balance of sensors and safety mechanisms. Possible malfunction and damage to the ETS may occur if modified.

EV AND HEV RFI CONCERNS

The inverter uses PWM to convert dc battery voltage to an ac waveform. The phase-to-phase terminal voltage appears in **Fig 27.32** as rectangular blocks with positive and negative amplitude equal to the battery voltage. For example, a 350 V dc battery pack will provide 700 V peak-to-peak at the motor terminals. In Fig 27.32, the same terminal voltage signal is sent through a low pass filter to show how PWM forms a sinusoidal waveform. Each pulse is essentially a square wave. Harmonics from these pulses fall within most of our amateur HF bands, affecting radio performance. Because EV/HEV systems are evolving rapidly, check the ARRL's Automotive RFI Web page (**www.arrl.org/automotive**) for more information.

EV AND HEV RFI REMEDIES

Troubleshooting techniques described earlier apply in diagnosing RFI from EV/HEV systems. Limited RFI remedies are available associated to components within the ETS. Work with your dealer when you suspect the ETS as the RFI source. Do not attempt to modify or repair your ETS; the dealer's service center is most qualified to inspect and repair your EV/HEV electrical traction system.

During installation, mobile equipment power cables and antenna coaxial cables should be routed as far as possible from the bright orange cables. Common-mode chokes can decrease noise on 12-V dc power cables. Additionally, antenna placement plays a critical role in mobile equipment performance. Areas such as the top of a roof or trunk sometimes provide additional shielding.

27.9.6 Automotive RFI Summary

Most radio installations should result in no problems to either the vehicle systems or any issues with the transceiver. However, manufacturer, make and models differ, thus introducing challenges during amateur equipment installations.

Begin by researching your vehicle of interest and visiting the dealer. Insist on transmitting and receiving your favorite frequencies as you test drive. Request information pertaining to the manufacturer's transceiver installation guidelines. If manufacturer information is not available, follow the guidelines described earlier.

After installation, RFI problems may appear. Report you problem to the dealer, because they have access to manufacturer service bulletins which may describe a repair solution. Additional troubleshooting and remedies are also described previously to assist in successful communication.

Limited RFI remedies are available associated to components within the ETS. Work with your dealer when you suspect the ETS is the RFI source. Do not attempt to modify or repair your ETS; the dealer's service center is most qualified to inspect and repair your EV/HEV electrical traction system.

Lastly, the latest version of the *ARRL RFI Book* contains additional information on RFI in automobiles. More details are given about noise sources, troubleshooting techniques, a troubleshooting flow chart, additional filtering techniques, and information on EV/HEVs.

27.10 RFI Projects

Note: Additional RFI projects appear on the CD accompanying this book.

27.10.1 *Project*: RF Sniffer

Every home is full of electrical equipment capable of emitting electromagnetic radiation to interfere with radio amateurs trying to listen to signals on the bands. This project detects the radiation that causes problems to the amateur, and the noise can be heard. This device will allow you to demonstrate the "noise" with which we have to contend.

CONSTRUCTION

The circuit (**Fig 27.33**) uses a telephone pick-up coil as a detector, the output of which is fed into a LM741 IC preamplifier, followed by a LM386 IC power amplifier. See **Table 27.4** for the complete component list.

The project is built on a perforated board (**Fig 27.34**), with the component leads pushed through the holes and joined with hook-up wire underneath. There is a wire running around the perimeter of the board to form an earth bus.

Build from the loudspeaker backwards to

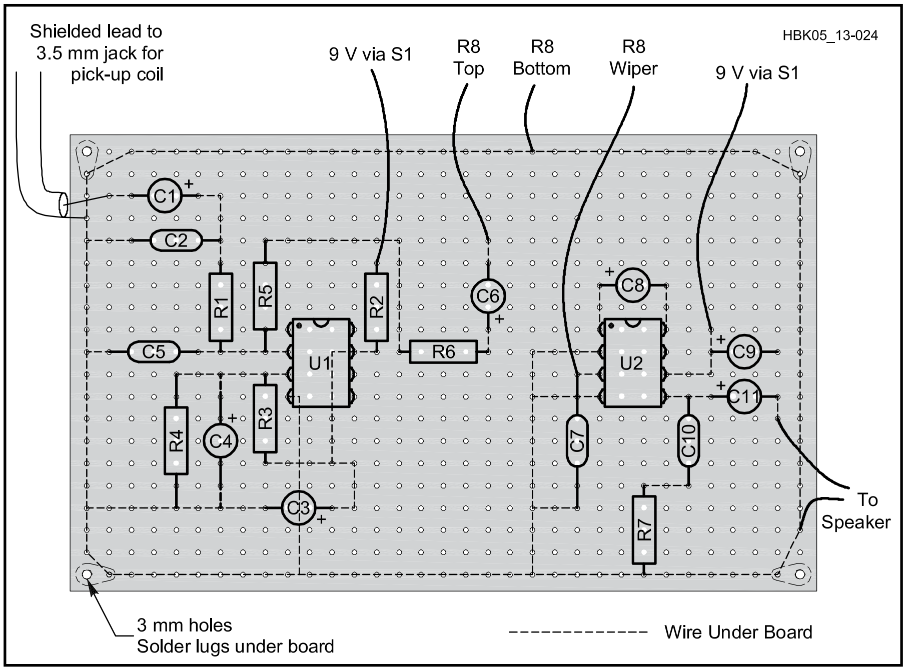


Fig 27.34 — The project is built on perforated board with point-to-point wiring underneath.

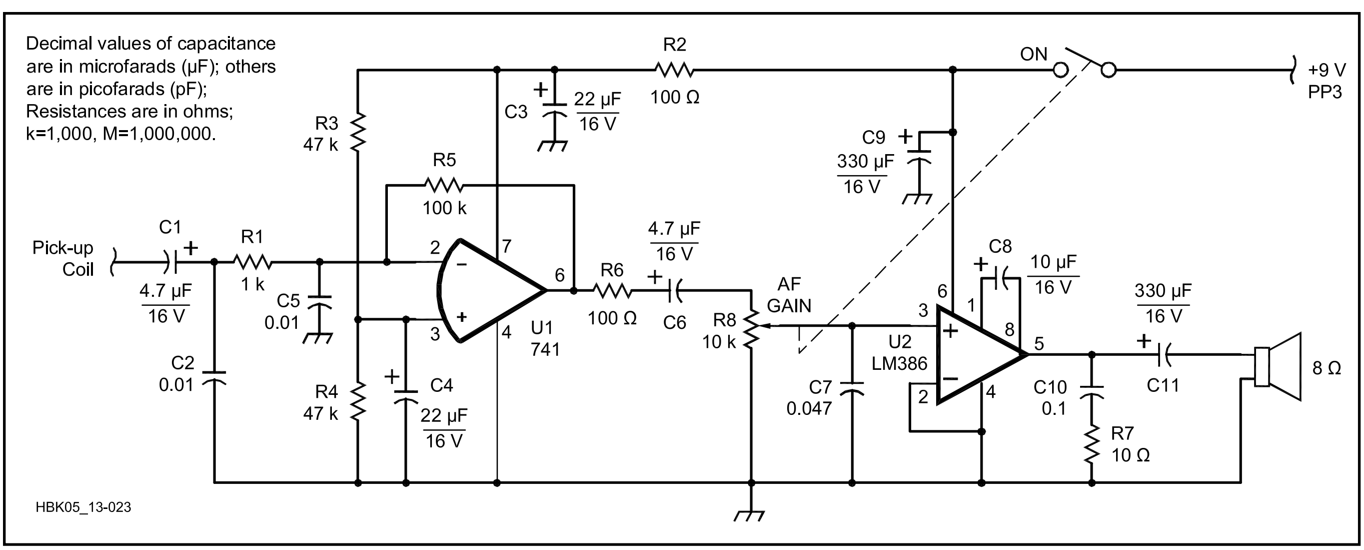


Fig 27.33 — The detector works by receiving stray radiation on a telephone pick-up coil and amplifying it to loudspeaker level.

Table 27.4
Components List

Resistors	Value
R1	1 kΩ
R2, R6	100 Ω
R3, R4	47 kΩ
R5	100 kΩ
R7	10 Ω
R8	10 kΩ, with switch

Capacitors	Value
C1, C6	4.7 µF, 16 V electrolytic
C2, C5	0.01 µF
C3, C4	22 µF, 16 V electrolytic
C7	0.047 µF
C8	10 µF, 16 V electrolytic
C9, C11	330 µF, 16 V electrolytic
C10	0.1 µF

Semiconductors	
U1	LM741
U2	LM386

Additional Items	
LS1	Small 8-Ω loudspeaker
Perforated board	
9 V battery and clip	
3.5 mm mono-jack socket	
Case	
Telephone pick-up coil	

Table 27.5
Readings (pick-up coil near household items)

29-MHz oscilloscope	0.56 V
Old computer monitor	0.86 V
Old computer with plastic case	1.53 V
New computer monitor	0.45 V
New tower PC with metal case	0.15 V
Old TV	1.2 V
New TV	0.4 V
Plastic-cased hairdryer	4.6 V
Vacuum cleaner	3.6 V
Drill	4.9 V

R8, apply power and touch the wiper of R8. If everything is OK you should hear a loud buzz from the speaker. Too much gain may cause a feedback howl, in which case you will need to adjust R8 to reduce the gain. Complete the rest of the wiring and test with a finger on the input, which should produce a click and a buzz. The pick-up coil comes with a lead and 3.5 mm jack, so you will need a suitable socket.

RELATIVE NOISES

Place a high-impedance meter set to a low-ac-voltage range across the speaker leads to give a comparative readout between different items of equipment in the home. Sample readings are shown in **Table 27.5**.

27.11 RFI Glossary

Balanced circuit — A circuit whose two conductors have equal impedance to a common reference, such as a reference plane or circuit common.

Bond — (noun) A low-impedance, mechanically robust, electrical connection.

Common-mode — A voltage or current that is equal, in phase, and has the same polarity on all conductors of a cable. Common-mode current excites a cable as an antenna, and a cable acting as a receiving antenna produces common-mode current.

Conducted RFI — RFI received via a conducting path.

Coupled RFI — RFI received via inductive or capacitive coupling between conductors.

Differential mode — A signal that that is exists and is transmitted as a voltage *between* two conductors of a cable. At any instant, signal current on one conductor is equal to but of the opposite polarity to the current on the other conductor. Ordinary connections between equipment in systems are differential mode signals.

Disturbance — The improper operation of a device as a result of interference.

Electric field — The field present between two or more conductive objects as a result of potential difference (voltage) between those objects.

Electromagnetic field — The combination of a magnetic field and electric field in which the fields are directly related to each other, are at right angles to each other, and move through space as radio waves in a direction that is mutually perpendicular to both fields. An electrical conductor designed to produce electromagnetic fields when carrying an RF current is called an antenna.

Equipment ground — The connection of all exposed parts of electrical equipment to the Earth, or to a body that serves in place of the Earth.

Fundamental overload — 1. (Receiver Performance) Interference to a receiver caused by a signal at its input whose amplitude exceeds the maximum signal-handling capabilities of one or more receiver stages. 2. (RF interference) — Any disruption to the function of any RFI victim caused by the fundamental component of a transmitted signal or intended in-band output of a transmitter.

Ground — 1. A low impedance electrical connection to the Earth, or to a body that serves in place of the Earth. 2. A common signal connection in an electrical circuit.

Immunity — The ability of a device to function properly in the presence of unwanted electromagnetic energy. (After Ott, section 1.3)

Intentional radiator — A device that uses radio waves to transmit information by antenna action. A radio transmitter, with its associated antenna, is an intentional radiator.

Interference — 1. Disruption of a device's normal function as a result of an electromagnetic field, voltage, or current. 2. Disruption by a signal or noise of a receiver's ability to acquire and process a desired signal.

Magnetic field — The field produced by a permanent magnet or current flow through a conductor.

Path — The route by which electromagnetic energy is transferred from a transmitter to a receiver or from a source to a victim.

Radiated RFI — RFI received through radiation.

Shielding — A conductive barrier or enclosure interposed between two regions of space with the intent of preventing a field in one region from reaching the other region.

Source — A device that produces an electromagnetic, electric, or magnetic field, voltage, or current. If RFI is the result, the source is an *RFI source*.

Spurious emission — An emission outside the bandwidth needed for transmission of the mode being employed, the level of which may be reduced without reducing the quality of information being transmitted. Spurious emissions are most commonly the products of distortion (harmonics, intermodulation), of circuit instability (oscillation, including RF feedback), or of digital transmission with excessively fast rise times (including key clicks). Phase noise, such as that produced by a frequency synthesizer is also a spurious emission.

Susceptibility — The capability of a device to respond to unwanted electromagnetic energy. (After Ott, section 1.3)

System ground — A bond between one current-carrying conductor of the power system and the Earth.

Unintentional radiator — A device that produces RF as part of its normal operation but does not intentionally radiate it.

Victim — A device that receives interference from a *source*.

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