Synchronous noise blanker cleans up audio signals

by M.J. Salvati
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Fluorescent lights, gas rectifiers, neon lamps, SCRs, and triacs all produce a substantial rf signal that often radiates through their power-line connections and interferes with nearby communications receivers. This type of radio interference desensitizes the receiver and makes the recovered audio signal very difficult to understand.

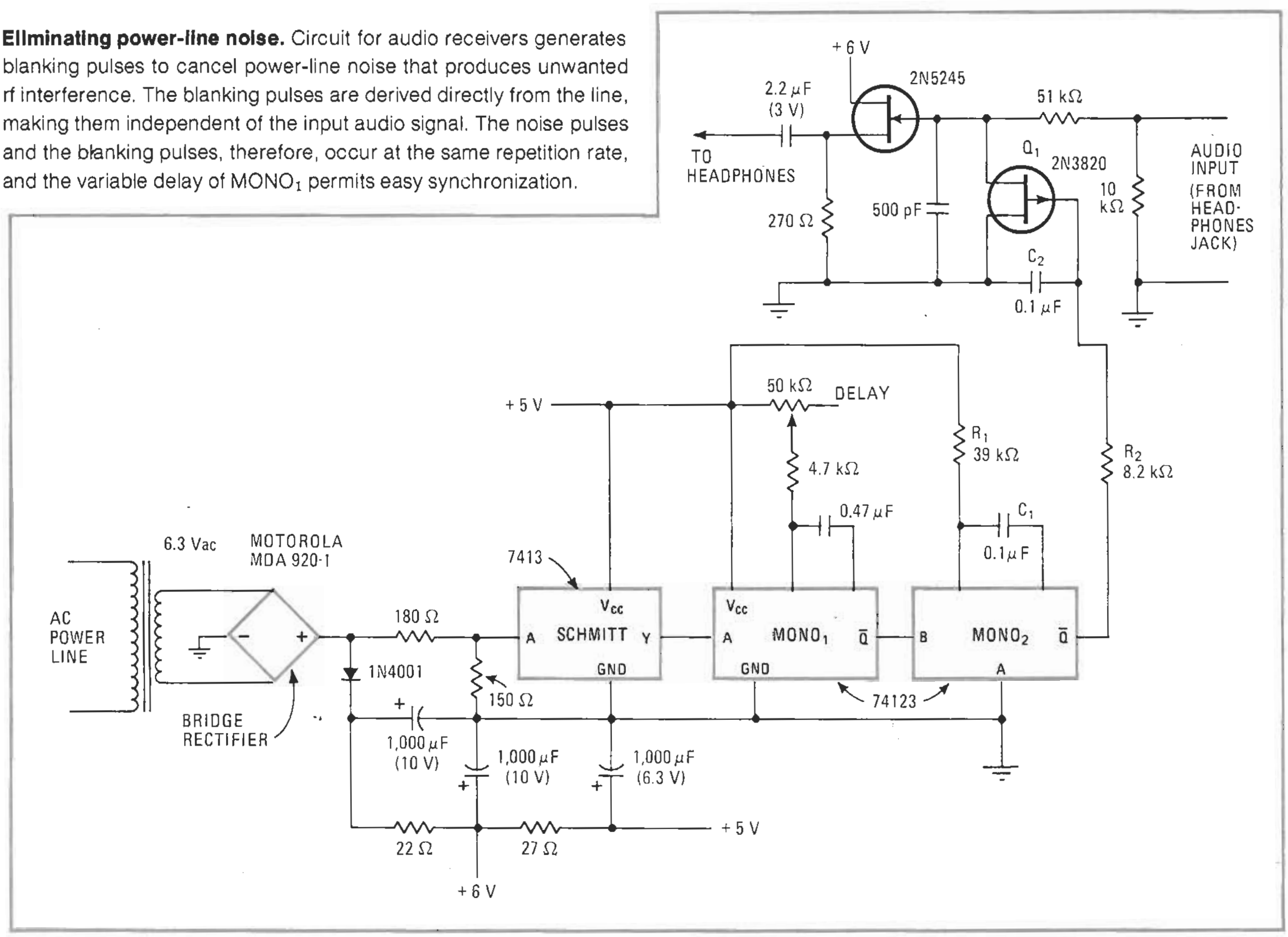
The circuit shown here significantly improves the audio intelligibility of a receiver by eliminating the noise pulses generated by a single dominant nearby noise source. The noise pulses are removed from the audio signal with only slight distortion. Moreover, since this noise-blanking circuit is not internally connected to the receiver, it can be moved from one receiver to another as needed.

The noise pulses produced by power-line radiation occur at a repetition rate of twice the local power-line frequency. Since the noise-blanking circuit is driven by the same power utility as the noise source, the output signal from the bridge-rectifier section of the noise blanker will have the same rate as the noise pulses.

The source of the blanking pulses, therefore, is independent of the input audio signal. The blanking pulses cause the FET gate (transistor Q_1) to conduct to silence the receiver. Since the blanking pulses are not derived from the input signal, their timing does not depend on the shape and rise time of the noise pulses, nor is it affected by the modulation characteristics of the desired signal.

The output from the bridge rectifier is shaped by a Schmitt trigger that drives a dual monostable multivibrator. The first monostable ($MONO_1$) delays the blanking pulse, which is produced by the second monostable ($MONO_2$), relative to the rectifier's output. The delay is variable so that the blanking pulse can be positioned to coincide with the noise pulse.

The width of the blanking pulse is determined by resistor R_1 and capacitor C_1. The fast rise time of the blanking pulse (from $MONO_2$) is slowed down by the low-pass filter formed by resistor R_2 and capacitor C_2, thereby minimizing the distortion of the recovered audio signal □



Eliminating power-line noise. Circuit for audio receivers generates blanking pulses to cancel power-line noise that produces unwanted rf interference. The blanking pulses are derived directly from the line, making them independent of the input audio signal. The noise pulses and the blanking pulses, therefore, occur at the same repetition rate, and the variable delay of $MONO_1$ permits easy synchronization.

ELIMINATION OF R.F. INTERFERENCE IN AUDIO SYSTEMS

By

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Part 1. A survey of the interference problem, eliminating r.f. at the source, shielding, and grounding procedures.

RADIO-FREQUENCY interference with electronic equipment is a problem as old as radio. The various broadcast and communications services may interfere with each other and, in turn, may suffer interference from household appliances and industrial equipment. As a result, a large body of literature has accumulated on this general subject, augmented by comparatively recent work done to reduce interference in and to television receivers. In this latter connection, there is an excellent summary of corrective measures for TV in a recent *Remington Rand* publication[1].

The present article discusses r.f. interference with audio equipment. This is a phase of the general problem which has received little attention in the literature, at least in this country, and which is becoming increasingly important with the rapid growth of the audio field. The gear subject to r.f. interference includes broadcast audio facilities, tape and disc recorders, motion picture sound systems, high-fidelity home music layouts, public address equipment, intercoms, and other installations operating in the audio spectrum. Some of the remedies listed herein are peculiar to audio systems; others include standard shielding and grounding practices and other general interference suppression techniques.

It should be noted that a well-designed and carefully installed professional plant, such as a recording or broadcast audio facility, should experience little trouble with r.f. interference from transmitters, even in the presence of strong radio frequency fields. However, not all installations approach the ideal, and not many non-professional audio devices, such as home tape recorders and music systems, are designed with "built-in" automatic interference protection. It is hoped these articles will be useful for affected gear in both categories.

The r.f. interference may be heard in the earphones or speaker as the actual transmission of a broadcast or communications transmitter, or as various noises such as clicks, pops, whines, "hash," etc. The familiar radio elements—radiation (and/or conduction), detection, and amplification—are present when this occurs. The fact that the audio gear may have no front end or tuner as such is, alas, no bar to the excellent reception of unwanted r.f.

Radio frequency energy is generated not only by transmitters, but also by motor and generator brushes, household light switches, relay contactors, heating appliance thermostats, and sometimes by the innocent-appearing lamp bulb. The arcs and sparks of some of these devices are essentially oscillatory discharges which create wave-trains of many frequencies. Other possible sources of r.f. noise include the older type of diathermy machines, induction furnaces, and r.f. test equipment. Microphone cables, phonograph cartridge leads, d.c. power supply wiring, and a.c. power lines act as antennas which pick up r.f. from the sources mentioned and re-radiate or conduct it to associated audio equipment. The a.c. lines may also conduct r.f. directly from source equipment to audio facilities. The tendency of various kinds of conductors to collect radio frequency energy is shown by the fact that it is possible, under certain critical conditions, for the long wires carrying the firing current for blasting caps to collect enough r.f. to detonate the cap and set off the explosive charge.[2] Getting back to audio, r.f. may also be picked up by inductive elements like amplifier input transformers. Somewhere in the system, rectification takes place in a non-linear element. The demodulated energy is then amplified along with the wanted signal. There are two main ways of eliminating or reducing this trouble. One is to prevent it at the source—in other words, the prevention of radiation and/or conduction. The other way is to get rid of the interference after it arrives at the audio gear.

Elimination at Source

The first step, of course, is to identify the source of the interference. This may take some doing unless the offending agency is a broadcast station or other generator whose signal is recognizable. For pin-pointing other sources of r.f., the characteristics of the offending sound may offer clues. A whining noise which occasionally changes pitch suggests a motor or generator with speed varying under changing loads. "Hash" may be due to fluorescent lights or to small a.c./d.c. appliances like shavers or fans. Clicks and pops at irregular intervals may be caused by light and power switches. Other characteristics such as time of day, frequency of the interfering voltage, and rate of repetition may further narrow down the possibilities. In smaller buildings where this is practicable, all lighting and power circuits, except the a.c. feed to the audio gear, can be turned off and restored one by one until the noise reappears. The familiar tracing technique of using a receiver with an electrostatically shielded loop antenna as an exploring coil sometimes brings results.[3] So does a wavemeter and also an ingenious and easily-built neon bulb gadget called an "r.f. sniffer,"[4] in the presence of fairly strong fields. Having located the origin of the trouble, it may be possible to reduce or eliminate the difficulty by one or more of the following measures, which are standard "suppression-at-the-source" techniques used for r.f. protection of various types of electronic gear.

1. Supply a.c. power to the offending equipment through r.f. filters, or use bypass or feedthrough condensers. This prevents radio frequency energy from being carried away from the source equipment by the power lines which

zero base line. The distance from the zero base line to the voltage minimum therefore provides a measure of the attenuation due to losses in the line. Care must be used in this method to prevent the existence of any large degree of reactance at the short itself. To make an effective short for 300-ohm line, it is convenient to strip back the line about one-half inch and twist the leads together. For coaxial lines, it is better to strip back the inner polyethylene insulation about one-quarter inch and short the outside braid directly to the inner conductor.

When measurements are made at v.h.f., the transmission line should be 75 to 100 feet long. 300-ohm line may be wound around a cardboard box, a packing carton, or any low-dielectric form. The spacing between the turns should be equal to or greater than the width of the line being used, as shown in Fig. 1. Coaxial cable may be placed in any convenient location without regard to spacing between turns.

For most applications in which the frequency is below 216 megacycles, the detector or demodulator used in the measurements may be an *RCA* WG-291 demodulator probe or a simple detector such as that shown in Fig. 5A. An alternate detector for balanced input is shown in Fig. 5B. Either of these detectors may be constructed on a phenolic board 1/16-inch thick.

The entire test setup may be checked by the connection of a 1/4-watt or 1/2-watt carbon resistor, having the same value as the line impedance, directly across the termination or output end of the line. The line connection to the resistor leads must be made in the area directly adjacent to the body of the resistor. The pattern observed on the screen of the oscilloscope should be similar to that shown in Fig. 6. It may be necessary to try several resistors having the same nominal value as the line before a good match is obtained because of variations in the resistance values and in the characteristic impedance of the line due to manufacturers' tolerances. When a good match has been obtained, the characteristic impedance of the line may be determined by measurement of the resistor.

Use of Comparison Method

The application of this method to the determination of impedance matches can best be illustrated by an example. If it is desired to determine the match of a 300-ohm transmission line to a television tuner, the tuner is connected as the load in the arrangement shown in Fig. 3. In this case, because the effect of the match is limited to a bandwidth of 4.5 megacycles, a television calibrator such as the *RCA* WR-39C is used in conjunction with the sweep generator and the oscilloscope. The calibrator is loosely coupled to the input end of the line. See Fig. 7.

The sweep generator is set to the same frequency as the television tuner. Fig. 8 shows typical traces produced on the screen of the scope, representing a good match and a mismatch, respectively. The efficiency of the match may be determined from the standing-wave ratio, as follows:

Efficiency = (*v.s.w.r.* − 1)/(*v.s.w.r.* + 1)
where: *v.s.w.r.* = E_2/E_1

E_2 = peak of reflected wave
E_1 = valley of reflected wave

A similar arrangement may be used to determine the transformation ratio of a matching transformer. The primary of the transformer is connected as the load, and resistors are substituted across the secondary until a *v.s.w.r.* of unity is obtained.

This arrangement is also useful in the matching of a transmission line to an antenna. In the case of a two-element array, for example, the sweep generator and demodulator are connected to the same end of the line as the receiver or transmitter, and the antenna is connected as the load. A good match is obtained by adjustment of the spacing between the two elements of the antenna to give a *v.s.w.r.* as close to unity as possible. See Fig. 4.

The technique described in this article is simple, and the instruments are readily available. Accuracy of the method is within ten per-cent of that obtained using a slotted-line technique. The engineer or technician willing to spend the few minutes necessary to set up the equipment will find this method extremely useful.

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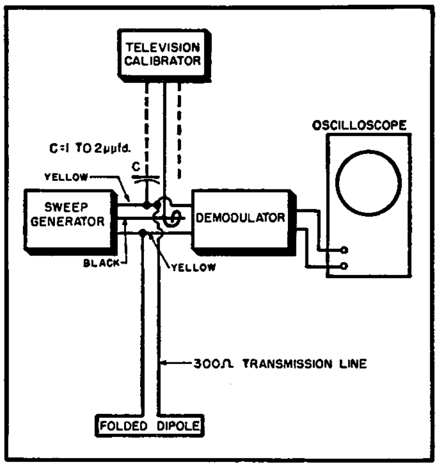

Fig. 4. Simplified block diagram shows the arrangement of test equipment for matching a transmission line to an antenna.

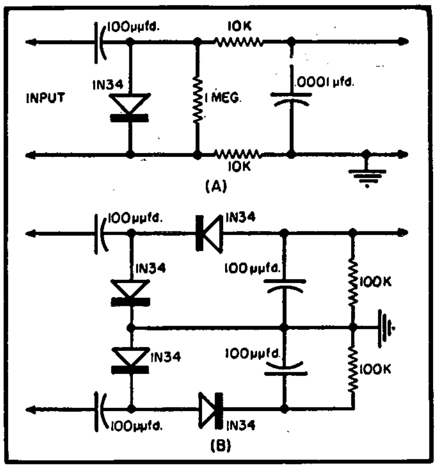

Fig. 5. (A) Detector circuit for use with test equipment shown in Fig. 1. (B) A detector circuit for a balanced input.

Fig. 6. Oscilloscope pattern produced by a 300-ohm line terminated by 330-ohm resistor.

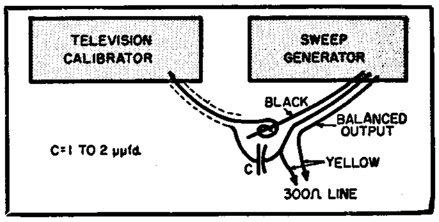

Fig. 7. How a television calibrator is coupled to the input end of transmission line.

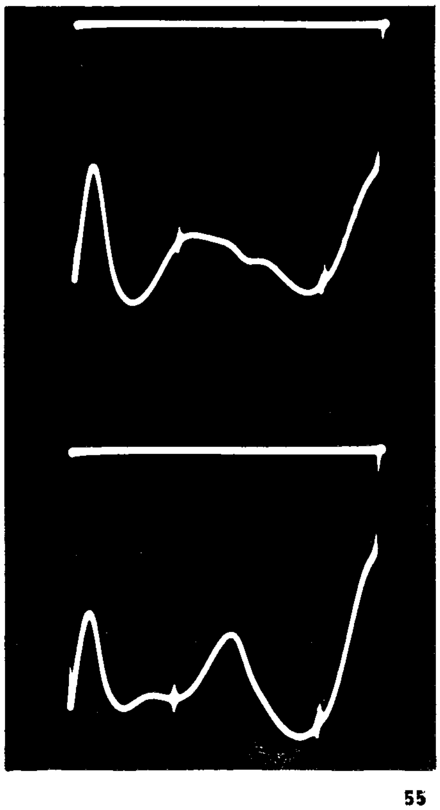

Fig. 8. Tube loading effect across the antenna circuit of a TV tuner. (Top) The tuner presents a good match to the antenna over the passband as indicated by the two marks. This is the condition with the filaments turned on and "B+" applied to the circuit. (Bottom) Trace with the power removed from the tuner and the reactive components of the tuner circuit less tube grid loading causing a mismatch. This shows that the input transformer is properly designed for the type of tube used in this circuit, i.e., the grid circuit applies a resistive component across the antenna transformer so as to effect a good match from the 300-ohm input to the tube.

may conduct it or re-radiate it to audio systems. Fig. 1 shows a filter of this type.

2. Induction heating furnaces and some r.f. test gear may require shielded rooms to prevent excessive radiation, even when properly operated and individually well shielded.

3. Keep the negative brush lead on d.c. motors as short as possible.[5]

4. Check with utility company on the possibility of insulators on nearby high-tension lines causing interference. Even if the insulator is not cracked, any roughness on its surface may cause breakdown of the air over that area and cause corona discharge. Low-voltage circuits from the same or adjacent poles may pick up the radiated disturbance and conduct or re-radiate it to audio gear in the building served.[5]

5. Check for "stuttering" thermostats or defective contacts in heating appliances, and chattering power relays that fail to close their contacts firmly.

6. Switches for lighting and power circuits can cause interference by their arcs. This is especially true of heavily inductive circuits. These may be suppressed by *RC* or *LC* filters.[6]

7. Connect condensers from motor and generator brushes to ground or frame, keeping condenser leads as short as possible to reduce radiation. Note that condensers so used may constitute a shock hazard on ungrounded devices. Safety considerations generally limit the size of the condenser to .1 μfd., and the degree of suppression obtainable by this means is therefore limited accordingly.[6, 7] The local electric code authority can be of help on this point.

8. Incandescent bulbs of the rough-service type, old style tungsten lamps with "W" filament[8], and even miniature panel pilot lights[9] may generate very annoying disturbances.

9. Neon bulbs used in oscillator circuits may cause r.f. interference.

10. Fluorescent lamps are a familiar source of trouble and can sometimes be suppressed by a small plug-in type filter inserted in the wall socket supplying the lamp. A typical unit of this type is the *Cornell-Dubilier* "Quietone" IF-6. In aggravated cases, chokes, condensers, or filters like the *Mallory* Z8A may be installed in the internal circuits of the lamp. It may also be helpful to move the ballast reactor closer to the lamp to shorten the internal wiring and thereby reduce radiation.[6] It should be noted that fluorescent lamp interference is often unpredictable. Not all lamps of an identical type will give trouble, and a particular unit may interfere at some times and not at others. It has been the writer's experience that fluorescent lights should not be used in broadcast and recording studios, although there are numerous installations in which they are used successfully.

11. Neon signs are potential causes of trouble if their high-voltage leads have poor connections and/or are not well shielded. All metal portions of the sign, the transformer housing, and the wiring shields should be bonded together and grounded.[6]

12. Mercury rectifier tubes can be silenced by condensers between the positive terminal and ground, and by r.f. chokes in the positive lead.

13. When the number of interfering sources and the number of affected audio installations warrants the cost, the use of the *Aerovox* type ANL37 interference analyzer may simplify selection of the proper type of filter for a.c. power lines.

14. In case of interference from the stepping relays of private automatic telephone exchanges, the telephone company should be asked to install filters.

15. For detailed data on locating and suppressing r.f. interference sources, the reader is referred to G. L. Stephens' excellent volume[6] from which some of the prevention-at-the-source material in this article was obtained.

Suppression at Audio Gear

While it is certainly desirable to eliminate interference at the source, there are numerous occasions when this is difficult or impossible, as for example, in the case of a broadcast transmitter. Remedies must therefore be applied to the affected audio equipment. These include treatment of audio and power lines, modification of circuits, substitution of special components, and most important of all, careful analysis of the shielding and grounding of the entire audio system. In this connection, it bears repeating that r.f. interference from transmitters should be no problem in a professional audio facility if it is carefully designed and installed in accordance with the best broadcast and/or recording standards. The following data includes design and installation precautions of good engineering practice as well as what might be called "brute-force" remedies. The distinction between the two approaches, and the applicability to non-professional equipment of the various measures described, should be obvious from the text.

Faced with an existing r.f. interference problem, the first thing to do is to find out what element in the system is acting as the antenna or the pickup coil—the audio wiring, the power cables, or circuit components. An audio pair can be checked by determining whether the interference ceases when the pair is disconnected from its destination across which an equivalent load resistor has been shunted. Inductive elements acting as pickup coils—transformers, filters, and equalizers—can sometimes be located by circuit tracing with a crystal or diode probe feeding a high-gain amplifier. The r.f. pickup and rectification may occur in the same element, or each phenomenon may take place at a different point. In the latter case, the effective point of rectification will be farther along toward the system output. This point may be determined by applying the input of a test amplifier with a shielded audio probe successively to various circuit or chassis components and wiring joints, working back from the system output until the interference disappears. This procedure should be used with caution, to make sure the application of test leads to high impedance circuits does not of itself cause noise, hum, and other interference. Having determined the circuits and/or components involved, the measures described herein may be applied. These are grouped under the headings "Shielding and Grounding" (in this article), "Lines and Cables," "Amplifiers and Power Supplies," "Prevention of Rectification," and "Miscellaneous Remedies" (in Part 2).

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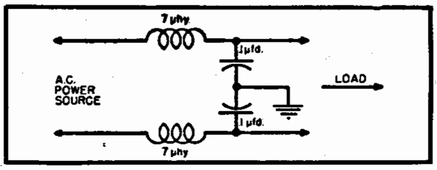
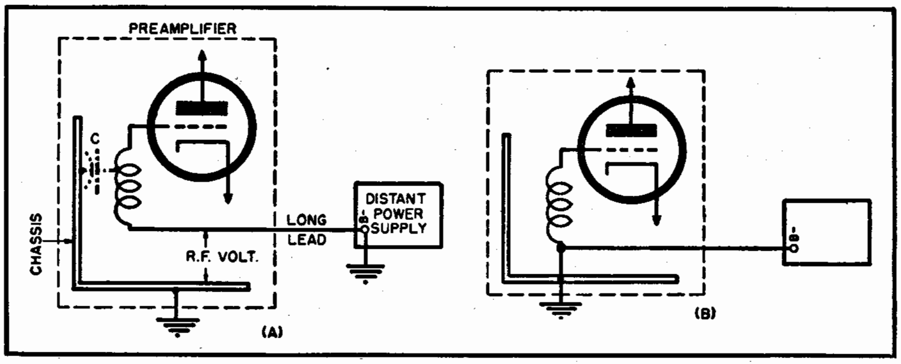


Fig. 1. Filter used to prevent high-frequency industrial equipment from feeding r.f. to a.c. supply line. May also be used in the a.c. leads of audio gear to keep out r.f. conducted along the power line. Inductance values refer to the Ohmite Z-20, 5 ampere power-line choke, in which two 7 μhy. windings are on a single ceramic core. Suppression range includes the b.c. band and extends upward to 15 or 20 mc. Whether condensers are to be on the line side or the load side of the chokes should be determined by trial. Circuit by Ohmite.

Fig. 2. (A) The r.f. voltage appears between ground and long "B—" leads and is coupled to preamplifier proper through stray capacities such as C. (B) Remedy is to ground low side of input transformer secondary to preamplifier chassis and remove ground from power supply to prevent ground loop. Circuit from the book "Elements of Sound Recording" by Frayne and Wolfe, John Wiley & Sons.



R.F. in Audio Systems

(Continued from page 57)

Shielding and Grounding

1. Analyze and lay out the grounding system with care. Run a very heavy conductor from a central grounding point in the studio, either to a cold water pipe as close as possible to the street main—or to a transmitter-type radial ground system. *Do not ground to a.c. conduit.* One network uses #4 copper conductor in conduit for the ground lead and specifies a maximum d.c. resistance of .1 ohm over its length. Use a heavy conductor to bond all rack and console frames to the central grounding point which may be a heavy bolt in the bottom of one rack. Bond all amplifier chassis firmly to their racks.

2. Run a heavy ground bus up the inside of each rack and connect to it all cable shields and the low sides of any unbalanced circuits. The rack bus should be grounded to the rack frame at only one point.

3. Shields and unbalanced circuits should be grounded only at one end to avoid ground loops which are one of the main causes of r.f. interference. When a shield or conductor is grounded at two points some distance apart, an r.f. voltage may appear across these points, since what appears as a dead short to d.c. may present an impedance to r.f.

4. Determine by trial whether or not to ground the center taps of balanced transformer windings and balanced pads. Such grounding may do more harm than good from an r.f. or longitudinal voltage standpoint.[10]

5. The r.f. pickup may occur in a preamplifier in which the input transformer secondary low side is grounded to the "B-minus" terminal of a distant power supply, instead of to the preamplifier chassis. See Fig. 2. An r.f. voltage may appear between the "B-minus" lead and the chassis and be coupled to the preamplifier proper through stray capacitances. The remedy is to ground the transformer secondary low side to the chassis, and remove the ground from the "B-minus" lead at the power supply, to avoid a ground loop.[11]

6. Use cables whose shields are tightly woven, especially in low-level circuits. This condition is often expressed as a high percentage of shielding. It should be a minimum of 80%, which means that the metal in the braid should constitute 80% of the braid area.

7. In cases of severe r.f. interference, install a second shielding braid over the cable insulation. The added shield should be carefully soldered all around to the original braid. Whether this should be done at one or both ends should be determined by trial.

8. Use shielding covers on open-bottom amplifier and power supply chassis.

9. Shield the glass tubes in low-level stages, and make sure the shell of

metal tubes (generally #1 socket pin) is grounded.

10. It may be necessary to shield not only the grid lead but also the plate lead and the plate load resistor in low level stages. The resistor shield should be of copper, brass, or other metal of high electrical conductivity.

11. Under extreme conditions of interference, build a shield of copper screening around preamplifiers, and a sheet copper shield around inductive elements like equalizers, and ground the shield. Larger sheet metal shields should have their edges turned over to form a flat surface on which to mount the cover. To maintain good contact for a removable cover, knitted wire mesh gaskets are available (*Metal Textile Corporation*, Roselle, N. J.). Such shields are obviously a "brute-force" expedient and should rarely be necessary in an audio installation.

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(To be continued)

MOUNTING CRYSTAL DIODES

By CHARLES ERWIN COHN

CRYSTAL diodes are handy components to wire into a circuit, but their installation is complicated by the fact that they can be injured permanently by excess heat during the soldering process. Furthermore, when wired and unwired many times in experimental work their leads tend to break off.

In the case of a resistor costing five cents one can take such a loss without too much grumbling, however a dollar diode is an entirely different matter and one always hopes to be able to salvage an otherwise good unit.

Soldering new leads to the diode is not too practical for the previously mentioned problem of heat damage.

All of these considerations point to the desirability of a solderless mounting for crystal diodes. Fortunately, there are two convenient methods available. Where it is possible to mount on a panel or chassis, the diode can be slipped into an 8AG fuse clip, which is just the right proportions to hold it firmly after the leads have been clipped off. Of course, this applies only to the Sylvania 1N34 and similar types with the ceramic body and two metal end caps.

If it is desired to mount the diode on leads, then the end caps can be pushed into octal-type grid clips. The National Type 8 is preferable because the diode end caps are slightly oversize. —30—

appliance clinic

TVI FROM HOME APPLIANCES

by JACK DARR
SERVICE EDITOR

FORMULA FOR A DOMESTIC CATASTROPHE: Pop in living-room watching the evening news. Mom in kitchen decides to make up a batch of slaw in the blender. Or daughter decides to dry her hair with her new drier. Or son decides to finish *his* hair-do. Result; machinery starts, and there is a loud roar from the alleged head of the family; "Turn that thing off! it's tearin' up my TV!"

In other words, one of these useful household gadgets has decided to become a miniature broadcasting station, radiating assorted rf interference like mad. (TVI, for short.) Let's see what to do about it, to restore peace to the home.

Practically all appliances that cause TVI use small, high-torque "brush-type" motors. A few use "buzzer-type" contacts. Either of these cause tiny arcs, and the resulting hash contains noise components in every common frequency-band—AM, FM, TV, you name it.

There are two ways of reducing or eliminating this noise. The first is to reduce the amplitude of the arcing at brushes or contacts. Clean up the commutator, if it is dark and pitted. Check the brushes for length; if they're worn so that the springs do not have enough tension to hold them tightly against the commutator, the arcing is much worse. The end of a good brush is smooth and shiny.

A commutator can be cleaned, if you can get at it, by cutting a thin strip of fine sandpaper, wrapping it over the end of a small stick, and holding it against the commutator while it's running. **DON'T use emery-cloth.** The abrasive material is conductive, and will get into the motor. For most small motors, the standard "nail-boards" (sandpaper coating on stiff cardboard, available in the manicure section of drugstores) are very handy. They can be cut into thin strips, small enough to get into even very small commutators. Check to see that the brushes are not sticking in their holders and be sure that the springs have enough tension. If brushes bounce, this makes the arcing worse. If you can't reduce the arcing, and you see the "ring of fire" all the way around the commutator as it runs, the armature is apt to be defective. The only cure is to replace the motor.

The second method is filtering. This means providing an easy path for the noise to get to ground, or keep it inside the case of the unit. Fig. 1 shows the general idea. This noise is mostly very high frequency hash. We make use of the basic property of a capacitor—it will pass ac but block dc, and low frequencies. So we connect a bypass capacitor from the noise-source to a ground. This provides a very low-impedance path for the *noise*, but has no perceptible effect on the 60-Hz ac line voltage.

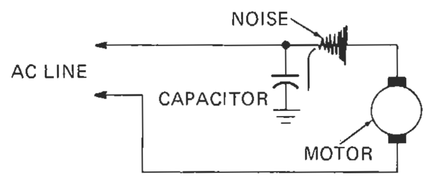


Fig. 1

In older appliances, with metal cases, the filter capacitor can be connected from the brush to the frame of the motor. One capacitor should be connected from each brush to the frame. If the unit has one of the 3-wire line cords, with the separate external ground lead (the green one), filters could be connected from the brush to this wire, which is an external ground.

In the bigger units, space won't be too much of a problem. You'll be able to put the filter capacitors on the end of the motor, and tuck them away tightly. In some of the more compact types, with plastic cases, you won't have too much room. However, you can get disc capacitors now up to 0.05-μF, that are small enough to tuck away inside of the smaller ones. Be sure to insulate the leads well. Use a good grade of braid or glass fiber spaghetti (**NOT a thermoplastic tubing,** that will melt if the case gets too hot!)

For 117-volt circuits, use capacitors with a minimum voltage rating of 200 volts. 600-volt types are better if you can get them in. For subminiature types, using dc motors and low voltages,

(continued on page 94)

APPLIANCE CLINIC
(continued from page 24)

even the little transistor-type capacitors can be used. Average value of these capacitors will run around .05-μF, as I just said. However, they aren't too critical. Use whatever value cuts down the noise the most.

If the filter capacitors won't cut the interference to a suitable level, you may have to try small rf chokes in series with the motor leads. These can be hand-wound, air-core, out of solid wire. Cover them with tape and tuck them away in the case.

If there isn't room for anything like this, you may have to use an external filter. Fig. 2 shows a typical circuit for

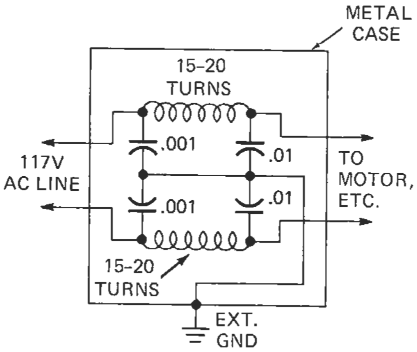


Fig. 2

one of these. If there is room inside the appliance case, this works better at that point. If not, you can build it, and connect it in series with the ac line. There are several different types and makes of these, made with a plug and socket, so that they can be plugged into the outlet, and the appliance line cord plugged into the filter. Some of these have an external ground terminal on the side of the case. In severe cases, this will often help a good deal. Run a short lead to a cold-water pipe, etc. While I don't know the model number right now, there is undoubtedly a filter built with one of the 3-wire plugs, that will do its own external grounding when plugged into a correctly-wired outlet.

If you want to make up one of these, put it in a small metal case, and make the case the external-ground terminal. Do not try to use the "line ground" or white wire. Keep both ac line conductors well insulated from the case of the filter. Use terminal strips, etc. to support the connections.

The basic principle of all noise-filtering, of course, is to keep the noise inside the apparatus generating it. Once it gets out onto the line-cord, you have it on a pretty darned efficient antenna for radiating it. If this isn't practical, then kill the noise as soon as possible; by a plug-in filter at the line-cord plug. **R-E**

R-E's Service Clinic

Hardware Noise—A type of TVI

How to identify and localize it.

JACK DARR
SERVICE EDITOR

OUTSIDE OF CERTAIN COMMERCIALS, one of the things that annoys TV viewers the most is interference or noise in the picture. It comes in all shapes and sizes; from older cars, home electrical appliances, and so on. Anything in the house can be tracked down, and identified, by simply turning it on and off. Filtering can then be used to clear it up. Some interference can come from outside sources, though. We used to call this "hash", but now I supose we should say noise pollution. Either one is correct.

An irate reader wrote me "I've got so much interference on my TV set that I don't like to watch it. There are two wide bands of dots and streaks that roll slowly up the picture. They interfere with the sound, and even make the picture roll at times. Looks like ignition noise, but I don't think it is. What can I do about it?"

Complain loudly to the power company. I've seen this a great many times. The polite name for it is hardware noise. It's caused by old or defective equipment on the ac lines feeding your house. You'll notice that the interference shows two bands of dots, meaning that it has a characteristic 120-Hz frequency. Without going into too much detail, it's due to a *corona* discharge. Not on your home's service wiring, which is 230 volts maximum in most places, but on the feeders or tertiary lines which supply the pole step-down transformers. These lines run around 7,600 volts, etc.

Several things can cause it, including defective or cracked insulators, but probably the most frequent offender is the terminals on the transformers themselves. If these are old, or not correctly designed, the corona discharge takes place *inside* the transformer, above the oil, from the shank of the bolt to the metal case. I have seen some "horrible examples" of these after they'd been replaced, and the shank of the terminal bolt is actually pitted and eaten away by the corona! There are newer types, designed to prevent this; they have plastic insulation, etc. on the shank of the bolt. Your power company, especially the REA, has a training film on this, which shows all of the effects and how to cure them.

The reason for the 120-Hz effect is simple. The corona discharge takes place twice during each cycle of the voltage; once on the positive peak and again on the negative peak. Each peak generates the corona discharge, which in turn generates a burst of high-amplitude rf "signals", which cover all frequencies. We're going to do something with this effect in a moment.

The first step should be to file a complaint, in writing, with your local power company. Tell them you have hardware noise, and they'll know what you're talking about. Most companies have noise locating equipment, and it shouldn't take them long to find the offending unit.

If you want to try finding it yourself, there are a couple of ways. Drive around the area with a radio equipped car, or even a portable radio. Set the dial off-station, somewhere near 800 kHz. For some reason, this noise peaks at that frequency. When you find a place where the noise is very loud, turn the dial of the set back and forth. It will usually be of such a high amplitude that you won't be able to use "loudness" alone to pin it down.

When you get closer to the source, the noise will start to spread; it will cover more and more of the dial. For example, if you get noise from 600 to 900 kHz, you're getting closer, but you're not there yet. Keep on looking and tuning, and when you find a place where you can get nothing but noise from one end of the dial to the other, you're getting warm—really warm.

Find the nearest pole. If it has a transformer on it, so much the better. Listen to the noise, and hit the pole a sound whack with a heavy hammer. If

(continued on page 78)

This column is for your service problems—TV, radio, audio or general and industrial electronics. We answer all questions individually by mail, free of charge, and the more interesting ones will be printed here.

If you're really stuck, write us. We'll do our best to help you. Don't forget to enclose a stamped, self-addressed envelope. Write: Service Editor, Radio-Electronics, 200 Park Ave. South, New York 10003.

SERVICE CLINIC
(continued from page 73)

this changes the noise, there you are.

Second method. If you have a highly directional TV antenna with a rotator, turn it all the way around, and watch the screen. Find the direction where the noise is most intense. Make a line along this bearing, on a city map. Now locate a friend with an antenna of the same type. Take a bearing on the noise with his antenna. Draw this on the map. At the point where the lines cross, there's the noise. If you can get a third bearing, preferably at a point distant from the first two, you can pin it down even more closely. We used this method on a very bad case, some time ago, and pinned it down to a very bad insulator, on a pole almost two miles away. Some nut had shot the insulator with a high-powered rifle!

Due to the fact that power lines make excellent "long-wire antennas", you may run into some ambiguity in your bearings. In fact, it's more likely that you'll see a triangle instead of a single point where they cross. At any rate, you're in the ball-park.

Go to the general area where the noise is originating and then switch to the car radio or portable. Use the frequency-spread of the noise as the indicator and follow the power line until you find the pole where the noise covers the whole dial. There you are. Look for a little metal tab or label on the pole. This will give you the number, and you can report it to the power company. **R-E**

reader questions

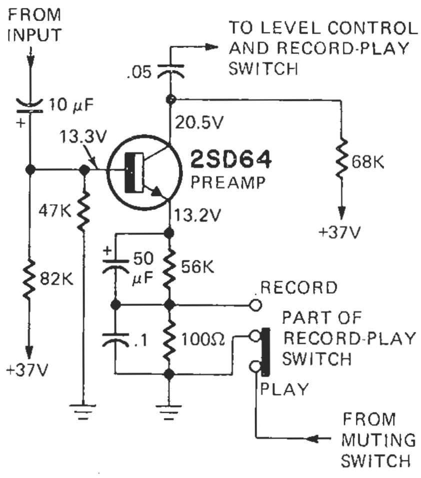
SUDDEN LOSS OF CONVERGENCE

Here's one for you. In a Sylvania D-15, I had a sudden loss of convergence. I couldn't get the center vertical line, red and green, to converge at all. The trouble turned out to be a shorted electrolytic capacitor, C-800, 6.8 μF located on the convergence board. This might apply to other chasses, too.—Harold Jones, Harold's TV, 810 College, Bowling Green, Ky.

Thank you very much, Harold. Filed and noted for future reference.

NO SOUND

I can't get anything through the amplifier of this Sony TC-102 hybrid tape recorder. The dc voltages on the 6AU6 second af amplifier are about



+60 volts, plate and screen, but I read +8 volts on all three elements of the preamp transistor. That doesn't sound right.—H.C., Monroe, La.

It certainly doesn't. From a reading like this, you have one or two possible things; the transistor is shorted to all three elements, or there is a resistor open in the supply! Take the transistor out and check it. If it shows a normal "diode-effect" reading out of circuit, then turn the power on, and check the voltages on the transistor connections on the board.

From these readings, I'd suspect something like an open collector load resistor, R9, 68,000 ohms. If this was
(continued on page 80)

SWAMPING INTERFERENCE

1.0 Record players, hi-fi and stereophonic amplifiers, tape recorders, electronic organs, public address systems, intercom systems, hearing aids and similar electronic devices are designed to amplify audio signals such as music and speech and are not intended to act as radio receivers.

1.1 Nevertheless, much of this equipment will act as a radio receiver, picking up strong signals from nearby radio or radar transmitters which are reproduced as interference. Such signals can originate from almost any kind of transmitting equipment ranging from high power radar units to passing police or taxi mobiles. Generally speaking, the higher the transmitter frequency, the higher its power and/or the closer it is, the greater the possibility of "swamping interference" being experienced by electronic devices such as mentioned in paragraph 1.0.

2.0 What happens in the presence of strong radio or radar signals is that some of the signal energy gains entry into the audio amplifier circuitry, overloads the amplifier, is then rectified and after being amplified, comes out of the loudspeaker as interfering sound.

3.0 This "swamping interference" appears as interfering music or voices or in some cases as morse code or radioteletype. With radar transmitters the interference appears as a short "beep" or "buzz" every few seconds. Generally the volume control setting has little or no effect on the level of this type of interfering signal.

4.0 This form of interference can also be experienced in AM, FM and TV receivers and manifests itself by the fact that changes in the tuning dial or channel selector have no effect on the interference. Similarly, changes in the volume control setting have little or no effect.

5.0 The incidence of this type of interference is increasing because -

a) there has been a tremendous increase in the amount of electronic equipment of this type being used by industry, business and in the average household.

b) of the increased use of solid state (transistorized) equipment.

5.1 While this form of interference can and is experienced on vacuum tube type equipment, solid state circuitry is more susceptible because of the fact that transistors are more inclined to overload on strong signals. Also, the printed circuit techniques now so commonly used often have little or no shielding thus permitting direct pick-up of strong radio or radar signals.

6.0 It must be emphasized that when such interference is experienced, the fault lies with the amplifier itself (or other devices containing an amplifier) and all methods applied to effect a cure must be applied to the amplifier itself. There is nothing that can be done at the transmitter short of it ceasing operation.

7.0 Recognizing the seriousness of this problem most equipment manufacturers will provide advice when this type of interference is experienced. Some have even developed modification kits for installation on their line of equipment. Others have changed their design to incorporate suitable shielding and/or filtering to deal with this problem.

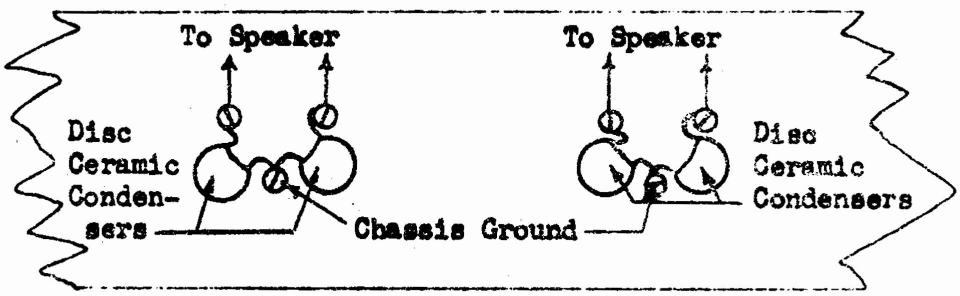
CURES

8.0 The most common entry point of strong radio or radar signals into an amplifier system is via the loudspeaker leads. This is because most good quality amplifiers have a feedback loop which couples a portion of the audio output signal back to the earlier stages to provide some degeneration for improved frequency response. Thus any signals picked up on the loudspeaker leads will find an easy path of entry to the early stages of the amplifier.

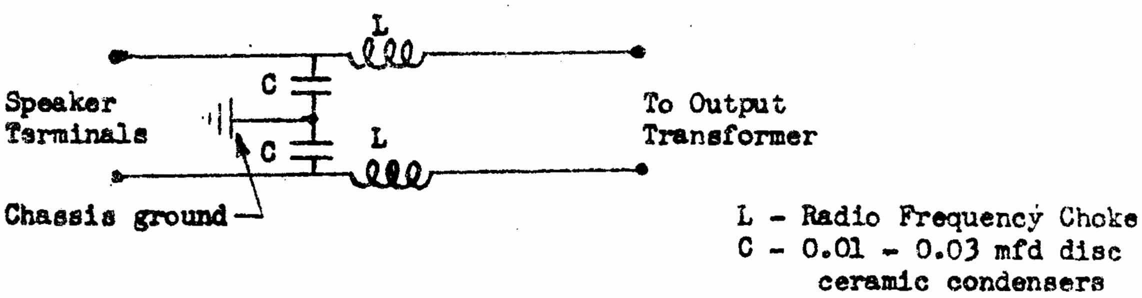
8.1 Recommended cures for the above are:

(i) Replace the speaker leads with shielded wire, grounding the outside metallic braid to the amplifier chassis.

(ii) By-pass the loudspeaker leads to the amplifier chassis using 0.01 mfd to 0.03 mfd disc ceramic condensers. Keep all leads as short as possible.



(iii) Another method used by some manufacturers consists of a filter network installed under the amplifier chassis between the speaker terminals and the output transformer. This filter consists of two condensers as in (ii) above plus two small radio frequency chokes. The latter can be made up by close winding 24 turns of number 18 solid enamelled wire on a ¼ inch diameter form (a pencil will do). Keep all leads as short as possible.



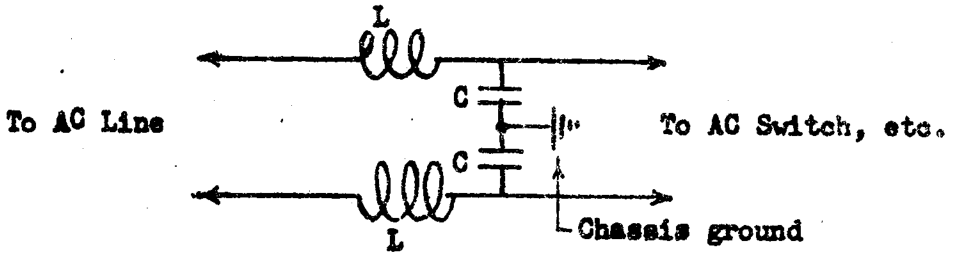
8.2 With the low impedance of the loudspeakers the above components will not affect frequency response of the amplifier.

9.0 In many instances strong signals gain entry via the powerline. This can be prevented by:

(i) installing 0.01 to 0.03 mfd disc ceramic condensers from each side of the AC line to chassis ground where the line enters the chassis.

(ii) installing a 0.01 mfd disc ceramic condenser across the high voltage power supply output filter condenser.

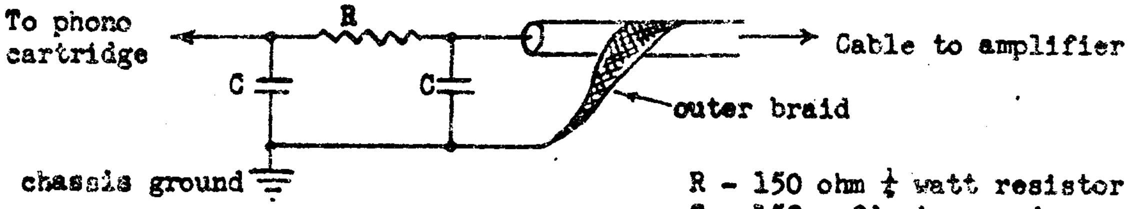
9.1 In extreme cases a filter network similar to that in paragraph 8.1.(iii) may be necessary as shown below. These chokes can be made up by close winding 24 turns of number 16 enamelled wire on a 3/8 inch diameter form.



L - R.F. Choke C - 0.01 - 0.03 mfd disc ceramic condensers

Again keep all leads as short as possible.

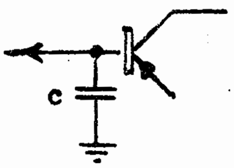
10.0 Some turntable phono arms use a short length of unshielded wire from the cartridge to terminals in the base of the turntable chassis where it connects to a shielded cable running to the amplifier input. This is an ideal entry point for strong radio or radar signals. Where possible this unshielded wire should be replaced by special light weight shielded wire made specially for this purpose. If the added weight of this shielded wire upsets the phono arm tracking force, the only alternative is to insert a filter at the tie point referred to above. This consists of two mica condensers and one resistor. In the case of stereophonic pick-ups a filter will be required in each lead.

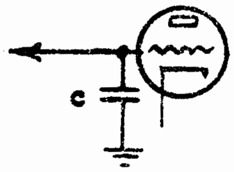


R - 150 ohm ½ watt resistor
C - 150 mmfd mica condensers

11.0 With component type installations all units including the turntable chassis should be bonded together using braided type metal flex. Do not rely on the shielding of inter-connecting cables to provide good bonding. If possible connect the installation to a good ground (such as a water pipe).

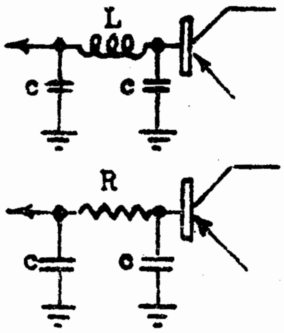
12.0 If the interference persists after applying the above cures, it may be necessary to apply filtering across the input of the first transistor stage (or grid of the first vacuum tube). This consists of a 100 to 250 mmfd mica condenser connected from the base of the transistor to chassis ground (figure a below) or, in the case of a vacuum tube type amplifier, from the grid to chassis ground on the first tube (figure b below). Keep all leads as short as possible.

a) 

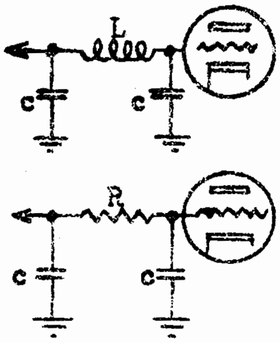
b) 

C - 100 - 250 mmfd
mica condenser

12.1 In extreme cases a small radio frequency choke or a 50,000 - 75,000 ohm resistor and a second condenser may be required as follows.

a) 

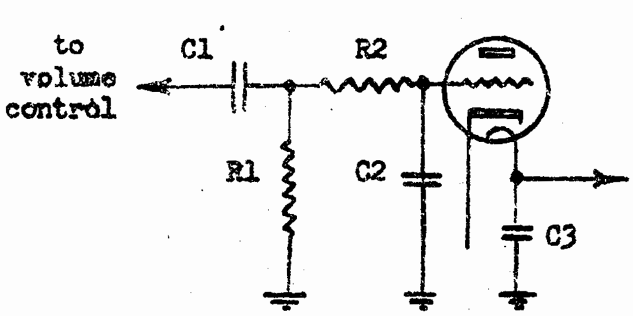
C - 100 - 250 mmfd mica condenser
R - 50,000 to 75,000 ohm ¼ watt resistor
L - Radio Frequency Choke, same dimensions as in para 8.1(iii)

b) 

12.2 In particularly stubborn cases the approach shown in paragraphs 12.0 and 12.1 above may have to be applied to the next amplifier stage or even to all the remaining stages.

13.0 Tube type radio and television sets, particularly the AC/DC variety, often use grid leak biasing on the first audio amplifier stage. The grid resistor in such cases is generally in the order of 5 to 10 megohms which places the grid so high above ground it is very prone to overloading by strong radio or radar signals. A suggested modification is shown below.

1st Audio Stage



C1 - 0.01 mfd paper or ceramic condenser
C2 - 100 to 250 mmfd mica condenser
C3 - 0.001 mfd ceramic condenser on AC/DC sets
R1 - 2 megohm ¼ watt resistor
R2 - 50,000 to 75,000 ohm resistor

14.0 There have been instances where replacing a missing tube shield has eliminated a direct signal pick-up problem and cured this type of interference. In another case the installation of a shield over the input amplifier tube cured the problem. In the latter case the unit, as distributed by the manufacturer, did not use any tube shields.

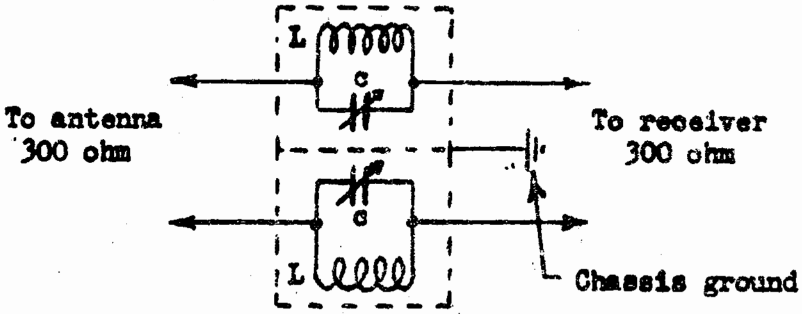
14.1 Some cases may require the addition of a metal bottom plate under the amplifier chassis and/or a cover over the chassis. Most amplifiers generate quite a bit of heat and consideration must be given to the need for adequate ventilation when applying any form of shielding. Ordinary copper fly screening is an excellent form of shielding material and provides minimum imparement of ventilation.

15.0 On some AM/FM stereophonic receivers, FM receivers, TV sets and combination units, strong radio or radar signals may gain entry into the chassis via the antenna circuit and eventually find their way into the audio circuitry to produce interference.

15.1 Disconnecting the antenna lead will prove whether or not it is the pick-up source. If this is found to be the case, the cure is to filter these signals out before they enter the chassis as follows:

a) If the interfering signal is below 50 MHz., connect a high pass filter in the antenna lead. Several models are commercially available.

b) Connect parallel traps in the antenna feed line, these being tuned to the frequency of the interfering signal.



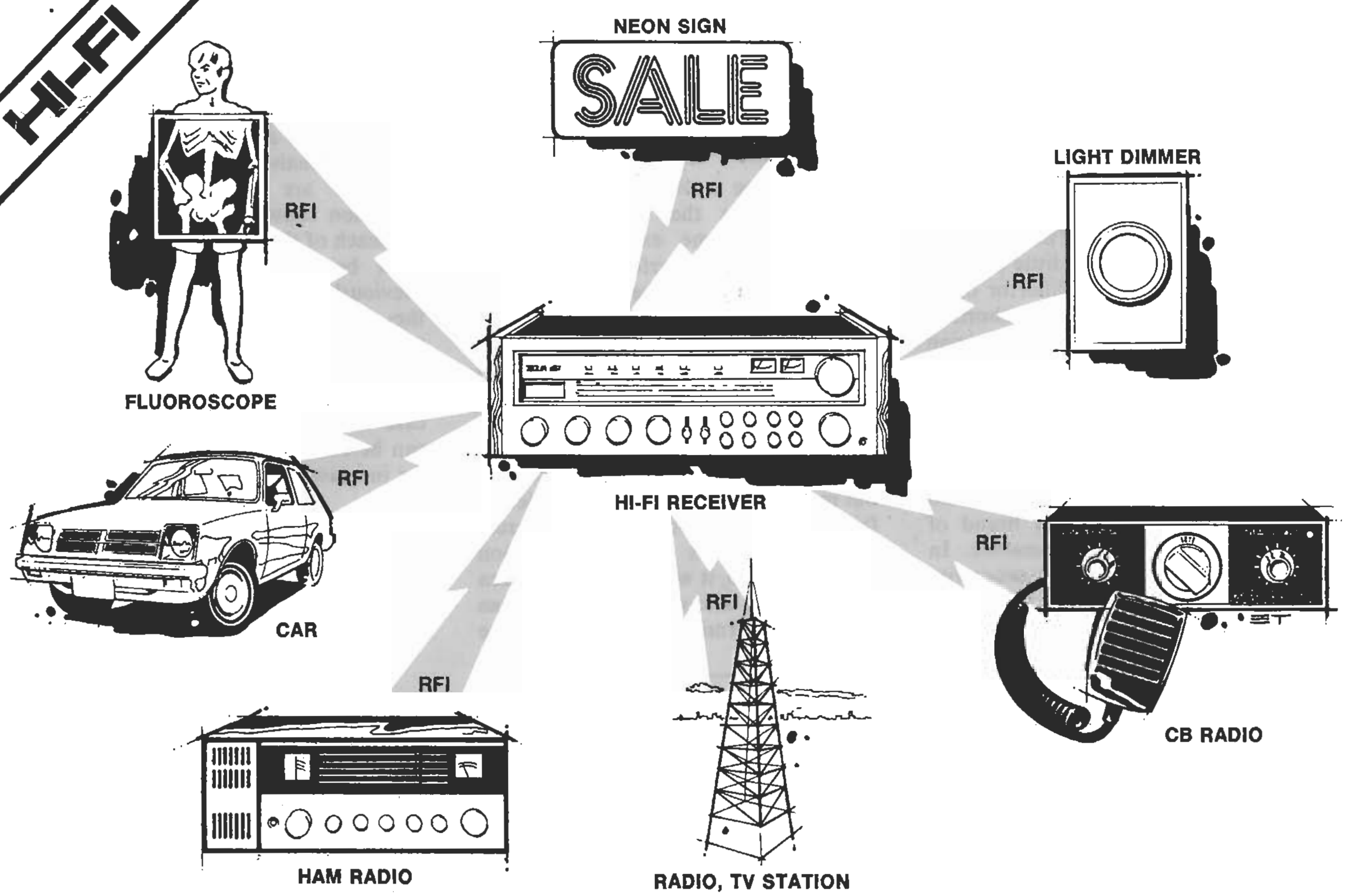
Values of L & C are chosen to resonate at frequency to be rejected. These circuits should be installed in a small metal box and each LC network must be isolated from each other.

c) Connect a quarter wave stub tuned to the frequency of the interfering signal across the antenna terminals. A copy of SII-13-54 outlining the construction of such stubs in the range 40 to 220 MHz. is attached.

16.0 Sets have been encountered where the interfering signal was fairly weak but on placing one's hand near or on the volume control, the interference increased greatly in level. Investigation revealed that the volume control shaft was insulated from the ground and was actually serving as the pick-up point. The cure here is to replace the volume control with one whose shaft is grounded.

17.0 Basically the approach to curing this type of interference is to find out how the signal is being picked up or where it is gaining entry into the amplifier and then eliminate its pick-up or entry by the addition of shielding or filters as outlined above. As a word of caution to the layman, it is strongly recommended that work of this type only be undertaken by experienced electronic technicians.

Department of Communications,



Getting Rid Of RFI

Don't despair when RF interference invades your hi-fi system. Here are some steps you can take to get rid of it.

LEN FELDMAN
CONTRIBUTING HI-FI EDITOR

IF YOU SUDDENLY HEAR A "GOOD BUDDY" warning of the imminent approach of Smokey over your expensive stereo hi-fi system while you are trying to audition a disc, don't get the idea that you are being singled out as a solitary victim by your neighborhood CB'er. You are just one of hundreds of thousands of victims of RFI (*R*adio *F*requency *I*nterference). In the last year alone, the FCC has received nearly 100,000 complaints regarding interference that degrades TV performance, intrudes upon the sounds of hi-fi and generally makes owners of home entertainment equipment miserable. In most cases, the FCC is powerless to do anything about the problem, especially since this sort of interference can and does take place even when the offending transmission equipment is operated within legal power limits. Even in cases where CB'ers use linear amplifiers to increase radiated power beyond authorized limits, the FCC is so understaffed (and CB usage has been proliferating at such a fast clip) that they would not be able to look into a specific complaint for months, if at all.

The Consumer Electronics Group of the Electronics Industry Association (EIA) has been considering this growing problem for some time and recently, they prepared a comprehensive booklet entitled *Electronic Technician's Interference Handbook, Audio Rectification.* Much of the material contained in this article is paraphrased from the final draft of that booklet, while some comes from personal experience with the problems of interference we have encountered over the past few years ourselves.

The most common type of audio interference encountered in hi-fi (and occasionally in TV) equipment found in the home is due to a phenomenon known as audio rectification. Audio rectification is the detection of modulated RF signals by an audio circuit of a radio, preamplifier, amplifier, or tape deck electronics that appear as unwanted or disturbing audio signals at the speaker output terminals. Since not all RF interference is created by RF transmitting equipment, the most common forms of interference can be divided into two groups: signals emanating from RF transmitting sources (radio or TV stations, amateur radio operators, CB operators, paging systems) and interference from electrical equipment or appliances (X-ray and diathermy equipment, neon signs, light dimmers, thermostats, commutators and switches).

The first category of equipment is usually not within direct reach of the "victim", and curing of interference problems from RF transmitting equipment is largely confined to working on the actual equipment experiencing the interference. The second category is more likely to be located within your house or apartment and, by turning off the suspected interfering source, it can at least be localized and identified.

Interference from the first group will prove more difficult to diagnose, because its point of entry into an audio device can be anywhere from the antenna to the speakers. Interference can be picked up by long connecting cables acting as antennas or a component acting as a detector, or it may be transmitted through the AC power lines, especially if the source of interference is in the same building as yours. Detection will then take place in the power-supply circuit of the audio equipment with the same disturbing effect on the listener.

Since the majority of interference problems occur because of nearby interfering equipment, there is little point in taking your receiver, amplifier or other equipment to a factory or authorized warranty service station. The technician at such service centers will be completely frustrated in trying to solve the problem remotely, because it would be impossible to duplicate the problem. Audio rectification happens with the best of equipment, and its absence is no indication that one piece or brand of equipment is better than another. In fact, equipment with higher sensitivity and gain is a better prospect than some inexpensive, low-gain audio equipment.

Correcting external interference

Before digging inside your receiver, amplifier or tape deck, there are several simple remedies you should try first. Check connecting audio (shielded) cables and replace overly long ones with shorter ones, wherever possible. If the interference is noticed only when the pick-up arm or the turntable is touched, a ground wire between the pick-up arm and preamplifier chassis ground is called for. If the phonograph pick-up headshell is bakelite or plastic, a small piece of foil or metal between the cartridge and headshell that is grounded to the metal portion of the pick-up arm or to the metal base of the turntable, may help. (See Fig. 1.) If the metal or

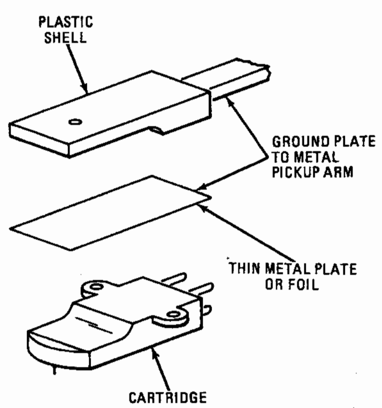


FIG. 1—GROUND PLATE between cartridge and pick-up arm may reduce interference.

foil alters the tracking force, this should be readjusted to maintain proper cartridge performance.

If the interference occurs when holding a microphone (but not when you place it on a table), a ground wire between the microphone shell and the preamplifier or amplifier chassis is called for. A "buzz" recorded on tape when using a hand-held microphone can also be caused by a defective or poorly shielded microphone, but this can be verified by making a recording in a location where the identified RFI is not present.

Interference is often caused by long speaker cables that can act as an antenna. In some extreme cases of strong RFI, the interference persisted (and was heard over the speakers) even after the entire system was turned off! Replacing unshielded speaker cables with shielded cable or installing a small capacitor across the speaker will often cure this problem. The audio purist will, of course, object to altering the load seen by the amplifier in this manner, but most modern amplifiers can tolerate fairly large values of capacitance across speaker terminals before oscillation occurs. Even so, it would be a good idea to check with a scope connected across the speaker terminals for any evidence

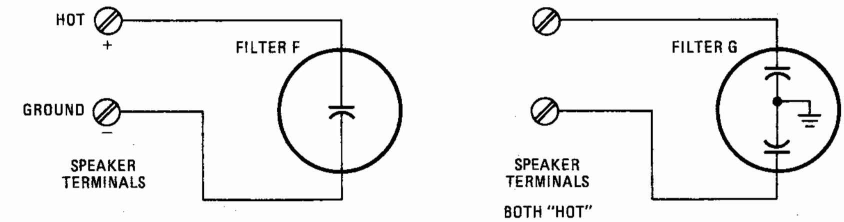


FIG. 2—LONG SPEAKER WIRES can act as a receiving antenna for RFI. Capacitors mounted across speaker terminals will eliminate this problem. Normal connection is shown as Filter F, and Filter G shows connection for strapped amplifiers.

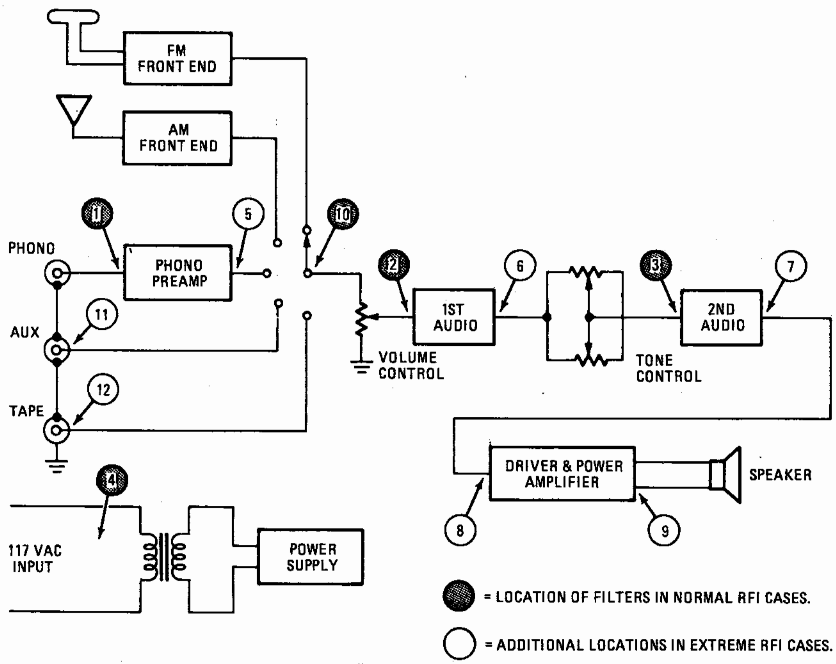


FIG. 3—FILTER LOCATIONS in AM/FM/phono equipment.

of oscillation before you run into a case of blown tweeter voice coils!

If you want to play things completely safe, you might try increasing the capacitance across the speaker terminals (while observing the scope trace) until evidence of high-frequency oscillation just begins. Final total capacitance should then be no more than half of the value required before oscillation takes place. Where speaker output terminals of the amplifier consist of a "hot" and a "ground" terminal, the capacitor should be connected as shown in Fig. 2-a. If both terminals at the output of the amplifier are "hot", use the configuration shown in Fig. 2-b, recalling that each of the two capacitors involved must be double the required value previously determined as needed to stop the interference. Such arrangements where both terminals are "hot" occur in some amplifiers that have been "strapped" for higher power (as in the case of some quadriphonic units that can be switched to 2-channel operation for increased output power.

Internal equipment modifications

If the few corrective steps enumerated above fail to eliminate or sufficiently reduce audio rectification, it's time to look inside your amplifier, receiver, preamp or tape equipment and to check for a few obvious causes. Check first for bad ground connections and poor solder joints. Sometimes, electrolytic capacitors that have been in service for many years develop a high internal-resistance. Paralleling a fresh capacitor across the suspected one will eliminate this as a possible source.

If the interference still persists at this

TABLE I—RFI TROUBLESHOOTING CHART FOR AM/FM/PHONO EQUIPMENT.

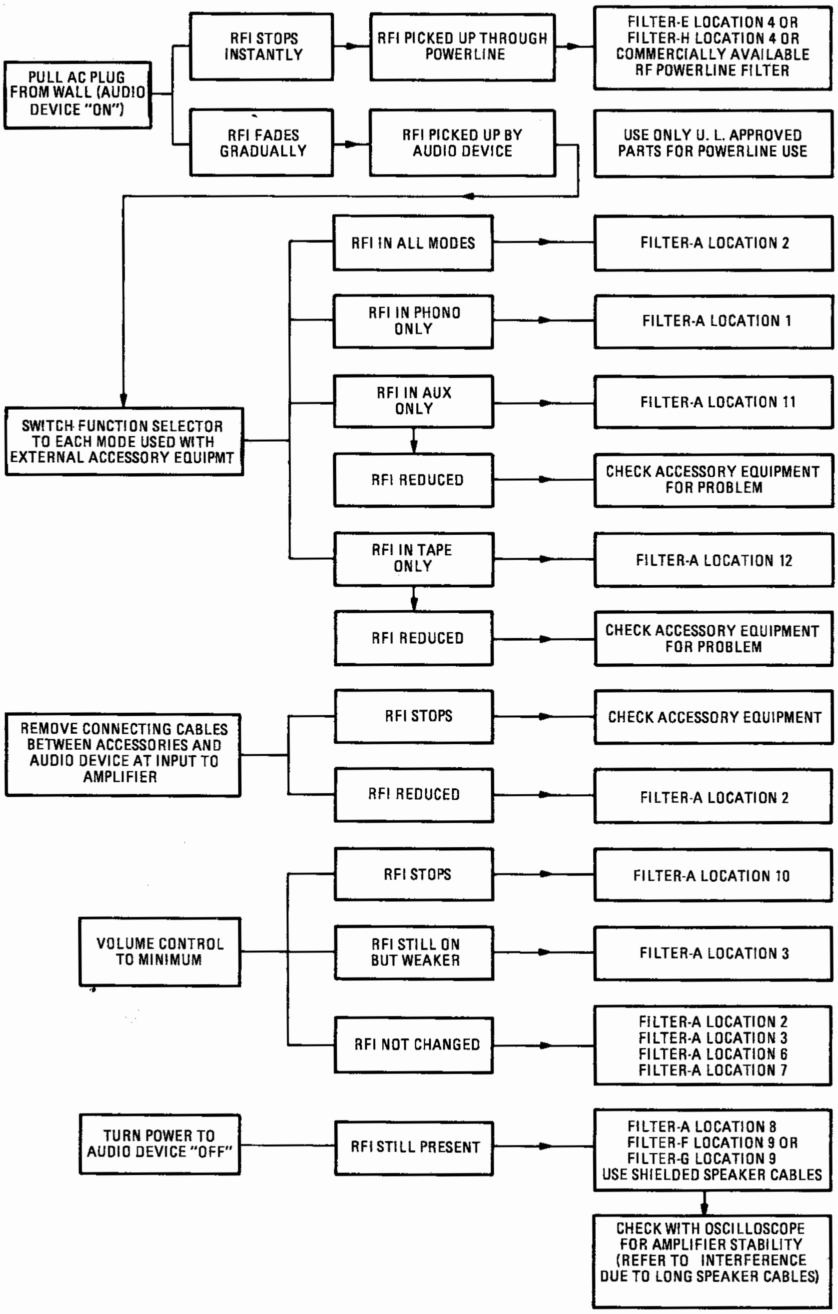
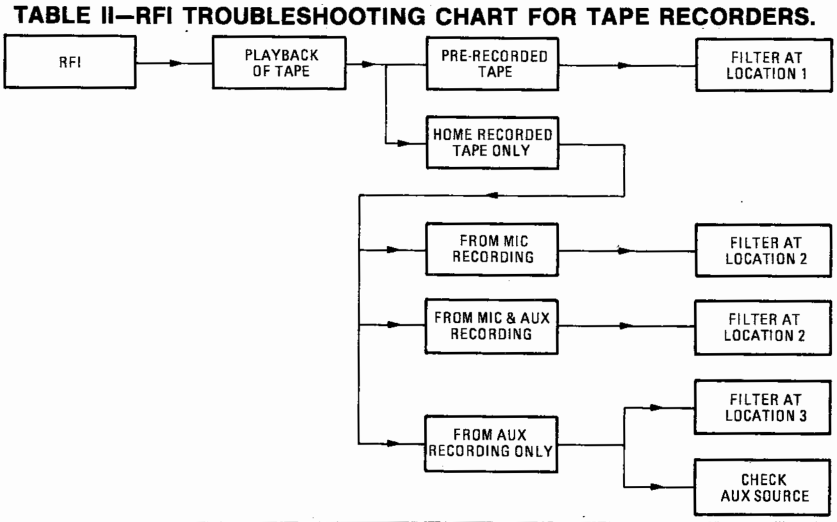


TABLE II—RFI TROUBLESHOOTING CHART FOR TAPE RECORDERS.



point, it's time to consider adding one or more filter networks. Table I is a troubleshooting chart that will help you to isolate AM, FM and phono interference-problems logically. Associated with Table I is Fig. 3, which is a simplified block diagram of a typical home hi-fi installation. The circled numerals indicate points of insertion of various filter circuits as called out in Table I. Filters are designated by the letters A through H.

Table II is a troubleshooting chart designed to help you analyze and correct RFI problems that occur in connection with the use of tape equipment, and Fig. 4 shows the location of possible corrective filters. The filter identified as "A" should be used for correcting tape RFI problems.

Filter networks

The most effective RFI filter, from practical experience, is a "pi" filter-network consisting of a series RF-coil and two shunt capacitors. Suggested values for this filter, designated as Filter A in the troubleshooting chart of Table I, are shown in Fig. 5.

In mild cases of RFI, a single bypass capacitor between the base and emitter may be sufficient. This configuration is designated as Filter B in Fig. 6. Another fairly effective way to suppress RFI is through the installation of an L-type filter in the collector circuit, shown as Filter C in Fig. 6.

A coil inserted in series with the emitter leg of an audio input transistor, as shown in Fig. 7, may help in very mild cases of RFI. If such a remedy is used (Filter D), the coil should not be bypassed. This filter is the least desirable because of difficulty of installation in printed circuits and because of the possibility of oscillation that might take place in some circuits after it is installed.

Filters designated as E and H are generally used when it has been ascertained that RFI is coming in through AC power lines. Wiring diagrams for these two filters are shown in Fig. 8. In cases where the line cord is part of an indoor antenna system, there may already be a pair of coils wired in series with each side of the line cord. In that case, either Filter E or Filter F should be wired between these existing coils and the primary of the power transformer, as shown in Fig. 9.

Filters F and G have already been discussed and illustrated (see Fig. 2) in relation to speaker-cable pick up of RFI.

Filter installation

Several precautions should be observed whenever adding any of the filters illustrated. Install the filter network as close to the input of the audio stage that follows the so-called RFI

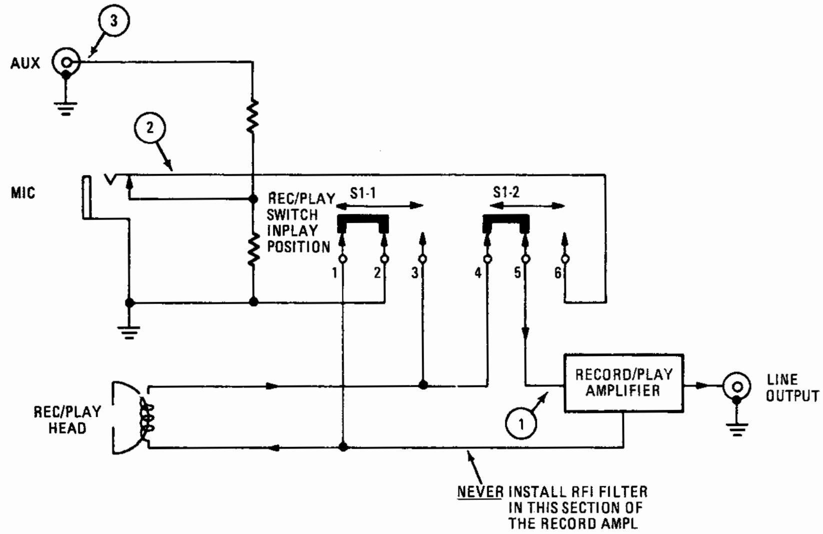


FIG. 4—FILTER LOCATIONS in tape recorders.

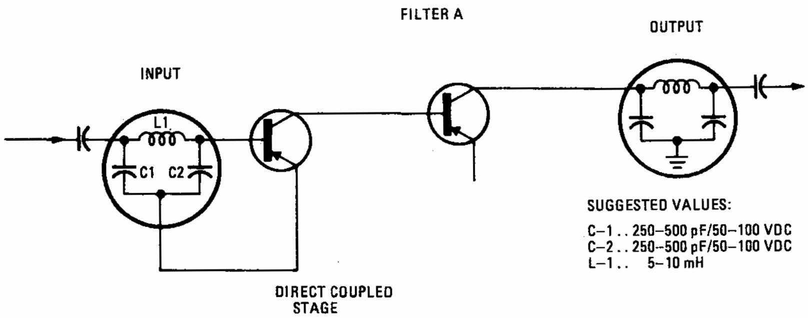


FIG. 5—FILTER A is a pi-filter network, which is very effective in the reduction of RFI. This network is usually inserted in the base and collector circuits.

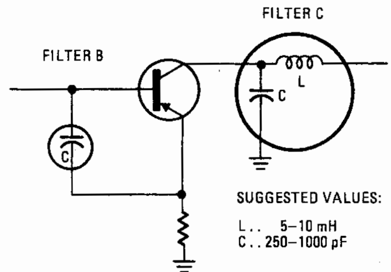


FIG. 6—FILTER B AND FILTER C. Filter B consists of single bypass capacitor between base and emitter. Filter C is an L-type filter in the collector circuit.

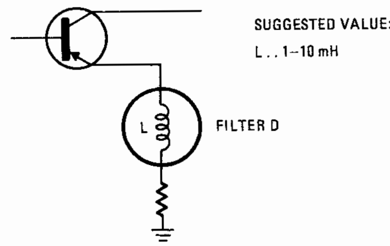


FIG. 7—FILTER D consists of a coil inserted in the emitter circuit.

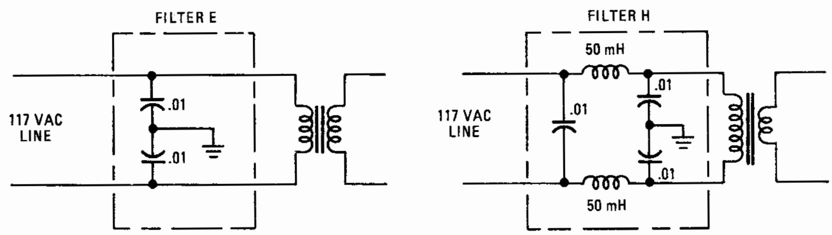


FIG. 8—FILTER E OR FILTER H should be used when the interference is coming through the AC power line.

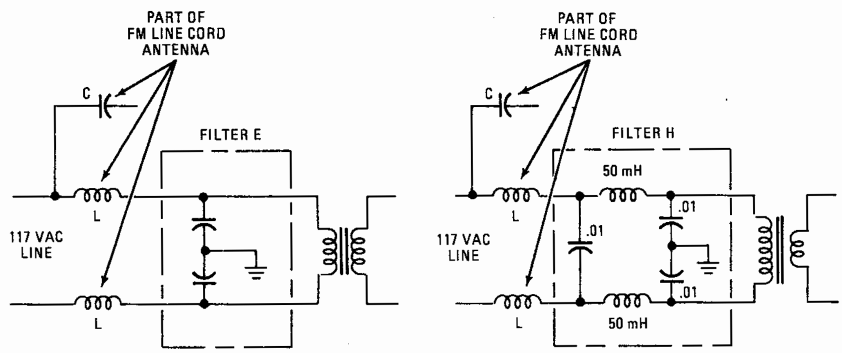


FIG. 9—CONNECTION OF FILTERS E AND H when coils are already attached to the AC power line, as is the case when the power line is also being used as an indoor antenna.

pickup point (close to the base of the transistor or grid of a tube in the preamp of a receiver, for example). Use physically small components; small ceramic capacitors are preferable to paper capacitors. Keep all capacitor and coil leads (ground leads as well as "hot" leads) as short as possible. Long leads may compound the RFI problems instead of solving them. Install only as many filters as are found to be absolutely necessary. Too many filters may also do more harm than good.

It is advisable to run a frequency response check before and after filter installation to make sure that RFI filters have not changed gain or frequency response of the audio component significantly. A capacitor value that is suitable in a low-impedance circuit will not be a good choice in a high-impedance circuit.

IC's often pick up RF interference. Because of the feedback circuits incorporated in many IC applications, RFI filters should be installed both at the signal inputs and outputs of IC's, where they are suspect.

If RFI originates at the tape recorder source only, it must be determined whether it shows up only during playback of home recorded tapes or on commercially recorded tapes as well. In the former case, the RFI is actually recorded on the tape itself and will be heard whenever or wherever that tape is played back. A filter at the microphone preamp input will be necessary in such cases.

To avoid ground loops, shunt and bypass capacitors should be grounded to the emitter of the transistor when such filters are installed in the base circuit of a transistor stage.

Safety comes first

In your eagerness to solve your RFI problems, don't overlook the importance of component safety. Use only U.L. approved components, especially when installing filters *across* the power-line input of the equipment. Capacitors rated at 400 VDC are *not* safe for 120 VAC. Capacitors must be rated specifically for line bypass applications and suitable for continuous operation at 125–150 VAC, RMS, 60 Hz. Mount components carefully to avoid possible shorts or arcing.

RF chokes are made by several

continued on page 97

GET RID OF RFI
continued from page 46

manufacturers and are available from most electronic supply houses, especially those dealing in industrial electronic components. Because physical size is important, miniature or subminiature coils should be used. Capacitors should be disc ceramic types, of the HiK or TC type, and their size must be small, too.

Some final suggestions

If interference is known to originate from CB equipment, it might be a good idea to borrow a CB rig (unless you already own one) and operate it near the audio equipment while trying to cure the problem. By so doing, you won't have to wait for the interfering signal to come "on the air" to ascertain whether your attempts at a cure have been successful. If you are successful, record what parts you added to your equipment by adding them to the schematic diagram of your hi-fi component.

Remember, it is not always possible to cure RFI problems completely. In many cases only a reduction of interference may be possible, despite your best efforts, but reducing the problem is better than no solution at all. We know of at least one case in which just about all of the solutions we have outlined were attempted with no success. The listener was located directly across the street from a local FM transmitter tower. This frustrated audiophile had just about given up, and loved his hi-fi music enough to move to another location. Having disassembled his hi-fi in preparation for the move, he had stored all the components in his bedroom, which faced another exposure, away from the transmitter tower. Before packing the gear in shipping cartons, he decided to hook the units up for one last listen and, you guessed, the RFI was gone! **R-E**

Now that you've built your TV Typewriter, ur minicomputer, your digital clock, and r CB transmitter, do you think you're ready ackle a broken toaster?"

SUPPRESSING BLOWER HASH

Q. ***I built the CB converter described in the October issue and have installed it in a 1976 Plymouth Fury. However, the blower fan motor (for air conditioning, heating, and defrosting) creates so much static that it is impossible to operate it and the converter simultaneously. I do not have this problem when I use the AM/FM radio "straight through." Can you suggest a filter that will suppress this interference?—W. B. Grandjean, Baton Rouge, LA.***

A. I recommend the installation of 0.25-μF coaxial capacitors across the terminals of each blower motor. The capacitor will act as a short circuit to the r-f hash generated by the sparking at the motor brushes, but will not affect the system from a dc point of view. The capacitors can be obtained from most auto supply houses, and can also be used to silence noisy gauges and sender units. Be sure that the case of the converter and the shield of the antenna lead-in are well grounded.

PATRICK S. FINNEGAN

RF Tuned Circuits and Audio

• A considerable amount of audio is carried on rf transmission systems. Once the audio gets into the rf arena, it must contend with many factors that are not present in an audio-only situation. These rf factors can shape and distort the audio so that what is recovered at the receiving end of the system can be far different than what went into it. We will discuss one of these factors, the rf tuned circuit, and some of the effects it can have on the recovered audio.

CARRIERS AND SIDEBANDS

The rf signal is a carrier only, usually called simply, the *carrier*. This is the rf frequency assigned to the station or for a particular use. The rf carrier is generated and amplified to the value necessary to radiate it from an antenna (in an open circuit situation, such as broadcast) or over a cable system (as in a closed circuit situation). The plain carrier by itself is of little practical value.

Intelligence signals are impressed on the carrier in one or the other modulation methods. In the amplitude modulation (a.m.) process, the audio signal all goes into the sidebands. In standard a.m. broadcasting, there are two full sidebands. There are also variations of the a.m. process, such as vestigial sideband transmission as used for the visual carrier in t.v., single sideband as used in communications systems, and double sideband-suppressed carrier as used in communications and stereo multiplex.

Audio which modulates the carrier's frequency or its phase is called *frequency modulation* or *phase modulation*. These modulation processes not only create many sidebands, but they also cause the carrier to deviate, or swing from its normal resting (assigned) frequency, in accordance with the audio modulation signal. This is a more complex situation since the carrier is constantly changing its frequency position.

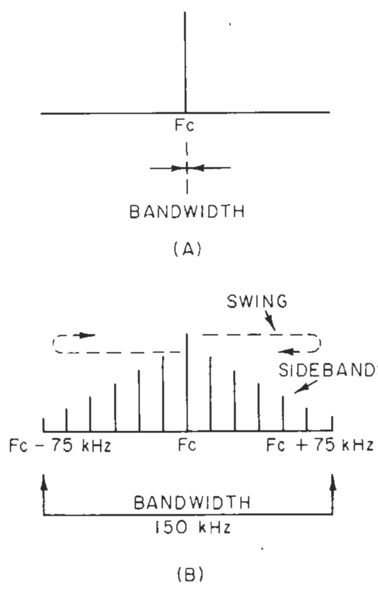
A modulated carrier takes up more spectrum space than does an unmodulated carrier. Signals occupy space (in frequency) both above and below the carrier frequency. This space is called the *bandwidth* of the signal. Any circuit then, which carries this modulated signal or is to amplify it faithfully, must have adequate bandwidth. In other words, the circuit must be broadband enough to pass the signal and its sidebands.

TUNED CIRCUIT

Circuit elements contain inductance, capacity, and resistance values that become more critical at rf frequencies. The higher the rf frequency, the more critical and important these elements become. Besides actual tuned circuits, these same elements are found in conductor lengths, transmission lines, and the antenna itself. The higher the rf frequency, the more peculiar these elements act. The inductive and capacitive reactances and the rf resistance will affect the signal, each in its own way.

In a given situation, the reactive components (which are opposite in sign) will equal each other and cancel out their *effects*—leaving only the resistance in the circuit. (The reactive components are still present, but they are counterbalanced by each other.) This is the natural *resonance* of the circuit. Circuit gain will increase tremendously, limited only by the resistance in the circuit. The bandwidth of this resonant point is also very, very narrow.

Figure 1. When modulation is applied to a carrier, sidebands are created which widen the spectrum space occupied by the carrier. (A) is an unmodulated carrier while (B) is f.m. modulated.



Circuits are designed with the correct values so that resonance occurs at a definite frequency rather than at some haphazard place. When we tune a circuit, whether this is an i.f. can in a receiver or the coils at the base of an a.m. transmitting antenna, we are adjusting one of the elements to produce resonance at the correct frequency..

An important parameter of a tuned circuit is its *Q*. This is a value which ia a ratio of the reactance to the rf resistance in the circuit. The circuit which has the highest Q will have the lowest resistance in it. Rf resistance is different than d.c. resistance because of *skin effect*. A circuit with very low d.c. resistance can still have a high value of rf resistance.

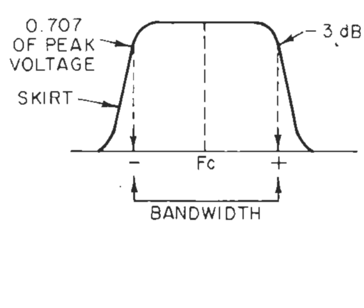
BROADBANDING

Very high Q circuits have their place as traps, matching and isolating units, etc., but for amplification of a modulated rf signal, the bandwidth is so narrow this can eliminate the sidebands—and the audio intelligence signal. The circuit must be broadbanded enough to pass the sidebands of the signal. When broadbanding is done (as it must be), there is always a tradeoff in circuit gain; the wider the bandwidth, the lower the gain. Additional stages must be used to make up for this loss in gain.

The resonance curve is measured at the lower and upper *skirts* where the signal is down 3 dB from the peak value. This is the point where the voltage measures 0.707 of the peak value. The ideal, of course, is a perfectly flat top curve without a lot of lumps in it. One way to broadband a circuit is simply to add a resistor across the tuned circuit. Many early communications receivers and the tube-type video circuits used this method to broadband the circuits.

Another way to broadband a chain or series of stages, such as an i.f. strip, is through *stagger tuning* the stages of the chain. In this case, the tuned circuit of each stage is tuned so that resonance occurs at a different place in the desired bandpass. In other words, each stage is mistuned from the ideal (each in a different way), so that the overall effect produces the desired bandwidth. This works well, but the tuning must be done carefully so as to distribute the correction equally among the various stages; otherwise one or more stages may be overloaded.

Figure 2. The typical broadband resonance curve. Bandwidth is measured at the 3 dB down points on the skirts (0.707 voltage points).



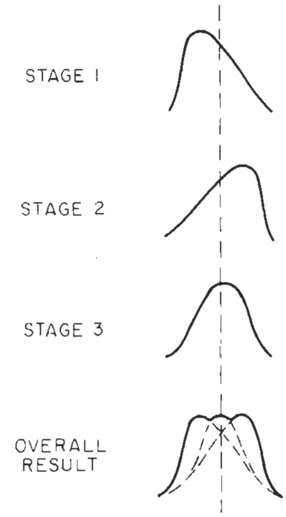


Figure 3. Broadbanding is often done by stagger tuning several stages in tandem.

SOME PROBLEM AREAS

System bandwidth is basically a design problem, but it becomes an operational problem when we attempt to make equipment operate on a particular channel. Commercial equipment must be designed so that it can be operated over a *band* of frequencies, but an individual station will operate on a *specific* frequency. This creates more problems for the designers. Consequently, the equipment as used on a particular frequency will have its own peculiarities—so this is where the operational problems enter the picture. All the rf circuits must be adjusted properly for *that channel*.

Transmission lines have their own peculiarities and characteristics when sending rf through them. This calls for special treatment. The line must have a proper termination all across the desired bandpass or there will be signal reflections from the load back into the line. These reflections will be out of phase with the basic signal and cause cancellations and phase shifts in the sidebands. In practice, this terminating load is usually an rf-tuned circuit of some type, which may be the matching circuit at the base of an a.m. antenna or the transformer section at the input of the f.m. antenna.

The transmission line exhibits the same characteristics when used in the receiving situation, but there is generally less consideration given to the receiving aspect than to the transmitting aspect. Yet, that receiving line can affect the signal just as much as can the transmitting line, although the power element is not present to damage the line itself.

There are other situations where coaxial line is used to carry modulated rf signals such as in closed circuit applications, or where the f.m. exciter in a transmitter is coupled to the power stages over several feet of line. These lines must be properly broadbanded and terminated. In the transmitter situation, the length of the line can be very critical as can be the termination. In uhf television, for example, the designers make use of this factor and actually make use of the line length for tuning the bandpass. The line is run through a *line-stretcher* circuit which electrically changes the length of the line.

Perhaps the most damage is done to the signal in the receiver tuning. Designers may skimp on the number of stages as a cost factor and try to obtain the necessary gain/bandwidth with fewer stages. The tuning can be very critical in such receivers. Unless the tuning is exactly correct, one or the other factors will suffer. That is, there may be gain with narrow bandwidth, or broad bandwidth with low gain—and attendant noise problems.

EFFECTS

The two most predominant effects on the recovered audio from mistuning in an rf system shows up in audio distortion and audio frequency response of the recovered signal. The next in order is noise.

Distortion can result from a variety of factors. As mentioned earlier, stagger tuning of an i.f. strip can cause one or the other stages to be overloaded. This can introduce phase and amplitude distortion elements to the signal. Another aspect which is basically a response problem but also can cause distortion, is the *tilting* of the system bandpass. Tilting can cause a particular segment of the bandpass to be emphasized—the recovered audio from this area then overdrives the audio stages and causes distortion.

Perhaps the most pronounced effect of mistuning shows up in audio frequency response of the recovered audio. If the bandpass is too narrow in the a.m. system, the higher audio

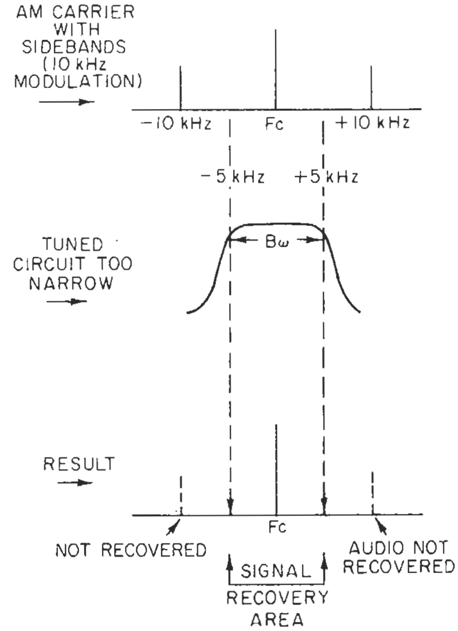


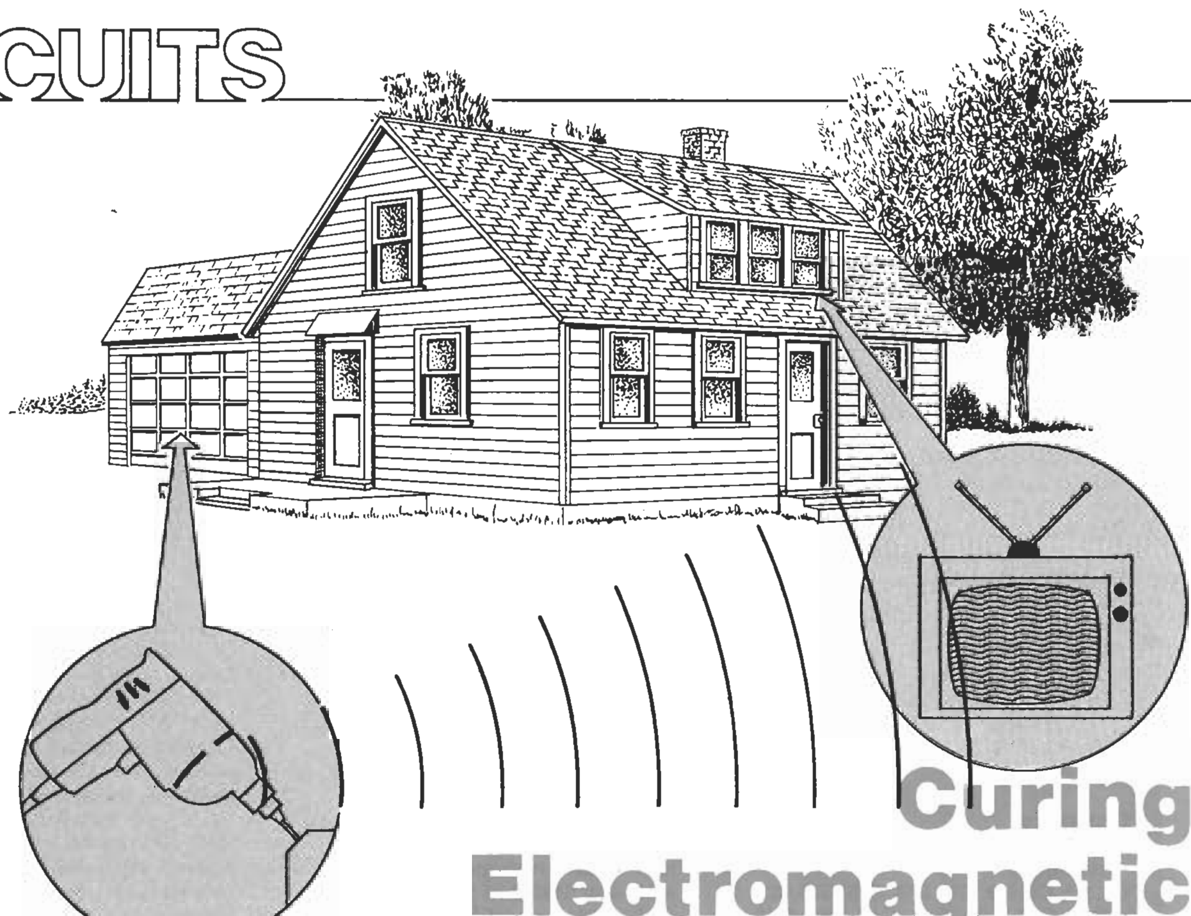
Figure 4. A circuit must be broadband or it will act as a filter on that part of the signal not in its bandpass.

frequencies will be attenuated or be non-existent in the recovered audio. The higher audio frequencies in the a.m. process create sidebands that are spaced from the carrier the same distance (in frequency) as the audio frequency. If modulating with 10 kHz, for example, the bandwidth is 20 kHz. But if the tuning is such that the system bandwidth is only 10 kHz wide, then everything above 5 kHz will be lost in the recovered audio.

The discriminator tuning in the f.m. receiver is especially critical and can affect response, causing distortion, and have a low output so the signal-to-noise ratio of the system is poor. This circuit must be tuned so that the carrier resting frequency is exactly in the center of the bandpass, and the upper and lower tuning curves must be in the linear region of the stage. If the carrier is off-center of the curve, then one side is favored over the other, and the carrier swing can extend into the non-linear region of the stage. Tune all stages of the system so that the carrier resting frequency is right down the center of the bandpass for that channel.

SUMMARY

Ideal audio can be less than ideal when it has passed through an rf system, riding on the rf carrier. Tuned circuits and tuned elements will exert a considerable effect on the signal and especially its sidebands, which must be passed faithfully. Although bandpass is a basic design problem, tuning of these elements then makes it an operational problem. Tuning must be done carefully. ■



Curing Electromagnetic Interference

MICHAEL F. VIOLETTE

Learn all about the causes of electromagnetic interference, and what you can do to neutralize its effects.

EACH AND EVERY ONE OF US HAS EXPERIenced the effects of electromagnetic interference (EMI). For instance, that phenomenon is what causes static on your TV every time someone turns on another appliance. But EMI can have some far more serious consequences. For instance, the EMI generated by an electrostatic discharge ("shocks" caused by static electricity) can severely affect nearby computers. In dry weather, it is not uncommon for those mild shocks to cause a computer located on the other side of a fair sized room to "crash." The effects of EMI can even cause an otherwise sound device or circuit to fail to operate at all. And the effects of EMI can be dangerous, such as when the starting of a motor inadvertently triggers a nearby remotely controlled piece of industrial equipment.

The above mentioned effects of EMI, as well as many, many others are familiar to hobbyists, engineers, and users of electronic equipment. Sometimes EMI-caused problems have simple solutions. Such solutions might involve rerouting some wires or adding a bypass capacitor to a circuit. Other times, a less-than-severe problem is simply tolerated. More troublesome cases are cured only after extensive trial-and-error attempts and a lot of wasted time.

This article is an introduction to a few of the most common causes of EMI and some of the remedies that can be used to combat EMI's effects. Our goal is to achieve "electromagnetic compatibility" (EMC). Electronic circuits and systems are said to have achieved EMC when they can operate within the same electrical and physical environment without any one circuit or system causing problems for another.

Types of EMI

EMI can be loosely defined as an undesirable signal that affects the normal operation of equipment such that the equipment malfunctions, or the performance of the equipment is degraded in some manner. The phenomenon, its causes, and its cure have all become especially important as new technologies that use low voltage levels and high-density packaging have been developed. Such technologies are especially sensitive to EMI.

Just as electrical energy is moved from one place to another either by conduction (through wires) or radiation (through the atmosphere or space), EMI "reaches" its "victim" via radiation and/or conduction. For instance, consider the case of static on a television caused by someone using an electric hair dryer. If you look at the dryer motor while the dryer is in use, you can see electricity arcing between the motor's commutator and brushes. Those arcs are a source of both conducted and radiated broadband electric noise that can affect the normal operation of a TV set. By *broadband* we mean that the noise signal contains a wide variety of frequencies, including in most cases those that fall in the TV band (54–216 MHz VHF, 470–890 MHz UHF).

Figure 1 shows a situation that is found in millions of households—an electric

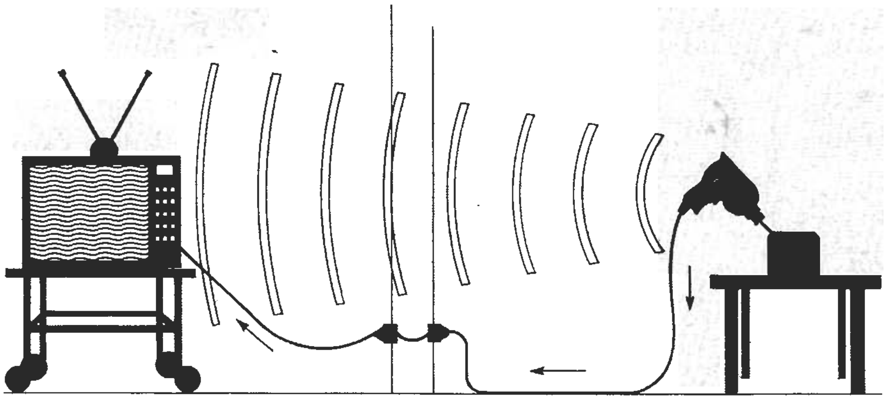


FIG. 1—A COMMON INTERFERENCE SITUATION. The electric drill generates EMI, which is coupled to the TV set via two separate paths.

drill in use in one room affecting the operation of a TV set in another. Note that though the drill and the TV set are physically separated, they are both fed from the same branch of the house's wiring. The signal generated by the arcing within the drill motor is conducted to the TV set via the line cords of the two devices and the house wiring. Once the signal reaches the TV set, it can be *coupled* into the set's circuitry (more on that in a moment) and processed as if it were a video signal. The result is displayed on the screen as static.

At the same time, the noise signal traveling through the line cord of the drill causes an electromagnetic field to form around that cord; that is, the line cord becomes a "transmitting antenna." The noise signal that is "broadcast" from that antenna can then be picked up by the TV antenna and processed like any other signal.

Table 1 lists some typical sources of EMI, both man-made and natural. That list is not intended to be exhaustive, but only to give you an idea of the variety of those sources. Table 2 is a brief list of the types of equipment that are subject to electromagnetic interference.

Also, it is possible that the source and victim of the interference is the same piece of equipment. That "self-jamming" occurs when there are several different systems within the same piece of equipment and one of those systems is interfering with another.

TABLE 1—SOURCES OF ELECTROMAGNETIC INTERFERENCE

Man-Made Sources
RF transmitters
Automotive Ignitions
Electric motors
Arc welders
Computers
Fluorescent lights
Relays
Neon signs
High-voltage power lines
Switches
Dimmers
Natural Sources
Electrostatic discharge
Lightning

TABLE 2—VICTIMS OF ELECTROMAGNETIC INTERFERENCE

Computers
Medical equipment
TV's
Radios
Electronic control equipment
Ordinance (explosives, etc)
Telephone equipment

Coupling paths

We've already seen that for EMI to occur there must be a path between the source and the victim. That path is called a coupling path. Usually, the task of locating the coupling path or paths responsible for the transmission of the EMI is the most difficult aspect of solving the problem. That is the case, because there may be a number of paths contributing to the problem. Often, the EMI may persist even though you have eliminated one or more paths. The only solution in those cases is to keep searching until all coupling paths are found.

A further complication that multiple coupling paths presents is that it makes it difficult to determine if eliminating a suspected path has actually done any good. If two or more paths contribute equally to the problem, eliminating only one path may provide little apparent improvement.

In order to discuss the various ways in which EMI can couple from one system to another, it is necessary to define a few terms.

When dealing with conducted interference, there are two varieties that we are concerned with. The first variety is *differential-mode interference*. That is an interference signal that appears between the input terminals of a circuit. The other variety of conducted interference is called *common-mode interference*. A common-mode interference signal appears between each input terminal and a third point; that third point is called the *common-mode reference*. That reference may be the equipment chassis, an earth ground, or some other point.

Let's look at those types of interference a little more closely. In Fig. 2-*a* we show a simple circuit consisting of a signal source, V_S, and a load, R_L. In Fig. 2-*b* we show what happens when differential-mode interference is introduced into the circuit by an outside source (more on that in a moment). As is shown, an interference voltage, V_D, appears between the two input terminals, an interference current, I_D, flows in the circuit. The result is noise at the load. If, for instance, the load is a logic gate in a computer, and the amplitude of V_D is sufficiently high, it is possible for the gate to incorrectly change states. It is possible that such an occurrence would alter the results of any computations being performed at the time—a rather undesirable situation.

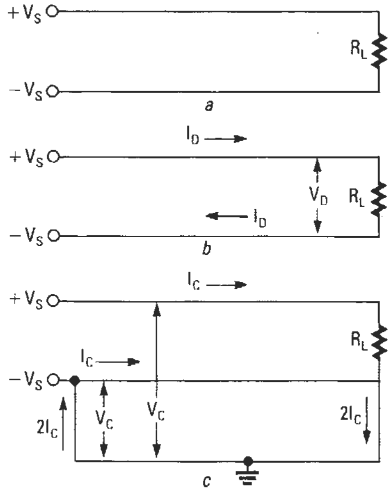


FIG. 2—TWO TYPES OF INTERFERENCE. In differential-mode interference (*b*) the noise voltage appears between the inputs of the circuit. In common mode interference (*c*) the noise voltage appears between each input and a third point called the common-mode reference.

Figure 2-*c* shows what happens when a *ground loop* is added to our circuit. Ground loops, which are undesirable current paths through a grounded body (such as a chassis), are usually caused by poor design or by the failure of a component. In the presence of an interference source, common-mode currents, I_C, and a common-mode voltage, V_C can appear, with the ground loop acting as the common-mode reference. The common-mode cur-

rent flows on both input lines, and has the same instantaneous polarity and direction (the current and voltage are in phase), and returns through the common-mode reference. The common-mode voltage between each input and the common-mode reference is identical.

Coupling itself can take place in one of several ways. Some of those include field-to-cable coupling, cable-to-cable coupling, and common-impedance coupling. Let's look at those types of coupling one at a time.

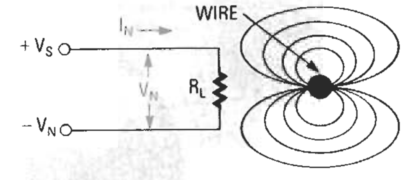


FIG. 3—FIELD-TO-CABLE COUPLING. If a circuit is placed within a time-varying electromagnetic field (such as that generated by a current carrying wire), the field will induce a current and voltage in that circuit.

The principle behind field-to-cable coupling is the same as that behind the receiving antenna. That is, when a conductor is placed in a time-varying electromagnetic field, a current is induced in that conductor. That is shown in Fig. 3. In that figure, we see a signal source, V_S, driving a load, R_L. Nearby there is a current carrying wire (or other conductor). Surrounding the wire is an electromagnetic field. The presence of the field causes the circuit to act as a loop antenna. As such, an interference current, I_N, and and interference voltage, V_N, are induced in the circuit. The magnitude of the induced interference signal is roughly proportional to the frequency of the incoming field, the size of the loop, and the total impedance of the loop.

Cable-to-cable coupling occurs when two wires or cables are run close to one another. Because any two conducting bodies have capacitance between them, called stray capacitance, a time-varying signal in one wire can couple via that capacitance into the other wire. That is referred to as capacitive coupling. Another mechanism of cable-to-cable coupling is mutual inductance. Any wire carrying a time-varying current will develop a magnetic field around it. If a second conductor is placed near enough to that wire, that magnetic field will induce a similar current in the second conductor. That type of coupling is called inductive coupling. In cable-to-cable coupling, either or both of those mechanisms may be responsible for the existance of an interference condition.

Figure 4 shows how cable-to-cable coupling works. Figure 4-*a* shows two lengths of cable (or other conductors) that are running side-by-side. Though there is no physical connection between the two cables, the properties we have just described make it possible for the signal on one cable to be coupled to the other. Mutual inductance, as shown in Fig. 4-*b*, makes the cables behave as if a poorly wound transformer were connected between them; stray capacitance, as shown in Fig. 4-*c* makes the two cables behave as if there were a coupling capacitor between them.

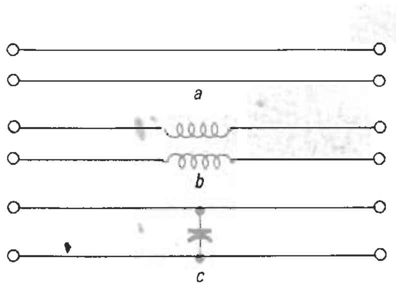


FIG. 4—CABLE-TO-CABLE COUPLING can occur via either inductive coupling (*b*) or capacitive coupling (*c*).

Either or both of the above-mentioned properties cause the cables to be electromagnetically coupled such that a time-varying signal present on one will cause a portion of that signal to appear on the other. The "efficiency" of the coupling increases with frequency and inversely with the distance between the two cables. One example of cable-to-cable coupling is telephone "crosstalk," in which several phone conversations can be overheard at once. The term crosstalk is now commonly used to describe all types of cable-to-cable coupling. Sometimes it is also used to describe any type of induced interference, though such use is incorrect.

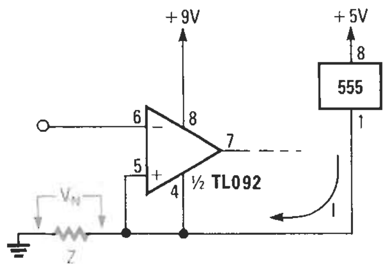


FIG. 5—BECAUSE THE GROUND return does not have an impedance of zero, the current from pin 1 of the 555 will cause a noise voltage to be generated. That voltage will appear in series with the input to the op-amp.

Common-mode impedance coupling occurs when two circuits share a common bus or wire. In Fig. 5 we show a circuit that is suseptible to that type of coupling. In that figure a TL092 op-amp and a 555 timer share a common return or ground. Since any conductor (including a PC-board trace) is not ideal, that ground will have a non-zero impedance, Z. Because of that, the current I from pin 1 of the 555 will cause a noise voltage, V_N, to develop; that voltage is equal to $I \times Z$. That noise voltage will appear in series with the input to the op-amp. If that voltage is of sufficient amplitude, a noise condition will result.

Curing EMI problems

Electromagnetic interference problems can be cured in three ways: through filtering, shielding, and isolation.

Filters are used to eliminate conducted interference on cables and wires, and can be installed at either the source or the victim.

Figure 6 shows an AC power-line filter. The values of the components are not critical; as a guide, the capacitors can be between .01 and .001 µF, and the inductors are nominally 6.3 µH. Let's see how that filter does its job. Capacitor C1 is designed to shunt any high-frequency differential-mode currents before they can enter the equipment to be protected. Capacitors C2 and C3 are included to shunt any common-mode currents to ground. The inductors, L1 and L2, are called common-mode chokes, and are placed in the circuit to impede any common-mode currents.

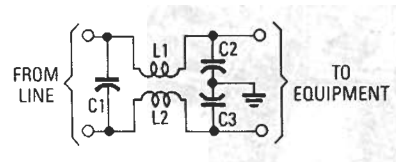


FIG. 6—THIS AC LINE FILTER is designed to eliminate both common-mode and differential mode interference currents.

Shielding is used to reduce the amount of electromagnetic radiation reaching a sensitive circuit. Shields are made of metal and work on the principle that electromagnetic fields are reflected and/or attenuated by a metal surface. Different types of shielding are needed for different types of fields. Thus, the type of metal used in the shield and the shield's construction must be considered carefully if the shield is to function properly. The ideal shield has no holes or voids, and, in order to accommodate cooling vents, buttons, lamps, and access panels, special meshes and "EMI-hardened" components are needed.

Isolation is often the cure for many EMI problems. In general, high-voltage circuits and devices such as power supplies and motors need to be isolated from low-voltage analog and digital circuits.

To be most effective, the above points should be considered during the design of a circuit. If nothing else, such consideration may help eliminate some difficult troubleshooting. In the next part of this article, we'll look at how you can design electromagnetic compatibility into your projects. **R-E**

Booooooom

I would like to offer a solution to the problem of electric fuel pump noise in R.L.'s Vega. First, remove the gas tank to get to the top of the fuel pump. From the "hot" terminal of the fuel pump, solder a .001 micro-farad capacitor to ground. Also, solder another .001 mf capacitor from the fuel gauge terminal to ground. Then replace the tank in the reverse procedure of removal. I have tried all kinds of external capacitors with no success at all. Do it my way and you'll clean up the noise in Vegas and Toyotas.

—L. M., Roper, NC

Old Hank suggests you empty the fuel tank first and eliminate all gasoline vapors. I once knew a garage man who put a pint of alcohol into the tank, sloshed it around and emptied it. He said alcohol fumes don't explode. Me? I'd fill the tank with water.

LINE NOISE

Q. ***I have a serious problem with static interference on my CB radio (a mobile used with a line-powered supply). It's not there all the time, but close to it. The interference usually comes on around 6:45 AM, increasing the ambient noise level from about S2 to S8. I think the source is on the ac line, because it is on or off at regular intervals. It's not caused by any of the appliances in my house. Can you recommend a filter that I can use to block the signal?—Jeff Brown, Akron, OH.***

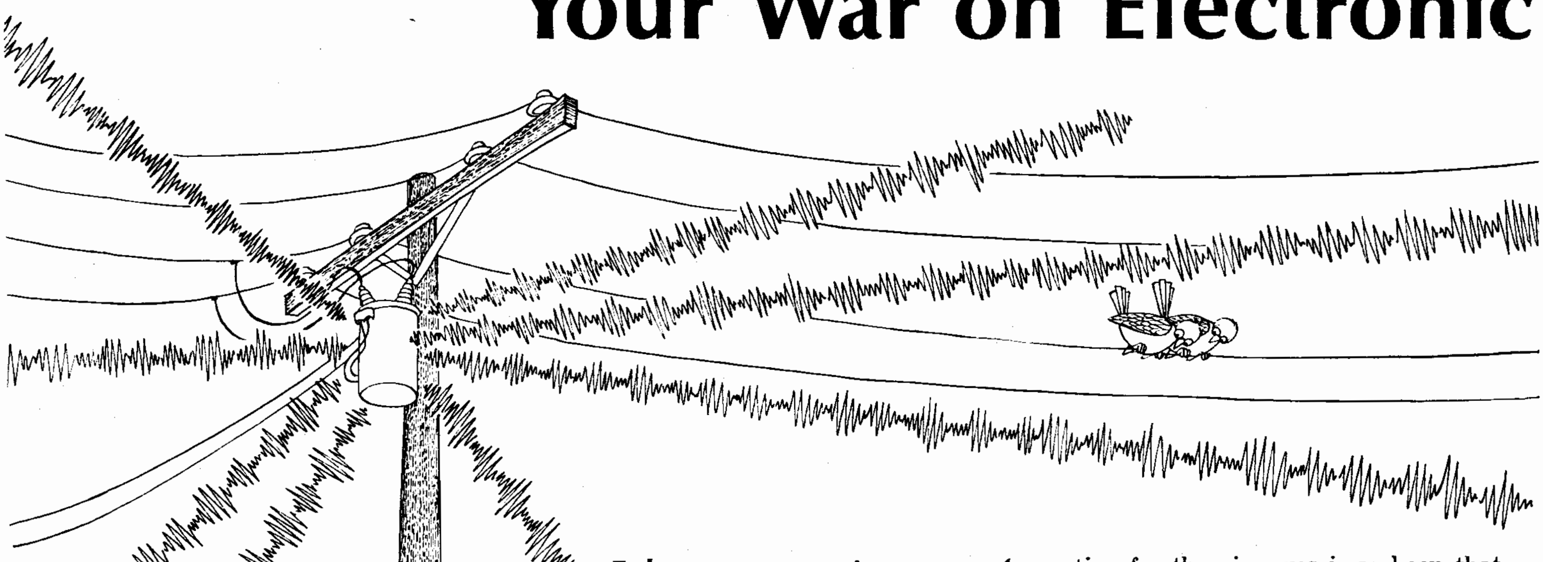
A. First, try powering your transceiver from a 12-volt battery. If the noise is no longer present (which I doubt), it is reaching the transceiver via the ac line. This can be prevented by installing a "brute force" filter such as those manufactured by Sprague, J.W. Miller, Cornell Dubilier, etc.). If the interference persists, it is being radiated by the ac power line. There is *no* filter you can install between the antenna (which is picking up the noise) and the transceiver that will eliminate the noise but not the desired signal. The way to cure this problem is to sniff out the source of the radiation, which can be anything from a brush-type motor to an aquarium heater thermostat. Use the CB transceiver or a small AM radio to locate the source. A directional antenna like a small loop or ferrite loopstick can help isolate the offending appliance. If the interfering unit can be located, bypass capacitors or a line filter, (or even shielding) should be used to suppress the noise.

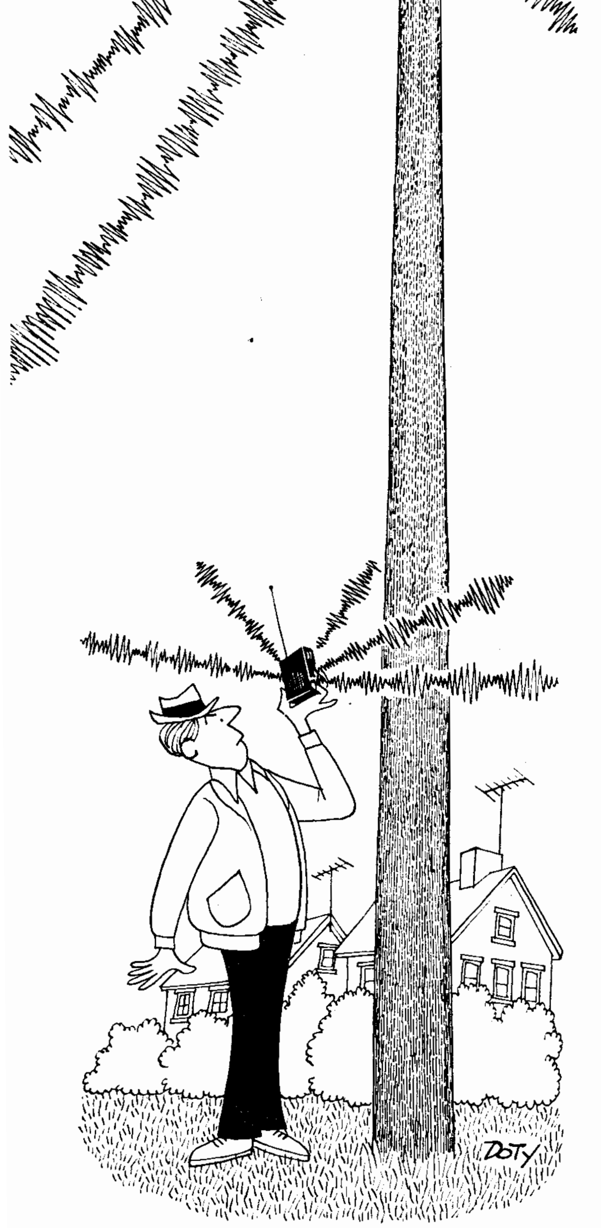
Sometimes, noise is generated by a component in the power line itself—a leaky insulator, intermittent contact, or loose hardware. Noise sources can be hard to locate, because the noise can travel along the line for some distance. Many power companies have interference-tracking programs, and will follow up complaints from hams, SWL's, and CB'ers. This type of interference can be continuous or intermittent, sometimes linked to the weather. Your problem suggests not a power line disorder but an electrical component drawing power from the line. However, your local power company might be able to offer more detailed information or some assistance.

Hav

PS EXTRA: 5-PAGE SPECIAL REPORT

Your War on Electronic





Enhance your enjoyment of entertainment electronics, and help your neighbors

By LEN BUCKWALTER
ILLUSTRATION BY ROY DOTY

The next time you drive down your street you may trail a wake of electronic pollution. Spark plugs shower neighborhood TV screens with annoying slash marks. Friction inside your car's front axles sends sizzling static to nearby car radios. Your own stereo tape player may sound a peculiar whine that rises and falls with your foot on the accelerator. Stretches of road lined with high-tension wires can drown your AM radio in a sea of "hash."

These signs of electronic pollution prove just as annoying at home. Maybe you can't listen to FM stereo when a vacuum cleaner is going. Or your TV paints curious herringbones on some channels, or its loudspeaker emits 15-year-old voices talking like police dispatchers.

The explanation of electronic pollution has a familiar ring: We are loading a natural resource—the electromagnetic spectrum—beyond its capacity. It's the region of invisible waves that carry a myriad of signals, from radio and TV broadcast to radar and two-way communications.

As with our air and water, this supply is straining under spiraling public demand for more and varied uses. In 1922, manufacturers built some 100,000 radio sets; last year they spewed out more than 80 million TVs, radios, phono and tape machines. Competition for the airwaves is so keen that police in California talk on an unused TV channel.

Squeezing so much into a shrinking medium is only one cause of electronic pollution. Today's receivers are often a marvel of sensitivity, but this quality also encourages interference pickup. The migration of people to cities jams too much electronic equipment—for home and for business—into small geographic areas.

There are dozens of steps you can take to reduce electronic pollution. They'll not only lessen interference transmitted to a neighbor's home, but will enhance the enjoyment of your own equipment. Antipollution measures clarify TV images, clear up radio reception, and improve hi-fi listening. In your car they'll make a skittery FM receiver more enjoyable.

The clean-up job is done with numerous accessories now available to filter, suppress, and bypass wandering waves. Most are reasonably priced (below $10) and widely sold in electronic stores or by mail order.

You won't need any special skill or costly instruments to fight electronic pollution. The battle requires, rather, a crafty approach to appraise the symptoms, identify the source, then apply the cure. The first part is easy, since dozens of polluters have giveaway clues that can be identified by the examples and illustrations on the following pages.

In some instances, the simplest filter cures a bad case of interference; in others, a combination of remedies turns the trick. But, by waging war on electronic pollution, you'll be contributing to a cleaner electronic atmosphere—and enjoy better TV and radio reception to boot.

Pollution

How to cure television interference

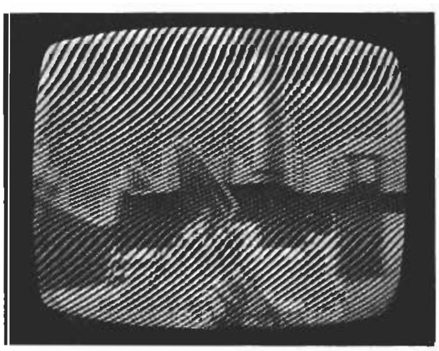
Tracking down interference to television reception is immeasurably aided by the expensive oscilloscope in nearly all American homes. You don't have one? It's your TV screen. Almost every brand of interference appears on this built-in tester with a characteristic pattern, as the following photos reveal.

But before trying any interference killer, you must be certain the trouble is not weak reception, which often produces similar symptoms. The antenna must have no broken elements, the lead-in should be checked for cracking or short circuits. On a windy day, sudden flashes of light on the screen almost certainly mean there's a broken conductor somewhere in the lead-in wire, usually where it attaches to the antenna.

If your set has tubes, a weak RF amplifier in the tuner can cause snow. If the set is several years old, dirty contacts inside the tuner can also produce interference-like symptoms. So clear up any trouble in the receiver and antenna system before proceeding. If you have an indoor antenna or rabbit ears, you'll probably fight interference better by changing to an outdoor type.

Most cases described below tell of interference *to* television reception. The TV set is also a notorious interference *generator*. Place a portable radio next to an operating TV, tune across the dial, and you'll hear numerous "birdies." They're caused by strong radiation (harmless to you) from the TV's horizontal scanning circuits. The easiest solution: put as much distance as possible between any TV and radio.

Bad cases of interference from TV have been treated by lining the inside of the TV cabinet with copper screening, which is then grounded. This means removing the chassis. But here are some interference problems you can easily do something about:



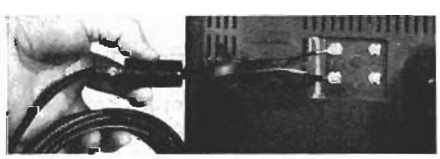
Harmonic interference. This appears as a series of lines, or a herringbone pattern, on one or two channels at once. The source is often a nearby transmitter in ham, CB, FM, or police two-way service. Besides normal signals, these stations unavoidably emit "harmonics" or multiples which create interference.

For example: Ham and CB stations operating near 28 mHz also send out a harmonic double on 56 mHz. Since 56 mHz is also TV Channel 2, there is risk of interference to sets in the vicinity. FM stations also produce harmonics.

But installing a harmonic filter also reduces the desired TV channel signal. A rotating, directional antenna might help some by favoring the TV station. A better cure is at the source (next photo).

The cure. If you can locate the local ham or CB operator causing interference, ask him to install a *low-pass filter* on his rig. If he's neighborly, he may follow well-known methods to reduce "TVI"—radio lingo for television interference: the filter (see photo), good shielding and bypassing. Don't be high-handed and say he has no right to cause television interference. In nearly all TVI FCC-investigated cases, the TV receiver is at fault, not the transmitter. Best results occur with amicable negotiation, since hams needn't "clean up" rigs beyond a reasonable point.

Ignition interference. This appears as short black, white, or colored dashes in horizontal bands across the screen. Another clue: It grows worse as traffic increases on a nearby road, or disappears during the wee hours. When windows are open, you may hear the vehicle and trace its progress across your TV screen by its ignition interference. Since you cannot suppress electrical noise of passing vehicles, the remedy is at your antenna, as shown in these examples.



One cure. If there's a choice, you can reduce ignition interference by running the antenna lead-in on the side of the house away from a busily traveled highway. Another noise-killing technique is replacing the entire lead-in with a shielded antenna lead-in. Since "shielded twinlead" has the same value of impedance—300 ohms—as common twin lead, it is directly interchangeable. A foil coating resists ignition noise pickup and a ground wire is supplied to drain away interference.

Another shielded line with high noise immunity is coaxial cable. Since it's rated 75 ohms (not 300) a matching transformer is installed at the set and on the outdoor antenna terminals.

Cure with boosters. Another step to reduce ignition interference is to install a preamplifier or booster in your antenna system. Strengthening the signal before it enters the lead-in increases resistance to noise pickup. Do not install an *indoor* booster behind the set for this purpose; it will merely increase the interference. The amplifier must be fastened at the outdoor antenna terminals. Antenna-mounted boosters are available for any combination of service: VHF, UHF, FM, or all three. UHF reception is especially susceptible to noise on a long lead-in run (say 100 feet) and a booster can help.

High-pass filter. Interfering harmonics that enter directly on channel frequencies, signals below the TV band (which starts at about 54 mHz) can also force themselves into a set to cause torn, unstable images, poor sync, voices, even oddly reversed, negative pictures. Usually, such signals arrive from strong, close-by transmitters.

A clue is that interference tends to appear simultaneously over many TV channels. A popular remedy is the "high-pass filter" shown here. It passes signals above 52 mHz (thus admitting TV channels) but attenuates potential interference signals below that frequency.

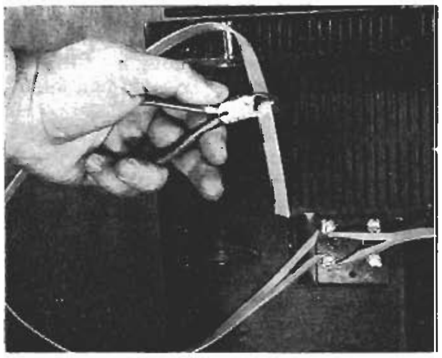
Best location is inside the set, close to where the lead-in attaches to the tuner, but mild cases are cured by the rear-cover position shown. Cost of the filter must be borne by the TV-set owner.

Adjacent-channel wave traps. A TV set may respond to more than just the channel to which it is tuned. In areas where

signals on adjacent channels (3-4, 9-10, etc.) are strong, the receiver is unable to reject one channel above or below. The symptom on the screen is usually a dark bar (above) which shifts across the tube, windshield-wiper fashion.

Wave-trap accessory devices zero in on an adjacent-channel signal elbowing its way into the TV tuner. The one pictured (previous page) has two tunable traps: one for the low group of channels, 2-6; the other for the 7-13 group.

As you view the desired channel, the knobs are turned until picture tearing, herringbone patterns, or other interference is minimized. The wave trap shown is called the TV Clarifier.



Tuning-stubs. A favorite cure for adjacent-channel interference that's cheap and easy is a tuning stub—a length of twinlead cut to an exact length and connected to the TV antenna terminals (along with the regular antenna lead). Electronically, the stub circulates the offending signal in a direction that causes self-cancellation.

This achieves the same result as the tunable trap just described, but is limited to a single interfering frequency. Which is better for your interference problem can only be answered by trial-and-error experiments.

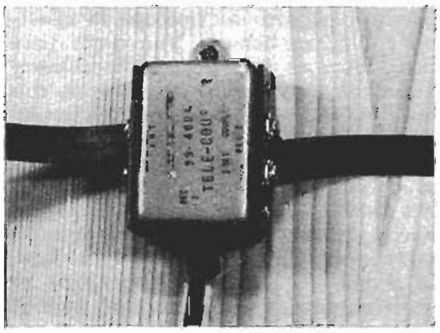
The stub must be carefully cut: Begin with eight feet of fully extended twinlead and short-circuit across the wires with a razor blade, side cutters, or knife. Experimentally move back and forth, cutting into the insulation, until you find the point of least interference while viewing the screen.

Cut the twinlead here and twist together the bare copper wires. The stub is roughly eight feet near Channel 2, and about two feet near Channel 13, with intermediate lengths in between.

Co-channel interference. TV stations are deluged every spring by complaints of interference from set-owners. Symptoms: Fine scanning lines across the screen coarsen, as shown; grinding noise is heard in the speaker, and fuzzy faces may appear behind the picture.

These are clues to co-channel interference—two stations are being received on the same channel position. The FCC generally prevents this by locating stations on identical channels well out of the broadcast range of each other.

In spring, however, increased electrical activity in the ionosphere creates the sporadic-E layer, which has a profound effect on TV signals. TV normally travels only line-of-sight, but this special condition carries them hundreds of miles. Mainly you must wait until conditions change. Some relief may be possible with an antenna that can be rotated away from the interfering signal but still intercept the desired channel. It's often a compromise.



Coupler interference. One sign that a TV set not only receives, but transmits, signals shows up as coupler interference. It happens when two TVs are connected to a common antenna with a two-set coupler (shown above).

One difficulty is that the splitting process reduces the signal delivered to each TV receiver by one half. If you already have some interference, or possibly see a trace of snow on the picture, a coupler will aggravate the situation.

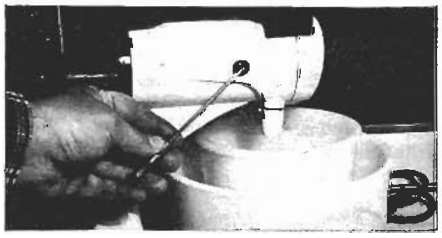
Another difficulty occurs as the local oscillator inside the TV set radiates a bit of signal back to the coupler. Although the signal is largely suppressed by the set maker, enough may reach the second TV through an inferior two-set coupler and cause a herringbone pattern. It appears on certain channels when both sets are in use. You can often avoid mutual interference by using a coupler of high quality to win good electrical isolation between the receivers.

How to cure radio and appliance interference

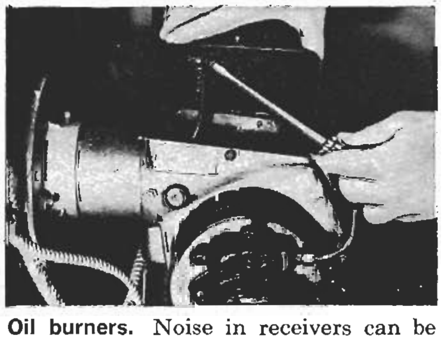
Household appliances generate considerable interference because they chop electrical current in an irregular fashion. The result is a rich supply of radio waves that spill back into the AC line or take off into the air.

They're heard on radio and TV (or even a telephone) as assorted buzzes or hash. The culprit is easy to identify if you can hear the appliance operating—a vacuum cleaner or electric razor, say—while suffering the interference.

It's best to nip such interference at the source. Although remedies described elsewhere in this article attach directly to the radio or TV, they treat the symptom. It's far better to attack the noise *generator*, not the victim. By treating the source, you cut off routes through house wiring and direct radiation through the air. And when you cure a noisy appliance you prevent potential interference to all your receivers and possibly the neighbors', too. Some common noisemakers and their cures:



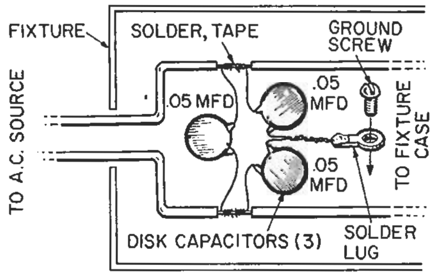
Electric motors. Carbon brushes in electric motors are often vigorous noisemakers. The cause—sparking due to brush wear and dirt—isn't difficult to treat. Be certain the appliance plug is removed from the wall, then take out the brushes and blow out all foreign particles inside the case. A cloth dipped in alcohol is also helpful. If the copper commutator is blackened from the brushes, use very fine sandpaper to restore it to good condition. Never use emery paper. If brushes are worn or their pressure springs weak, replace these items.



Oil burners. Noise in receivers can be caused by oil burners producing high-voltage discharges to fire fuel. It is not unlike spark-plug interference in automobiles. If you suspect this source, turn down your heating thermostat to see if the disturbance to radio or TV reception disappears within 15 minutes or so. Your oil company knows the problem and should have bypassing devices to deal with it. It's a job for the serviceman; contact the oil company for details.

Plug-in-bypass cure. Shown is one of the simplest devices for reducing appliance noise. The molded socket plugs into an AC outlet. A disk-ceramic capacitor (rated at .1 mfd, 200 working volts) inside it shunts noise energy to ground before it can back up into the AC line and cause trouble. It is inexpensive and convenient to use—you merely plug the appliance into it.

But a simple capacitor may not cure stubborn cases. Try it on the offending appliance first, then on the receiver experiencing interference. A pair may prove helpful, one in each location.

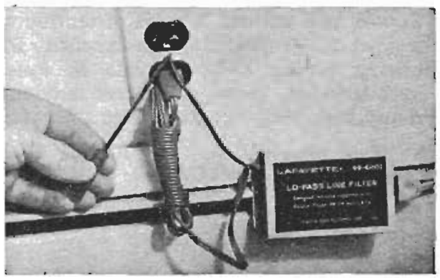


Fluorescent lights. These lamps cause prolific interference to radio reception because they create rapid electrical discharges 60 times a second. It's easy to spot by turning off the light switch while listening to the radio. The noise is heard as a rough buzz. In the case of portable lamps, try one of the bypass or filter devices already described.

For permanently installed fluorescent fixtures, you'll need a different approach. These lamps should be equipped with bypass capacitors mounted inside the wall or ceiling fixture, as in the diagram above. The careful handyman should be able to do the job by first removing AC power completely from the lamp (take out the house fuse or open the breaker), and lowering the fixture to expose the AC wiring.

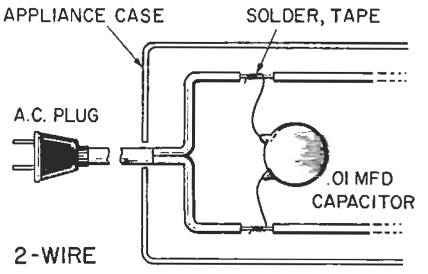
Where the wires enter the fixture, mount three capacitors, as shown in the diagram. They are 0.05-mfd disk capacitors rated at 600 working volts. Note how one lead of each capacitor connects to the AC line. The connection is made by removing some wire insulation, soldering the capacitor leads, and then covering the splice with plastic electrical tape to prevent any possibility of a short circuit.

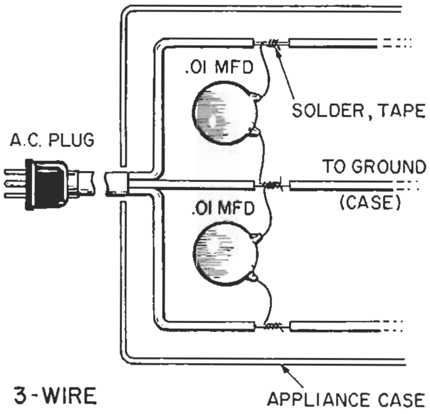
Two of the capacitors have their leads joined and are fastened under a nearby screw that grounds to the fixture case. A solder lug on the ground wires makes this easier to do.



Line-filter cure. This is often more effective than a simple bypass. Besides its capacitors for bypassing, the filter has coils that choke the flow of noise frequencies into the AC line. Try it on such noise generators as fluorescent lamps and portable appliances.

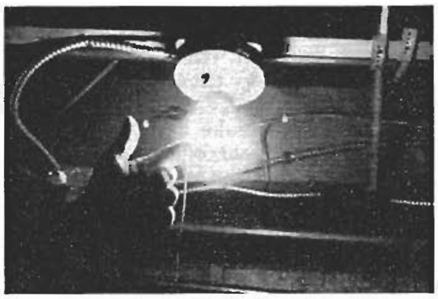
If interference is not reduced to a satisfactory level, you may also have to use additional line filters on the radio, TV, or hi-fi receiver. Note that a ground wire is seen emerging from the device. This should be connected to an electrical ground to aid filtering.



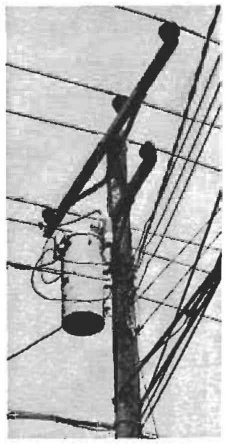


Other appliance noise. Motorized appliances, such as vacuum cleaners, produce a share of interference. Although a line filter or other external aid already described can cure part of the trouble, an internal bypass capacitor reaches interference closer to its origin.

An effective step is to open the appliance case and trace the AC leads. Where you find room to, install a 0.01 disk-ceramic capacitor rated at 600 working volts; wire it across the line, as shown in the top diagram. If the appliance has a three-wire cord (a trend these days) install two 0.01 units to ground (bottom diagram). Just be certain "hot" bare wires are soldered and taped to prevent risk of short circuits.



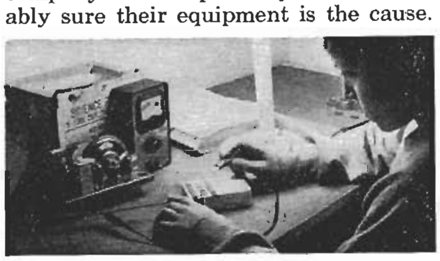
Incandescent lamps. Rarely do incandescent lamps produce the degree of interference possible from fluorescent types. Still, its possible that in your attic or cellar an ancient "straight-wire" filament lamp is triggering itself into high-frequency oscillation. It can emit signals that become audible in radios, or appear as herringbone stripes in a TV image. When you suspect this brand of interference, turn off lamps one at a time to determine the source. Since the lamp may produce intermittent oscillations, it may not cooperate during tests. In this case, coax it to oscillate with gentle tapping.



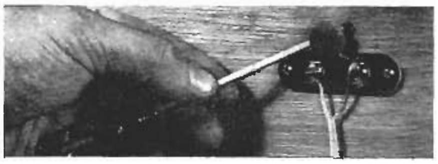
Power lines. Occasionally a cause of interference is high-voltage wires that produce noisy "corona" discharge; lower-voltage equipment suffers weather, dirt, cracking, contact with trees. These conditions are variable; you may not hear interference, usually a rough buzz, in any consistent pattern.

You may hear it on a car radio tuned to a weak station as you drive near the source. If it's near your home, a walk with a transistor portable may pinpoint a noisy pole, interference in the radio rising and falling in strength with distance. But this is not a foolproof method since lines carry noise great distances.

A TV's rotating antenna should be swung to point in the general direction of strongest noise. Notify the power company for a repair if you're reasonably sure their equipment is the cause.



Strange voices. Peculiar voices on your radio could be a neighborhood electronic genius playing with a "wireless mike." These are harmless hobby projects that broadcast the voice to a radio usually located in the same room. The FCC permits such gadgets, and they're fine activity for youthful disc jockeys. The problem flares when the constructor violates the law by adding an amplifier or long antenna (thereby greatly increasing range), then filling the airwaves with language or programs in very bad taste. To make a protest, call the nearest FCC field office. The case is usually closed after an official investigator informs the shocked parents.



Spooky hi-fi voices. This is often due to a powerful transmitter not far away inducing strong radio signals in loudspeaker wire. Since such wires may run many feet, they act as pickup antennas to feed the signal back to the amplifier.

One method for short-circuiting interference of this sort is to connect a 0.01-mfd disk-ceramic capacitor (of 50 working volts or higher) across the speaker terminals, as shown. Bad cases may require another capacitor at the speaker terminals on the amplifier.

A more drastic cure requires 50-pf mica capacitors from preamp input grids to ground (270-pf base to ground for bipolar transistors).

Quick-check tabulations help cure interference to vehicle and boat radios

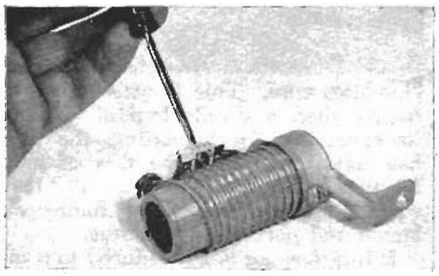
To test, have engine idling, radio on and set for normal listening. Adjust dial between stations. If radio is crystal-controlled, as in CB or marine two-way, turn to an unused channel (no station being received during tests).

SOURCE: Spark plugs.
SYMPTOM: Popping noise heard in radio speaker that changes with engine rpm. Disappears when ignition is turned off or to accessory position.
CURE: 1) Install suppressor-type spark plugs. 2) Install clip-on suppressors

(left and right edges of card in photo). 3) Check spark-plug cables for cracking. 4) Install kit for shielding spark-plug cables, distributor, and ignition coil.

SOURCE: Generator.
SYMPTOM: Buzzing or whining that rises in pitch as engine speed increases.
CURE: 1) Check condition of carbon brushes; sparking causes interference.

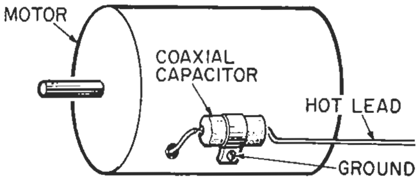
2) Install 0.5-mfd, 40-amp coaxial capacitor (photo above) to armature



terminal. 3) Install tuned-trap filter (photo above) on armature terminal.

SOURCE: Alternator.
SYMPTOM: Raspy, rough whine that rises in pitch as engine speed increases.
CURE: 1) Clean dirty slip rings, replace worn brushes. Recheck at 10,000-mile intervals. 2) Install 0.5-mfd, 40-amp coaxial capacitor on battery (output) terminal. 3) Install a tuned-trap filter on the battery terminal and adjust it for minimum interference.

SOURCE: Windshield-wiper motor.
SYMPTOM: "Hashy" sound as wiper motor operates.

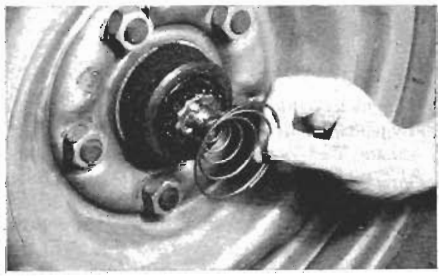


CURE: Install 0.25-mfd coaxial capacitor on motor frame, with hot wire to end terminals as sketched.

SOURCE: Poor bonding.
SYMPTOM: Increased interference from any of the preceding sources.

CURE: Install braided cable from hood to frame, and engine to frame. Additional bonding points: air cleaner to engine; exhaust pipes to frame.

SOURCE: Wheel static.
SYMPTOM: Popping noise that usually starts at over 20 mph. Noise changes in pitch with road speed.

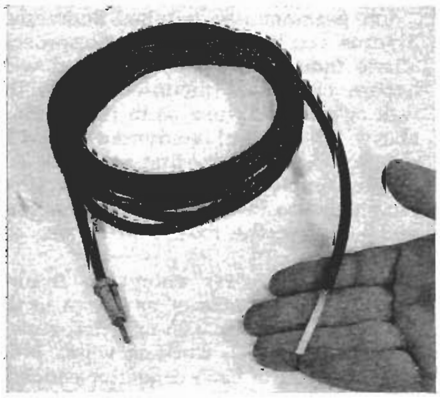


CURE: Install static-collector springs under front-axle dust covers.

SOURCE: Tire static.
SYMPTOM: Ragged noise that changes with speed, usually ceases on dirt road.

CURE: Obtain kit of antistatic powder and insertion tool. Inject into each tire valve with air hose.

SOURCE: Unknown.
SYMPTOM: Any noise of indeterminate origin while engine operates.



CURE: Construct "RF Sniffer," a coaxial cable plugged into antenna socket and held near suspected sources. Remove two inches of shielding.

COMMUNICATIONS CORNER

Digital RFI problems

HERB FRIEDMAN, COMMUNICATIONS EDITOR

HIGH TECHNOLOGY OFTEN CREATES A multitude of unforeseen problems. For example, back in the days when we were told that we should be seen and not heard, we got rid of insects in the vegetable garden by stomping on them, or we simply shared what mother nature had provided—we got what the insects didn't destroy. In time, we built an arsenal of chemicals to kill the insects. They did the job but they also destroyed the land, killed fish and birds, etc. The same problem often occurs in electronics. (You pay for what you get.)

In electronics, many of us grew up on Pyranol capacitors, a tremendous breakthrough in capacitor technology. Unfortunately, the stuff that makes it a great insulator and coolant can also harm birds, fish, game, and people. It's not our intention to start any arguments, but rather to simply point out the way the real world works. Remember that there is no such thing as a "free lunch." Every new "breakthrough" in the state-of-the-art hurts someone or something.

The latest "breakthrough" to cause unforeseen and extensive problems is digital communications or more precisely, digital anything. Back in the days when we simply stomped on garden insects, there were only two major forms of RFI (*R*adio *F*requency *I*nterference) as far as the general public was concerned. The first type was harmonics and spurious emissions from amateur-radio transmitters that wiped out some TV channels—usually Channels 2 and 4 (see Fig. 1). The other type of RFI was hash or electrical noise from the local utility's powerline hardware, such as "pole pigs" (powerline transmission transformers) and capacitor banks that jammed or wiped out radio communications from below the broadcast band to well up into the TV channels. And if you were lucky enough to escape the hash caused by powerline hardware, your neighbor's vacuum cleaner or mixer was certain to throw you a zinger every once in a while. But all that was easily handled: amateur-radio operators simply cleaned up their transmitters. Recently, however, the FCC for the most part has just ignored powerline and appliance hash.

But digital RFI is something else. It's hard to avoid and often hard to clean up, but it certainly can't be ignored because it's starting to permeate everything. Digital RFI, rather than the marketplace, might well determine whether some fantastic new communication technology will ever become viable.

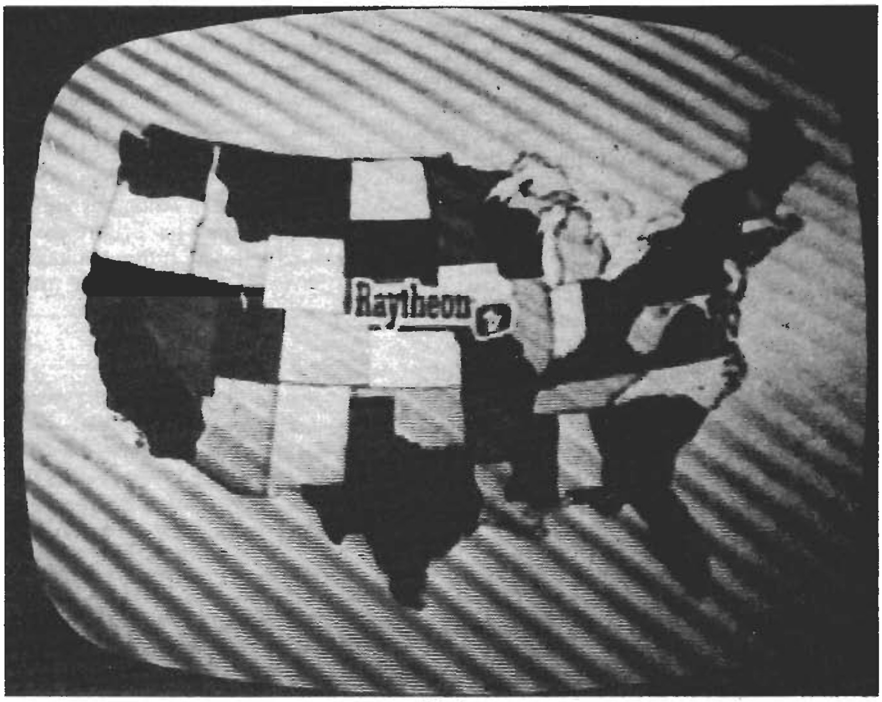


FIG. 1

Digital noise generators

Turning to home entertainment, the distributors of high-fidelity equipment see the digital disk as the gizmo that will eventually revive the Hi-Fi industry. But the engineers who design the systems know that the 41-kHz sampling rate is going to produce harmonics right up into the broadcast band. Without extensive shielding and RFI suppression (a technology not presently germane to Hi-Fi equipment), we might well be listening to our neighbor's latest records instead of the local DJ. That's because the signals from your neighbors digital-disc recording might be radiated into the air, superimposed on the radio transmission, and picked up by your radio receiver.

And now we come to the "biggies:" videotext, the computerized transactional services such as banking and shopping at home, and teletext. Between allowing AT&T to enter digital services via the telephone system, the transactional services through cable TV, and the recent approval by the F.C.C. for digital teletext encoding on TV signals, it's conceivable that eventually most homes will have digital signals running throughout the house wiring—radiating into places where they don't belong. Already engineers and technicians are worried about whether the other digital services will affect theirs; after all, it takes just a glitch or two to wipe out a simplified (non-redundant) digital transmission.

Digital RFI

Digital RFI comes about because harmonic generation is indigenous to the very waveforms used in the digital process. Whether the waveform is narrow or wide it starts off with "square" edges, as shown in Fig. 2-a. The leading and trailing edges are steep wavefronts that, if you recall from your early studies in electronics, are efficient generators of odd-order harmonics. Then there's also the digital repetition rate. Computer hardware such as that used for videotext and transactional services operate in the range of approximately 300 Hz to 19 kHz, and are controlled or determined by digital signals in the 2 MHz to 5 MHz range. Essentially, we're generating RFI from the mid-audio range well up into the RF region (Fig 2-b). And we're feeding much of that interference through unshielded cables to recorders, printers, video dis-

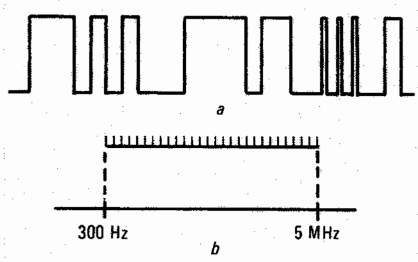
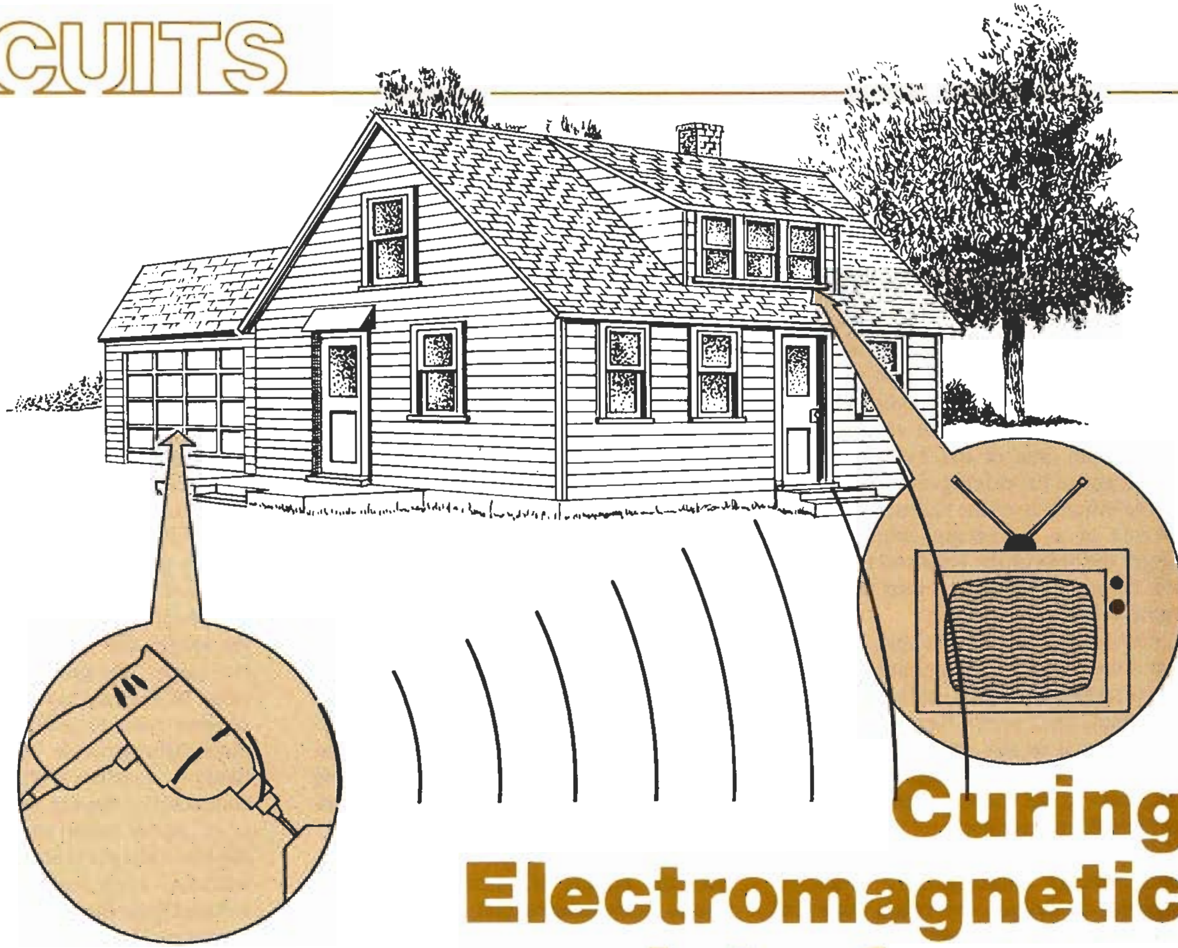


FIG. 2

plays, telephone equipment, and powerlines. (Powerlines? Yes powerlines.) Have you ever heard what a commonly-used digital remote-controlled light switch does to broadcast reception?

In actual fact, we haven't begun to experience the effects of consumer-equipment digital RFI on home and commercial communications systems. It might well determine just how far we can go with computerized high-tech devices in the years to come. R-E



Curing Electromagnetic Interference

MICHAEL F. VIOLETTE

This month, we show you how to head off interference before it enters your electronic equipment. We look at how to deal with power-line transients, too!

Part 3 ELECTROMAGNETIC INterference (EMI) can couple into your sensitive equipment in two ways. One of those is via radiation. Last time, we saw some of the techniques that can be used to eliminate that coupling path.

The second way is through conduction. This month, we'll turn our attention to conducted interference and see the various ways that we can combat its harmful effects.

As we saw in Part 1 of this article (see the November 1985 issue of **Radio-Electronics**), there are two forms of conducted interference. In *differential-mode* interference, the interfering signal appears across two conductors, such as a pair of single lines or the hot and neutral sides of a power line. In *common-mode* interference, the interfering signal appears on *both* conductors, with the reference being a third point (such as a chassis ground). In common-mode interference, the interfering signals on the two conductors may not be of equal amplitude, but they are in phase.

There are a couple of ways to deal with conducted EMI. One way is to carefully plan out and design any interconnecting cabling. Often, however, you have no control over such cabling (such as in the case of power or telephone lines). In those cases, the only alternative is to install a filter between the line and the equipment.

Cable design

Cables can act like pickup and receiving antennas. When a cable is acting like a pickup antenna, a radiated EMI signal is converted into a conducted EMI signal, which travels on the wires in the cable, through shields, and right into your circuitry. Or, conducted noise (from the commutator in the blower motor of a hair dryer, for instance) finds its way onto the power cord, travels over the AC wiring, and then into the "victim's" circuitry through its power cord. Either way, the result is interference.

Your projects can either radiate or pickup EMI, or they can do both. In this installment, we will see how to deal with radiation of EMI, but the techniques discussed are also effective against EMI pickup in the vast majority of instances.

Last time, we saw that antennas can be classified by their impedance; of interest here are the low-impedance types. Let's see why.

In many circuits, the operating voltages are relatively low, often ranging between 5 and 24 volts; the impedance of the source of that voltage, the power supply, is generally low. To get an efficient radiator when the EMI antenna is being driven by a low impedance voltage source, the "antenna" must have a relatively low impedance. One type of low-impedance antenna is a simple wire loop. In a circuit or a project, that loop can take many forms. For instance, any loop of wire, such as the power feed and return to a disk drive, or the power supply and ground traces on a PC board can become a surprisingly efficient radiator. Loops can also be formed by any signal-carrying conductors such as the data or clock lines.

Just how much energy is put out by those unintentional antennas? The radiated field strength of a loop is proportional to the product of the current in the loop, the frequency of the signal carried by the loop, and the area of the loop. All three variables play a role in determining how much energy is output. The current in the loop determines how much energy is available to drive the radiator. The area of the loop, and the frequency of the signal that is driving it, determine the efficiency of the radiator. Generally speaking, the greater the area of the loop and/or the frequency of the driving signal, the greater the efficiency of the radiator. The same is true of a "receiving antenna"—the larger the area of the loop and the greater the frequency of the received signal, the more efficient the pickup.

Obviously, the current and frequency are determined by the parameters of the circuit; that means that, in the majority of the cases, their values can not be reduced (or changed in any manner) without affecting the correct operation of the circuit. The area of the loop, however, is an entirely different matter.

That leads us to one of the most important rules for reducing EMI: When designing or laying out cable runs and printed-circuit board traces, keep the area of any potential loops small. Consider the simple circuit shown in Fig. 1. It consists of a signal source, a load, and a ground. The area of the loop is formed by the product of the *physical* distance separating the source and the load (L), and the physical distance separating the "signal" and "return" (grounded) leads (H).

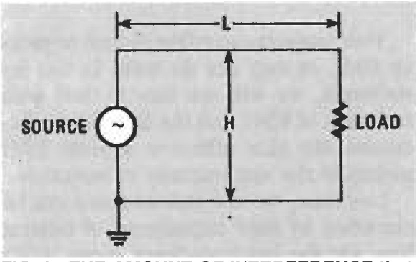


FIG. 1—THE AMOUNT OF INTERFERENCE that a circuit can pick up or cause is largely determined by the physical size of the loop that it forms.

The circuit shown can be realized in a number of ways. For instance, the source could be the output of one gate while the load could be the input of a second gate. The return line could be a common bus or the chassis ground of the project. But no matter what form the circuit takes, under the right circumstances, the whole thing can become a large radiating loop.

The way to minimizing the radiation output by such a loop is to reduce the distance between the source and the load, run the signal and return leads as close together as possible, or both. For instance, by running a dedicated return line alongside the the signal line, rather than having the return current flow through the chassis ground, the loop area is reduced significantly. With dedicated signal/return cabling, H is effectively reduced to the thickness of the insulation surrounding the two wires. That solution works, and it is much cheaper than using a shielded cable.

When dealing with differential-mode currents, using twisted-wire pairs for the signal line and the return can further help reduce interference. Twisting the wire pair significantly reduces the overall area of the loop. Each twist of the wires does form a small radiating loop, but the twisting causes the loops to be *polarized* in opposite directions. The result is that the radiation from one loop cancels out the radiation from the adjacent loop. The tighter the twisting the better the cancellation.

The foregoing assumes that the currents in the two lines of a twisted pair are balanced—that is, that they are equal in amplitude. The closer the lines are to being balanced, the better the reduction of differential-mode radiation and pickup.

Balancing also helps the circuit to reject the effects of common-mode currents. Let's assume that we are dealing with two lines feeding two inputs on an unbalanced receiver (a logic gate, etc.). Further, let's assume that the common-mode currents traveling in those lines are equal. Here, unbalanced means that the impedances, "looking" into the receiver, from all lines to ground are unequal. The result is that when the equal common-mode currents encounter the unequal impedances, unequal voltages are generated at the inputs. Those unequal voltages stimulate the inputs to the receiver, just as a normal signal is supposed to, and an undesired output signal can result.

That is a common problem. In fact IC op-amps have a parameter called the Common Mode Rejection Ratio (CMRR). That parameter is a measure of how well the op-amp can reject the effects of a common-mode input. The interference caused by common-mode currents is the reason that balanced line drivers/receivers are used in many cases for long signal-cable runs.

Crosstalk

Crosstalk is caused by the mutual inductance and parasitic capacitance that exists between any two conductors (see Fig. 2). One common example of crosstalk is the phantom conversations that are often overheard when you speak on the telephone.

Though the parasitic capacitance and mutual inductance are shown lumped in Fig. 2, those quantities are distributed along the length of the lines. Although there are no physical connections between the lines, the electrical coupling provided by the parasitic capacitance and parasitic inductance provides a path for the current in one wire to "enter" the other. At low frequencies, mutual inductance is the primary coupling mechanism; as the frequency gets higher, parasitic capacitance becomes the primary mechanism.

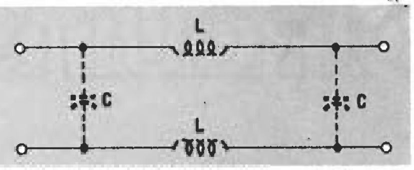


FIG. 2—TWO PARALLEL LINES are electromagnetically coupled because of the mutual inductance and parasitic capacitance that exists between them. That coupling is what causes the phenomenon known as crosstalk.

The closer the cables are together and the longer the parallel runs between the two cables, the greater the coupling. Because of that, the obvious and most inexpensive way to reduce crosstalk is to physically separate conductors that are likely to interfere with each other. Move conductors carrying high voltages (such as AC power cords) away from ones carrying low voltages (such as signal lines). In addition, keep input and output cables isolated from the wiring inside the equipment box. In addition, keep any parallel runs between conductors as short as possible. One way to do that is to make extensive use of twisted-wire pairs. Note that lines that cross at 90° angles have almost no mutual inductance and negligible parasitic capacitance (a couple of picofarads).

Shielded cable design

Using twisted-wire pairs is an effective method of reducing differential-mode interference. To combat common-mode interference, shielded cable is more effective. To combat both types of interference, shielded cables are often made of twisted-wire pairs. In very noisy environments, "double-shielded" cables, in which the individual twisted pairs are also shielded, are used.

The effectiveness of the shielding depends on the nature of its ground. Or, more specifically, whether one end or both ends should be grounded. When dealing with low frequencies, it is usually sufficient to ground the shield at one end only (usually the receiving end). In addition, grounding the shield at both ends can cause a ground loop to be formed. By low frequency we mean that the shield is electrically short when compared with the wavelength of the EMI signal (i.e., the shield is shorter than approximately 1/20 of a wavelength). Under that condition, every point on the shield can be considered to be at ground potential. At higher frequencies, however, both ends must be grounded. That grounding should be made directly to the chassis ground, and at the point where the cable enters the circuit enclosure.

The wide usage of flat ribbon cables in many types of circuits merits special consideration. When using ribbon cables, and when the circuit is especially sensitive to pickup of radiation (or when the circuit could potentially radiate), a return or ground conductor should be placed be-

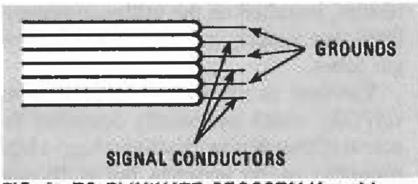


FIG. 3—TO ELIMINATE CROSSTALK problems in ribbon cable, alternate conductors should be grounded.

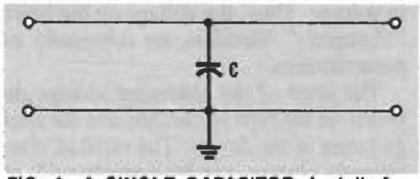


FIG. 4—A SINGLE CAPACITOR, installed as shown, can be used to filter out differential-mode interference. To handle common-mode interference, the capacitor should be installed between each line and ground.

tween *each* signal line (see Fig. 3).

Often, that is not done. It is common for a flat ribbon cable to have 25 or more conductors, only one of which is a ground. That can lead to high capacitance between signal conductors, resulting in crosstalk problems. The presence of a ground or return line between each signal line will "shield" the signal lines from each other.

Finally, if you want to be totally free from EMI radiation or pickup from cabling, use fiber optics. Made of glass or plastic fibers, such cables neither radiate nor pick up electromagnetic energy. They are coming into wide use in applications where long runs of data cables operate in noisy environments. Telephone companies, for instance, are now making extensive use of fiber-optic cables.

Filters

Even with good cable design and layout, sometimes a filter is needed to reduce conducted EMI. A filter is a circuit that allows certain frequencies to pass unimpeded, but blocks others. Depending on its design, a filter can allow only signals below a cut-off frequency to pass (lowpass filter), only signals above a cut-off frequency to pass (highpass filter), or pass or block signals within a given range or band (bandpass or notch filters, respectively).

A simple filter, consisting of but a sin-

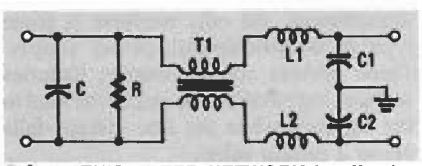


FIG. 5—THIS FILTER NETWORK is effective against both differential-mode and common-mode interference.

gle capacitor, is shown in Fig. 4. At high frequencies, the capacitor looks like a very low impedance to ground. As a result, any high-frequency signals are shorted to ground. At low frequencies, the capacitor is a high impedance, and the signals are unaffected. Thus, the capacitor is acting like a low pass filter. Capacitors are used in that way in a number of applications, such as across the terminals of automotive alternators, electric motors, and on printed-circuit boards (decoupling capacitors).

To use any filter effectively, including the simple capacitor filter, you need to know the nature of the EMI you are dealing with. That's because a filter designed to eliminate common-mode EMI will be largely ineffective against differential-mode interference, and vice-versa.

Let's look at a familiar and common source of EMI and see what kind of interference it creates. An electric razor is one such source. Because the electric motor in the razor is connected between the hot and neutral sides of the power line, the conducted interference it generates is differential mode. That is, the EMI voltage appears between the hot and neutral lines. On the other hand, when an overhead power line acts as a receiving antenna, coupling a broadcast radio signal to the AC power line, for instance, the EMI signal that results is common mode.

To filter differential-mode interference, the capacitor must be installed between the hot and neutral lines. For common-mode interference, capacitors must be installed between each line and ground.

If the interference is both common- and differential-mode, and/or is made up of a variety of frequencies, a more complex filter network is required. Such filter networks are made up of capacitors, inductors, or both. One popular design is shown in Fig. 5. That filter is effective against both common-mode and differential-mode interference. It is installed at the point where the power cord enters the equipment's enclosure.

The transformer in that circuit, T1, is a common-mode choke. As its name implies, its purpose is to block common-mode signals. The transformer is built in such a way that the flux generated by the common-mode signals in one winding opposes the flux generated by the common-mode signals in the other winding. That results in a high impedance to common mode signals, but differential-mode signals are not affected. That deficiency is taken care of by the series inductors, L1 and L2; those coils present a high impedance to the high-frequency differential-mode signals. The function of the capacitors in the circuit is to shunt differential- and common-mode signals to ground, as previously discussed.

If your interference problem is not severe, or if the victim circuit is not overly sensitive to EMI, you can build a circuit like the one shown in Fig. 6. In that circuit, or in any filter circuit, keep the capacitor leads as short as possible. A capacitor with long leads starts to behave like an inductor as the frequency goes up. Also, use a low-impedance ground connection (the "ground" connection of a

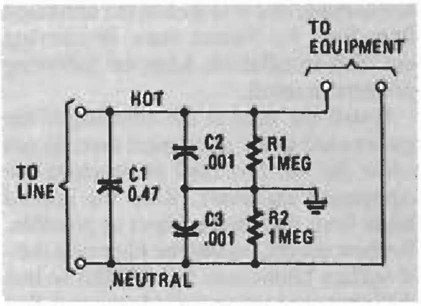


FIG. 6—IF THE EQUIPMENT is not overly sensitive to EMI, or the EMI situation is not severe, here's a practical circuit that will cure the problem.

three-wire power cord is suitable).

One common problem is the unwanted reception of AM radio stations or CB radios by tape decks, audio amplifiers, etc. That type of interference problem occurs when a radio signal is picked up by power or signal cables and causes a common-mode current to flow into the electronics. That type of problem can often be cured by placing a piece of ferrite around the cable as shown in Fig. 7. The effect caused by doing that is similar to the one caused by installing a common-mode choke. That is a quick and easy solution as it entails no soldering—just unplug the

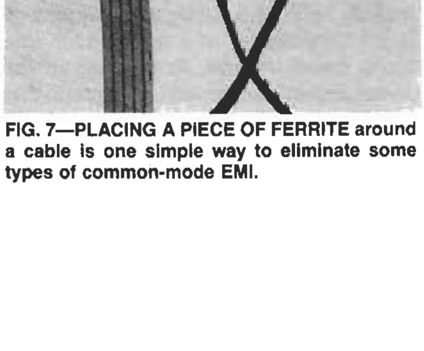


FIG. 7—PLACING A PIECE OF FERRITE around a cable is one simple way to eliminate some types of common-mode EMI.

cable and install the ferrite. (It must be mentioned that that solution will do nothing if the interference is differential mode.)

Interference is filtered from signal lines in much the same way, assuming that the interference signal differs in frequency range from the intended signal. But if the EMI is in the same frequency range as the desired signal, there is little that you can do to reduce the conducted interference with filters. In those cases, the interference must be prevented from getting into the cables by using proper cable design and shielding.

Filter installation

The important thing to remember when installing either a commercial filter or a home-made one is to isolate the unfiltered lines from the filtered ones. In carrying out such installation, keep the following pointers in mind:

Install the filter at the entrance of the power cord to the equipment box; do not allow the AC line cord to penetrate the equipment enclosure. Keep the ground leads from the filter as short as possible. For best results, mount the filter on a metal surface (aluminum foil will do) so that the input connection is made through that metal surface; the surface is then connected to the the ground wire of the equipment's AC power cord.

Transient suppression

Anyone who has ever lost a batch of data or has seen his program "crash" when the lights dimmed knows the frustration that power-line transients can cause. Severe transients are capable of causing damage to electronic devices, especially members of the very sensitive MOS logic families. The most common types of transients on the power lines are as follows: sags (the power line voltage drops below the normal value for a short period of time); surges (the line voltage rises above the normal value for a short period of time); dropouts (the line voltage drops to zero for a short period of time); impulses (fast-acting conducted spikes of positive or negative polarity that are superimposed on the normal line voltage), and frequency changes (when the frequency of the line voltage deviates from 60 Hz).

The duration of those types of disturbances, especially the first three, is usually very short, typically lasting for only a few cycles (at 60 Hz, the period of a cycle is approximately 16.7 milliseconds). They have a variety of causes. Some of those include lighting, starting and stopping of heavy machinery, and momentary line faults (short circuits to ground) in the power distribution system. Long term disturbances usually take the form of blackouts or brownouts.

For protection against the long-term disturbances, the only recourse is some type of uninterruptible power supply. Those devices contain storage batteries and sensing circuits that switch the load to the batteries when the line voltage falls below a certain value.

There are, however, many ways to protect your equipment from the effects of short-term transients. The first step is to recognize that transients can have two very different sets of characteristics. That is, transients can be unidirectional or oscillatory. An oscillatory transient has a fast rise-time and then becomes a decaying sinusoid, oscillating at some frequency until it damps out. The unidirectional wave has a very short rise-time and a comparatively long fall-time. Once the transient drops to zero, it shows no oscillation. Of the two, oscillatory transients are more commonly encountered.

Transients are capable of doing quite a bit of damage; impulse and surge voltages as high as 6000, and currents as high as 200 amperes have been observed. To prevent damage from occurring, the energy must be diverted before it enters sensitive electronics equipment. Power-line EMI filters will help to reduce some of the transient energy, but the amplitude of some transients can overwhelm the filters and cause damage. A device especially designed for transient suppression is needed.

There are a variety of devices that are useful in protecting your equipment from high-energy transients. Many of those are available commercially; you simply buy them and install them between the AC outlet and your equipment. They are generally satisfactory for most applications, if they are installed properly and if a good ground is used.

It is also possible to design and build an effective "home-brew" suppressor. The key components for such a device—gas tubes, varistors, and *S*ilicon *A*valanche *S*uppressors (SAS)—are readily available.

Basically, gas tubes consist of a pair of electrodes that are encased in a non-conductive (usually glass) envelope that contains an inert gas. See Fig. 8-*a*; the schematic symbol for the gas tube is shown in Fig. 8-*b*. One of the electrodes is connected to the hot line of the AC power cord, and the other is either grounded or connected to the neutral line. Normally, the presence of a gas tube in the line has no effect, but when a high-energy transient occurs, there is arcing between the two electrodes. That arcing is the dissipation of the transient energy. Lightning arrestors, installed on the utility companies lines, are usually made up of very large gas tubes.

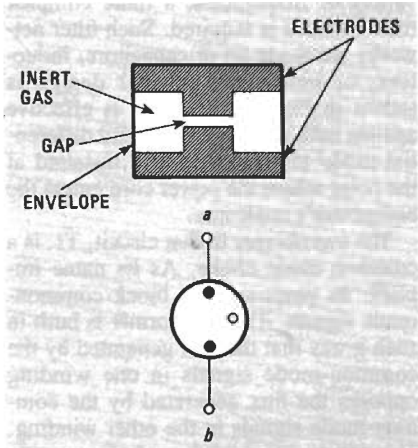


FIG. 8—A CROSS-SECTION of a gas tube is shown in *a*; its schematic symbol is shown in *b*.

Varistor is short for *VARI*able resi*STOR*, which essentially describes the action of that device. Varistors have a high resistance at low voltages, but as the voltage increases, the resistance greatly decreases. In the low resistance state, the varistor is capable of handling a large increase of current without a large increase in voltage. Thus, the voltage on the line is "clamped." Varistors are inherently bipolar devices.

The level of the clamping voltage depends on the type of varistor and the energy rating of the device. The varistor, if not properly chosen, can be over-stressed, resulting in damage to the varistor and a lack of protection for your equipment. However, varistors are available in various ratings that can be matched to the job at hand. In addition, varistors react very quickly to transients.

SAS devices are most suitable for use on signal lines, low voltage lines, telephone lines, and at the circuit-board level. SAS's, which are very fast-acting devices, are essentially large area p-n junctions or "beefy" diodes. The device's characteristic curve resembles that of a Zener diode, but they can handle much more energy. Both bipolar and unipolar devices are available.

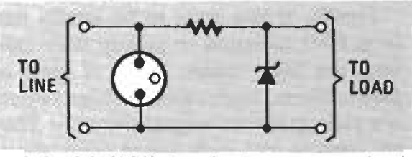


FIG. 9—A HYBRID transient-suppressor circuit allows you to combine the advantages of two or more types of suppressor devices.

It is possible to combine the above devices into a hybrid suppression network. Such hybrid networks are useful because the designer can combine the advantages of two or more suppressor components, such as the energy-handling capability of a gas tube with the speed of an SAS. Such a hybrid network is shown in Figure 9. The isolating impedance is included in the network to limit the transient current into the SAS; it also causes the voltage to build up high enough to trigger the gas tube.

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CURING EMI

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That isolating impedance is either an inductor (with a value between 50- and 500 μH) in power-line hybrids, or, as shown in Fig. 9, a resistor (whose value is typically a few tens of ohms) in signal-line applications.

Designing transient suppressors

The most severe source of power-line transients is a lightning stroke. Therefore, most suppressors are primarily designed to protect against lightning. Most of the energy associated with a lightning stroke is in the form of common-mode current and voltage. However, due to unequal wiring parameters and the fact that common-mode suppressors are not perfectly matched (do not suppress equally), some differential-mode energy will also be present. Thus, a lightning-protection network should incorporate both common- and differential-mode protection.

Varistors, which are commonly used as suppressors on household AC power lines (117 volts), are available from a number of electronics suppliers. When selecting a varistor for a particular application, you should consider the nominal operating voltages and currents that the circuit will see, and the maximum surge voltage and current that are likely to be encountered. In addition, the suppressor must be rated to withstand the energy that it will need to dissipate. In the case of 117-volts AC, as stated previously, the most powerful transient that is likely to occur will have a peak voltage of 6000 and a peak current of up to 200 amperes; that's a fairly sizeable wallop. If the suppressor clamped that surge voltage at 500, the amount of energy that the suppressor would need to absorb would be approximately 0.8 joule. Lower clamping voltages will mean that the suppressor will have to absorb more energy.

In addition to power lines, varistors designed to protect low-voltage circuits (as low as 5 volts) are available. The selection of such a varistor follows the same general procedure as above.

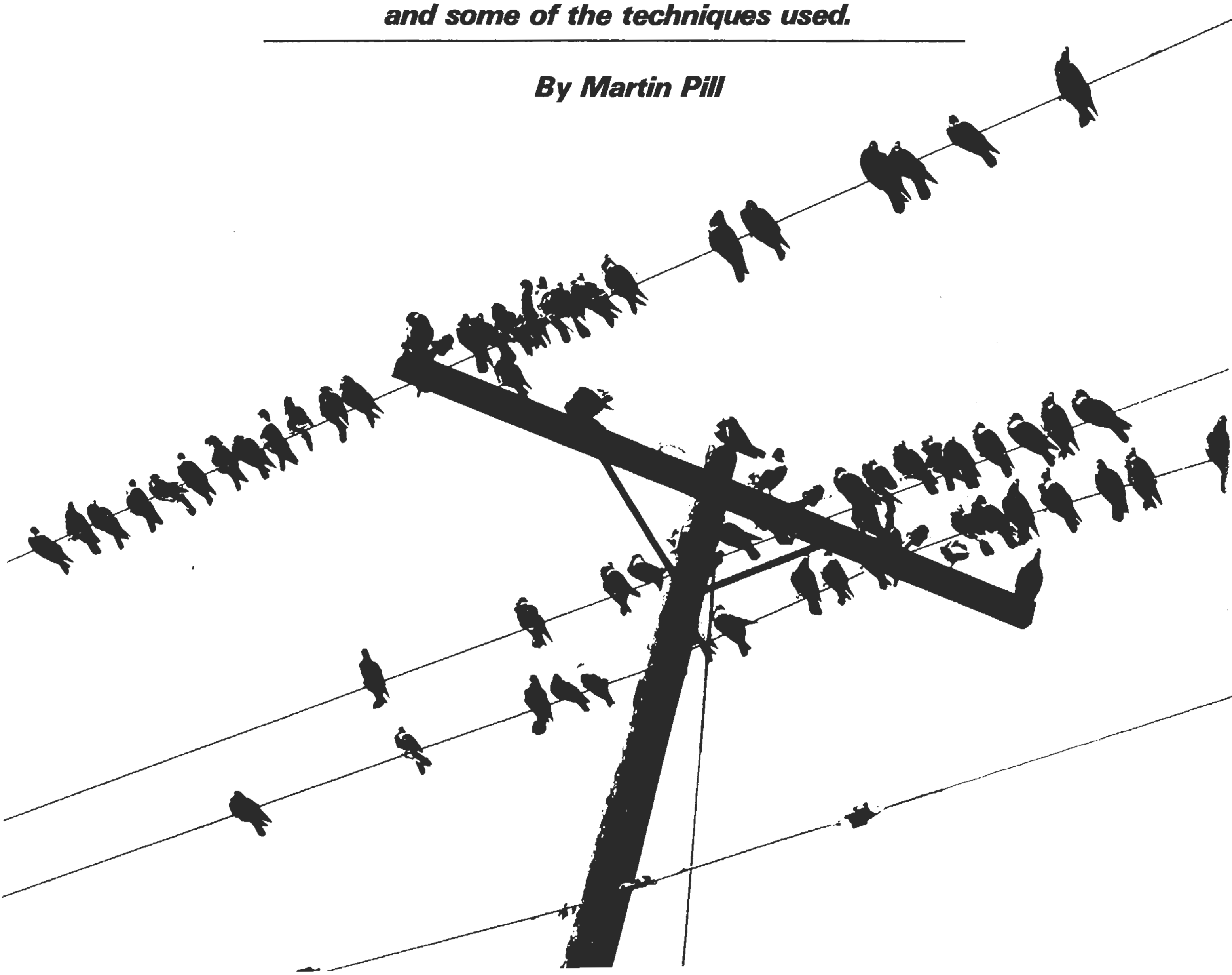
Silicon avalanche suppressors also are commonly used to protect low-voltage systems. For instance, to protect sensitive CMOS devices on a PC board, a 5-volt SAS could be connected between the power and ground connections on the board. Data lines similarly could be protected by installing SAS's between the lines and ground.

The suitability of an SAS for a particular application is determined by it power rating. Those power ratings range from 500 watts to several kilowatts. An SAS with a power rating of 1000 watts, that is designed to clamp the voltage at 5, can handle surge currents of up to 200 amperes. **R-E**

Designer's Notebook: Power Line Filtering

A look at getting clean power from the utility line, and some of the techniques used.

By Martin Pill



NOISE on the power line is at its worst when it consists of transients or radio-frequency interference (RFI). These go right through most power supply units and can be maddening when it comes to instrumentation or potentially disastrous if they cause data loss in computers.

The 120V, 60Hz supply is normally a fairly pure sine wave, but can be contaminated by appliances connected to the circuit, the main culprits being appliances whose operation produces sudden changes in the current drawn from the line. These sharp fluctuations can produce RFI noise currents which are transmitted via the power wiring.

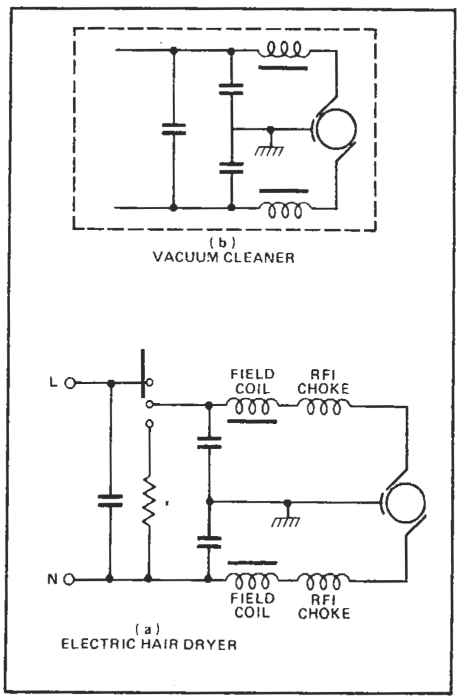
There are two ways in which RFI can be propagated. In the transverse or symmetrical mode, the RF current travels down one side of the line and returns via the other side. In the common or asymmetrical mode, the RF current flows down both the line and neutral and returns via the ground circuit.

Transverse mode signals are more likely to cause problems than common mode, but are more easily filtered out.

Common examples of offending appliances are vacuum cleaners, drills, industrial machinery and devices controlled by thermostats. Examples of filters which can be fitted by manufacturers or installed by the designer are shown in **Fig. 1.**

At What Cost?

Ideally, all this should be taken into account at the time of manufacture of the equipment likely to cause RFI; induction motors generate little radio noise and are preferable to commutator motors, quick acting thermostats reduce arcing at the contacts and cause less interference, and so forth. Where an appliance is known or likely to cause interference, suppression components should be fitted, or provision made for easy retrofit.



Unfortunately, this adds to the cost of the product and so is not often done. It is not possible for the home user to fit full internal RFI protection to equipment, but if it observed that the operation of a particular appliance is associated with interference, connection of a high voltage 0.1uF capacitor across the line and neutral at the appliance may help. The voltage rating should be as high as possible to allow for voltage spikes; 600V is a reasonable figure.

Even if all your equipment were to be suppressed, the computer or instrument would still be susceptible to interference from any other equipment on nearby property. In order to obtain full protection, a filter should be fitted in the line to the sensitive load.

The circuit for a filter generally consists of a solid-state transient suppressor, shunt capacitors and series inductors. The

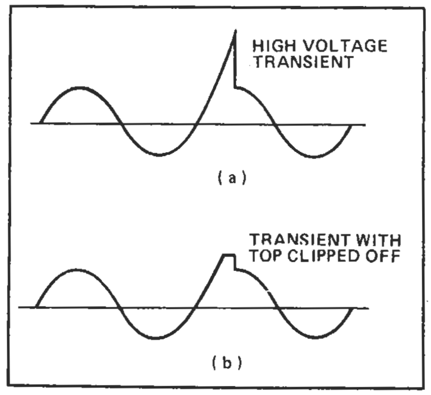


Fig. 2. The action of a transient suppressor. The high voltage spike has its top clipped off to bring it down from several thousand volts to a few hundred.

transient suppressor removes high voltage spikes caused by such things as lightning and the switching of inductive loads, and acts like a high-power bidirectional zener diode. It is connected across the line and neutral and conducts when the voltage across it exceeds a set value, often 200-300V, thus cutting off the top of the spike (**Fig. 2**). Part of the spike is left, and the fast-rising edge could still trigger a logic gate. However, the edge is rounded by the inductor in the RFI section.

Filters

RFI filters are made up from either capacitors or inductors, or a combination of the two. The reactance of a capacitor, the AC equivalent of resistance, is inversely proportional to the frequency and thus the capacitor provides a low impedance path for RF while presenting a high impedance at the power line frequency.

Taking the previously mentioned 0.1uF capacitor, at the power line frequency of 60Hz its reactance is about 26k ohms, and at a 1MHz interference frequency reduces to 1.6 ohms. From this it can be seen that little current will flow at 60Hz (about 4.5mA), but the RFI will be shorted out. The attenuation of the spike by a single capacitor across the line depends on the source impedance; if the power line impedance at 1MHz rises considerably due to its inductance, the spike will be nicely reduced.

Unfortunately, all capacitors have inherent inductance and resistance as shown in **Fig. 3**, so each capacitor must be considered as a complex impedance consisting of L, C, and R. The inductance and resistane are very small, but limit the upper frequency at which the capacitor will be effective: about 30MHz, depending on the physical construction of the capacitor. Increasing the capacitance would lower the impedance, but for safety reasons C1 should not be greater than 0.1uF.

A practical circuit is shown in **Fig. 4**. As explained, C1 should not exceed 0.1uf (100nF), and the ground capacitors C2 and C3 should not exceed 0.005uF (5nF) in case the unit is used with a faulty grounding system; the chassis of the load could then be energized via C2 and C3. The higher the voltage rating, the better. There are specially designed capacitors available with low inductance; if these can be obtained, so much the better.

Inductive Section

To improve the performance of the filter an inductive section is added. Inductors have the opposite property of capacitors in that the reactance increases with increasing frequency. Since the inductor presents a rising "resistance" to high frequencies it chokes out the RFI currents.

In order to provide suppression of the asymmetrical currents which flow down each lead, it will be necessary to connect an inductor in both the line and neutral leads. For VHF suppression, 5uH to 10uH will give good results. The two inductors can be wound on a common core (see below).

Despite the use of high quality components, there is always the chance that they might break down, and therefore a fuse has been inserted in the line lead. Note that the electrical code frowns on any fuses or switches in the neutral wire.

Construction

Design and construction of a filter is straightforward. The parts can be mounted in a utility box or other suitable enclosure. The transient suppressors are usually listed in parts catalogues as thyrectors or varistors; typical examples would be the GE-MOV 130 series or the International Rectifier Zenamic series.

The dual inductor can be wound on a 24mm toroidal ferrite core; the method

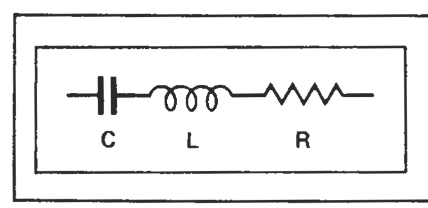


Fig. 3. The AC circuit equivalent of a capacitor: a capacitor incorporates capacitance, inductance and resistance.

used is bifilar winding: both leads are paralleled and then eight turns are wound onto the core and secured with epoxy (see **Fig. 5**). Since the unit is meant to be used with low-power devices such as instrumentation, a 2 or 3 ampere fast-acting fuse should be adequate.

Airborne Radiation

Sometimes the interference arrives (or leaves) in the form of external radio waves rather than the wire-conducted type we've been discussing. Many computers and even instruments have plastic cabinets for the sake of economy, and these permit unhampered entry and exit of radio waves. Computer and test equipment logic circuits generate a fair amount of RF due to the fast rise and fall times, and if radio and/or TV interference occurs, it

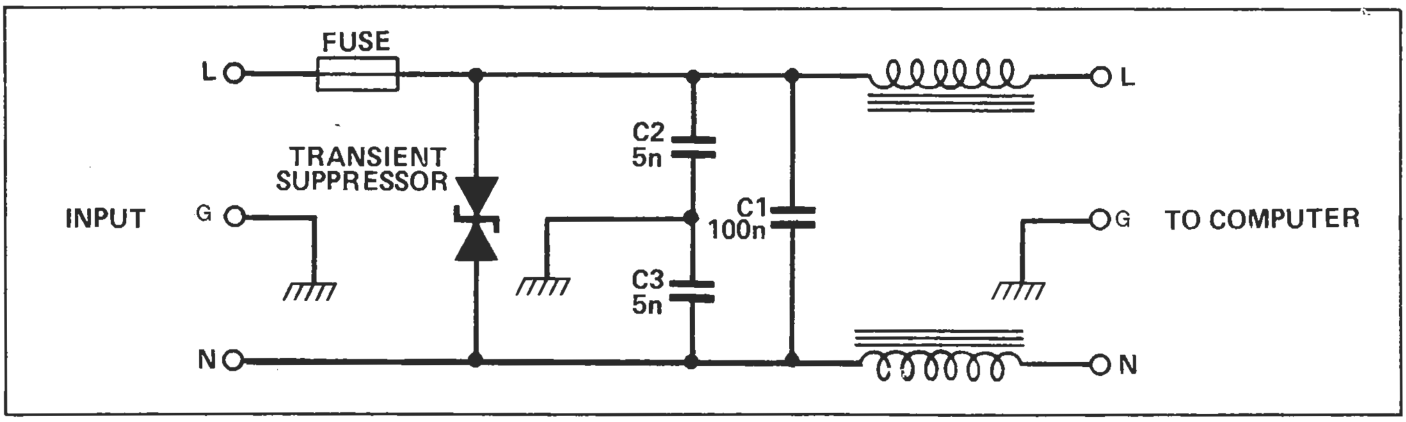


Fig. 4. The circuit diagram of the radio frequency interference filter.

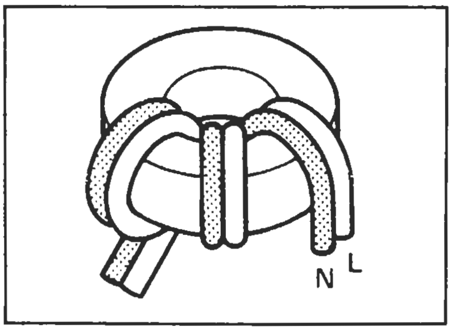
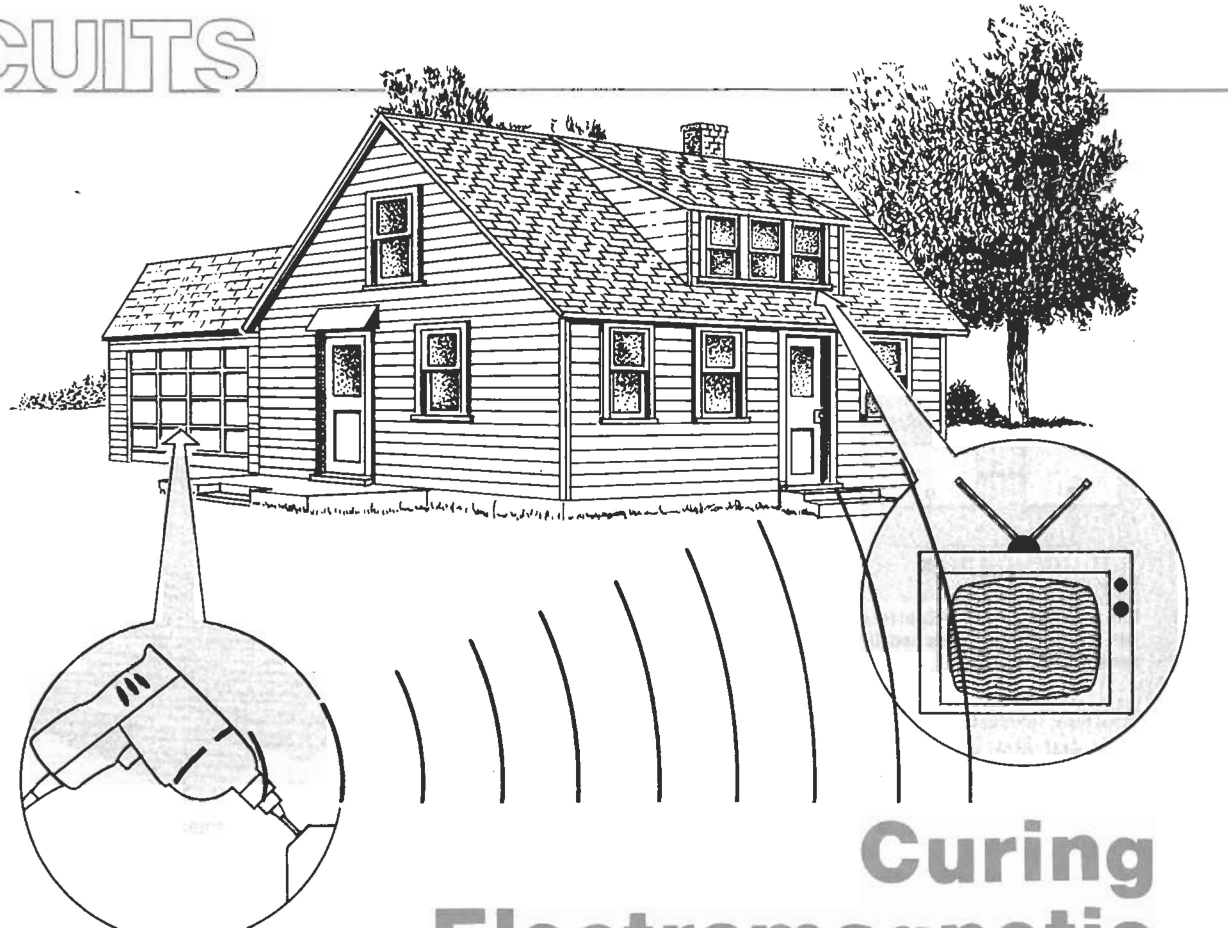


Fig. 5. Bifilar winding on a ferrite core.

will be conducted out through the power leads, radiated through the cabinet, or both. The power filter will stop RF from being injected into the power lines, but a plastic cabinet means some grounded shielding must be added, perhaps with thin aluminum sheets or foil. If the RF is leaving via signal cables, it becomes a test of the designer's skill in shielding, grounding, and relocating them to minimize interference. ■



Curing Electromagnetic Interference

MICHAEL F. VIOLETTE

Shields and grounds play an important role in minimizing the effects of EMI. In this article we learn how they work, and how to design an effective shield or ground system.

Part 2 LAST TIME, WE TALKED about the general nature of *E*lectro*M*agnetic *I*nterference (EMI). Among other things, we looked at its sources, what it affects (its victims), and how the interference gets from the source to the victim (the coupling path). We also looked at the two different types of EMI; common-mode and differential-mode interference.

This month we will delve more deeply into the ways EMI can be eliminated and *E*lectro*M*agnetic *C*ompatability (EMC) can be achieved. Specifically, we will be looking at grounds and shields, and how they can be used to eliminate the effects of EMI.

Grounds

Consider the grounding scheme shown in Fig. 1. In it, a long ground wire connects circuits 1 and 2, and circuit 3 is tied to the ground wire of circuit 2. The system ground or ground reference is shown at the left. Ideally, conductors have no impedance; if that were actually the case, the grounding scheme shown would work fine. However, real wires do have an impedance associated with them. Consider, for instance, Fig. 2. That figure is the equivalent circuit for the grounding system shown in Fig. 1. As shown in Fig. 2, ground currents I_{G1}, I_{G2}, I_{G3}, flow in the ground leads. Because of the impedances in the leads, noise voltages are generated, and they can be large enough to cause problems for the circuits connected to them.

Also, as is shown in Fig. 2, the design of the ground system is such that ground loops exist. A ground loop can be created when a circuit is physically connected to a ground lead or bus at more than one place. Because the nature of the connections between circuits 1 and 2, and circuits 2 and 3 is, at this point, unknown, it is entirely possible that the circuit shown could have two ground loops. Ground loops are un-

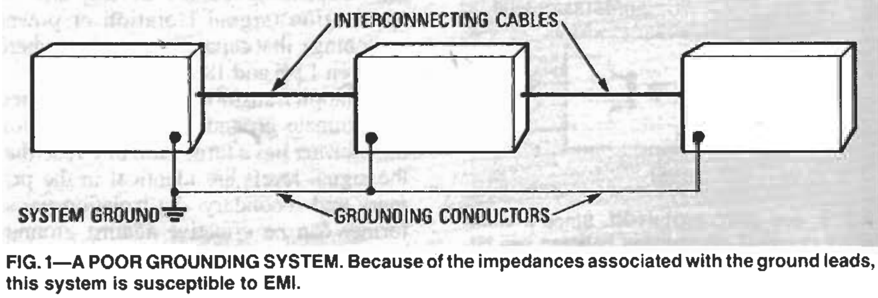


FIG. 1—A POOR GROUNDING SYSTEM. Because of the impedances associated with the ground leads, this system is susceptible to EMI.

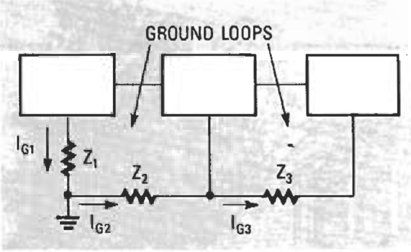


FIG. 2—EQUIVALENT CIRCUIT for the grounding system shown in Fig. 1. The ground currents flowing through the impedances of the ground leads will generate noise voltages.

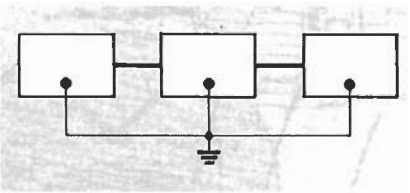
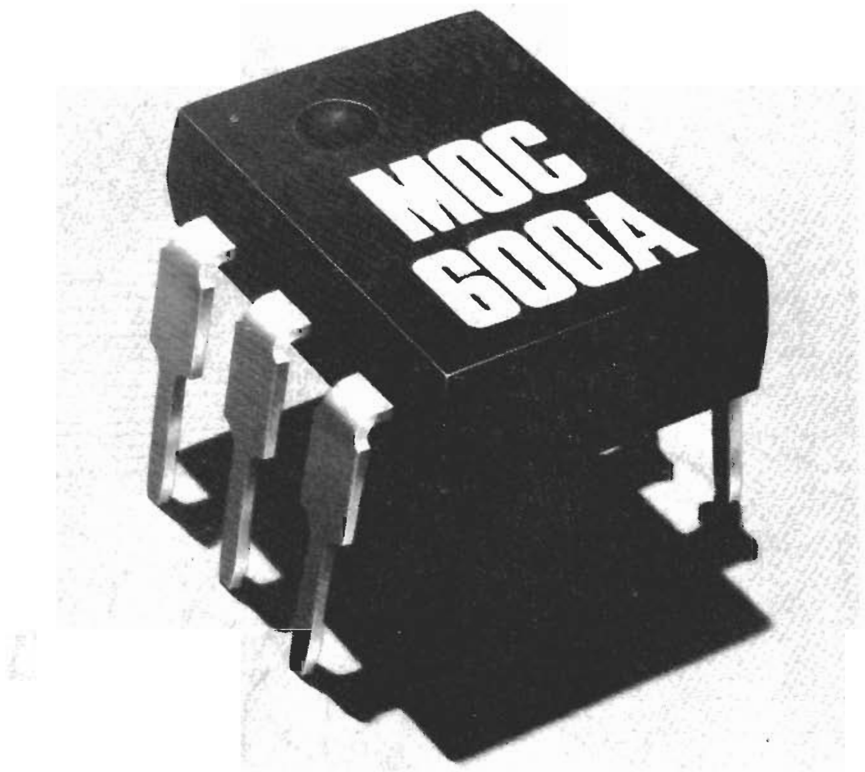


FIG. 3—A STAR GROUND. In this grounding system, all of the circuits are tied directly to a single system ground.



OPTO-ISOLATORS, such as the members of the Motorola MOC600A family, are inexpensive and readily available.

desirable because the common-mode currents that flow in them can couple into circuitry and cause interference (called common-mode interference).

A better arrangement is shown in Fig. 3. The grounding system shown there is called a star ground. Notice that each circuit is connected to a common ground point or system ground (sometimes called the star point) through a dedicated connection. To keep impedances as low as possible, those connections should be kept as short as possible. Star-ground systems are used in many electronic devices, including computers and TV's.

Breaking ground loops

There still may be ground loops in the system of Fig. 3 and they still must be eliminated. Several techniques are used to break ground loops. One technique is to "float" one or more of the interconnected circuits (disconnect the circuit from the system ground). That is not always possible, and it is unsafe in high-voltage circuits.

A better approach is to physically isolate the various circuits. That can be done with a opto-isolator. As shown in Fig. 4, that device consists of an LED and a phototransistor. Such devices are readily available in IC form and are fairly inexpensive.

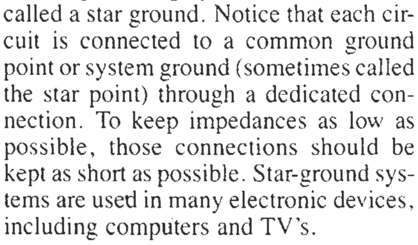


FIG. 4—AN OPTO-ISOLATOR. Since it eliminates electrical connections between two circuits, this device can be used to break up ground loops.

The operation of an opto-isolator is as follows: With no input signal the LED is off; but when an input signal is present, the LED turns on, and the light from the LED turns the phototransistor on. Current flows through the phototransistor, which results in a signal at the output of the opto-isolator. There is no hard-wire connection between the input and output of the opto-isolator, and therefore, no ground-loop currents flow.

The opto-isolator is also effective against common-mode currents. By definition, common-mode currents flow on both input lines of the device, but they are unable to flow across the opto-isolator because of the absence of connection between the input and the output of the device. One limitation of the opto-isolator is a parasitic (unintentional) capacitance that exists between the input and output of the device. At higher frequencies, that capacitance results in a degradation of the isolation between the input and the output. Depending on the device, and its application (signal isolation or power switching), that capacitance is somewhere between 1 pF and 180 pF.

Isolation transformers can also be used to eliminate ground loops. An isolation transformer has a turns ratio of 1:1, so that the signal levels are identical in the primary and secondary. An isolation transformer can be effective against ground-loop currents and common-mode signals because there is no hard-wire connection between the primary and the secondary of the isolation transformer. Again, the limitation to the isolation transformer is the primary to secondary parasitic capacitance, which can be significant (up to 1000 nF).

That parasitic capacitance can be reduced or eliminated by inserting an electrostatic (foil) shield between the primary and the secondary. That metal shield is made of a nonmagnetic material (nonferrous) and does not interrupt the normal flow of magnetic flux around the transformer; thus the magnetic circuit of the transformer is affected very little. At high frequencies, more than one shield may be required.

Figure 5-*a* shows an unshielded isolation transformer and the primary-to-secondary (input-to-output) capacitance, C_{IO}. Figure 5-*b* shows a single-shielded isolation transformer; such a transformer is usually effective at frequencies up to 100 kHz. The shield effectively reduces the primary-to-secondary capacitance by dividing C_{IO} into a primary-to-shield (input-to-shield) capacitance, C_{IS}, and a shield-to-secondary (shield-to-output) capacitance C_{SO}. The series combination of C_{IO} and C_{SO} is less than C_{IO}. Note that the shield in Figure 5-*b* is connected to the common-mode reference (ground) by a low impedance connection. As shown, a portion of the common-mode currents flow from the transformer primary through C_{IS} and return to ground, reducing the common-mode current on the secondary side of the transformer. Thus, the

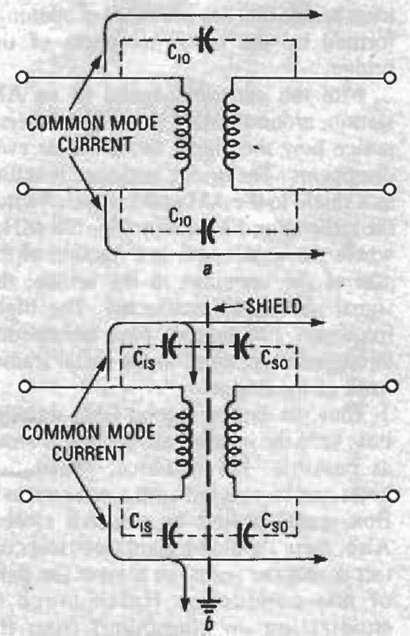


FIG. 5—ONE DRAWBACK in using an isolation transformer to break up ground loops is the high parasitic capacitance between the windings (*a*). One solution to that problem is to place a shield between the windings (*b*).

action here is that of a current divider, and the net effect is a decrease in common-mode currents on the secondary side.

Ground planes

Examine the PC board used for a high-speed digital circuit and you will likely see that the majority of the copper is unetched; the only copper removed is that needed to avoid shorting traces. The remainder of the copper, surrounding the circuit, is used as a ground plane. A ground plane is a flat metal plate or surface to which ground connections are made.

Ground planes offer several advantages. For one, their use helps eliminate the possibility of ground loops on the PC board. Also, at high frequencies, their large surface area (when compared with a PC trace) results in a low impedance.

Safety considerations

It is possible that a design intended to minimize EMI may be unsafe. For example, floating a circuit to break a ground loop may not be advisable because of the impact on the safety design of the system. If the circuit is a high-voltage one, a connection to the system ground must be provided in the event of a short. When dealing with AC-powered equipment, especially equipment housed in a metal cabinet or case, a safety ground (usually via a 3-line power cord) should be provided. Otherwise, should a breakdown occur and the "hot" side of the AC supply be applied directly to the case, there will be no path to ground. That is, until someone touches the case, perhaps with disastrous results.

Shielding against EMI

Shielding is used to reduce unwanted radiated energy from coupling to and from a system. Radiated energy is generated by many sources. In some cases, that is indeed the intended function of the source; those include RF transmitters of all types. Other times, the radiated energy is an unintended side effect. Many different types of equipment can be unintentional sources of radiated energy. Among the most common of those are computers and power lines. Radiated energy can also be generated by natural sources, such as lightning.

Electromagnetic radiation

An antenna is used to transmit and/or receive electromagnetic radiation energy. That energy is in the form of n electromagnetic wave that travels through space at the speed of light. Associated with that wave is a wavelength, λ, and a frequency, f, which are related through the equation $\lambda = C/f$, where C is the speed of light (3×10^8 meters/second), λ is measured in meters, and f is measured in hertz. Note that wavelength and frequency are inversely proportional; that is, as the frequency of radiation increases, the wavelength decreases. When the length of a wire is equal to about a quarter wavelength at some frequency (or some integral multiple of a quarter wavelength), the wire becomes an efficient antenna at that frequency. That means that it is capable of easily receiving or transmitting electromagnetic radiation.

While an efficient antenna is desirable when you are dealing with radio communications, if one of the conductors in your project becomes an "efficient antenna," it is a nuisance. That conductor becomes a means for electromagnetic energy to couple into the circuit. If the coupled energy is higher than the sensitivity (for analog circuits) or noise margin (for digital circuits) of the circuit, that energy can cause the circuit to malfunction. In addition, if the circuit is a high-frequency one, it is possible for it to become a source of electromagnetic radiation itself, affecting the operation of nearby equipment.

In either case, the way to cure the problem is to place a shield around the project. A shield is designed either to keep the EMI out or to keep it from escaping.

How does a shield work? A good EMI shield absorbs part of the electromagnetic wave and reflects part of the wave away. The theory behind shielding is quite complex. It is based upon aspects of Maxwell's electromagnetic radiation equations and it is beyond the scope of this article. But we can describe what goes on qualitatively, so that you can gain some understanding of how the process works.

The shielding mechanism

First, there are three different types of electromagnetic fields. All electromagnetic fields are composed of an electric field and a magnetic field. The relationship between the electric and the magnetic field is similar to the relationship between voltage and current. That relationship is given by Ohm's law, which states $V = IR$.

In electromagnetic field theory, there is a similar equation that relates the electric and magnetic fields. That equation is $Z = E/H$, where E is the intensity of the electric field and H is the intensity of the magnetic field. The variable Z is the impedance of the field; the three different types of electromagnetic fields are defined in terms of that impedance. Those are high-impedance, low-impedance, and free-space fields.

A high-impedance field is created by a source (antenna) that has a high impedance. For instance, a dipole antenna has a very high impedance because the antenna elements are not connected together (except through the capacitance in the air between the elements). It is difficult to shove current into the dipole because of that high impedance. The radiated wave that comes off of the antenna is also high impedance; it is called an electric field because E is large relative to H, which creates a large value of Z.

A low-impedance field is created by a source that has a low impedance. One type of low-impedance source is a loop antenna. A loop antenna has its ends shorted together and therefore has a low impedance at its terminals so current can easily flow through the loop. That creates a low impedance, or magnetic, field. An example of a source of magnetic fields is a power line in which relatively large current flows; such lines are the cause of many EMI problems.

High and low impedance fields exist when you are close to the source or the antenna; that region is called the *near field*. As you move away from the antenna, you approach what is called the *plane-wave* or *free-space* region. In the free-space region, the impedance of an electromagnetic wave is very simply equal to 120π (or approximately 377 ohms).

For proper design of the shield, it is important to know the impedance of the electromagnetic field. For that reason, it is also important to know where the near-field region ends and the free-space region begins. That distance, known as the transition distance (R), is defined as $R = \lambda/(2\pi)$.

Shield design

As stated, the purpose of a shield is either to reflect or to absorb electromagnetic radiation. A shield around a circuit acts as a barrier to electromagnetic energy by reducing the field strength on the other side of the barrier. The *shielding effectiveness* (SE) of a shield is a comparison between the amplitude of the field on one side of the shield (incident field) compared to the amplitude on the other side (the resultant field). If the SE of a shield is high, then the "problem" wave is reduced in amplitude.

A simplified model of how a shield works is shown in Fig. 6. An electromagnetic wave is incident from the left of the shield (although the wave can be generated from the inside of equipment). Part of the wave is reflected away and part of the wave penetrates into the shield material. When the wave penetrates to the other side of the shield, another reflection takes place at the interface between air and metal. The energy that is reflected travels back through the material and exits on the left side. Much of the energy that is not reflected is absorbed by the shield material. The remainder of the energy exits the right side of the shield as the resultant field.

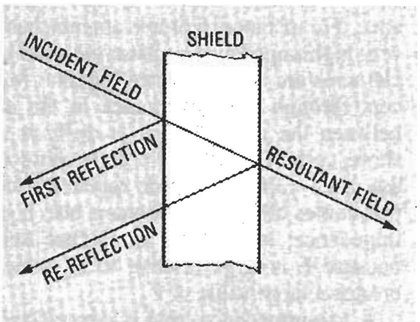


FIG. 6—HOW A SHIELD WORKS. Note that the electromagnetic energy is reflected at both shield/air interfaces. In addition, some of the energy is absorbed by the shield material.

Most shields are designed to attain an SE between 20 and 80 dB (10 to 10,000-fold reduction) and some "super shields" are designed for SE's between 100 and 120 dB (100,000- to 1,000,000-fold reduction). In general, any shield with an SE of less than 20 dB is not very effective.

Let's look at an example. Consider an incident electric field, E_I, with a strength of 1 volt per meter (V/m) that is causing an electronic system to malfunction. If a shield with an SE of 60 dB is installed, what is the resultant field on the inside of the shield? First, convert the electric field to dB: $E_{IdB} = 20\log_{10}(1) = 0$ dB

To find the resultant field strength, E_R, subtract the shielding effectiveness from the incident field strength. Thus, the resultant field is 0 dB – 60 dB = –60 dB. Or, in volts-per-meter:

$$E_R = 10^{(E_{RdB}/20)} = 10^{(-60/20)} = 10^{-3}$$
$$= .001 \text{ volts-per-meter}$$

That is a reduction of 1000.

To design a good shield, it is important to consider the type of field you are dealing with. The following "rules of thumb" should be followed to select the correct shield material:

To shield against electric waves, reflection is important. Use a high conductivity metal (such as copper or aluminum) for the shield. The high conductivity (which results in a low impedance) of the material essentially short circuits the electric field just as a piece of wire short circuits a voltage source in a hard-wired circuit. The field is reflected away by the short circuit. Reflection of the wave results in a reduction of the field on the opposite side of the barrier.

Likewise, copper and aluminum are suitable shielding materials when dealing with free-space electromagnetic waves. The shielding mechanism is a combination of reflection and absorption.

To effectively reduce magnetic fields, however, the shield material must have magnetic properties. For instance, the operation of a transformer depends on the material in the transformer core. Transformer cores are constructed of magnetic (ferrous) materials, such as silicon steel. The current in the primary of a transformer creates a magnetic field that pushes a magnetic flux around the core of the transformer. Very little flux exists in the air around the transformer because air is non-magnetic. The concentrated flux in the core is said to "link" the primary and secondary windings in a transformer. The result is that a time-changing signal in the primary will induce a similar signal in the secondary.

To reduce magnetic fields, then, the shield must be able to concentrate the magnetic flux from the source of the magnetic field. That creates a shield against the magnetic field. Magnetic field shielding is relatively difficult because of the weight and expense of the materials involved (such as steel).

Shielded-box design

An important aspect of shielding design is how the shield material is assembled. A perfect shield is a totally enclosed box, made of the proper shield materials, in which the circuit is placed. However, switches, knobs, power cords, signal cables, and ventilation holes are necessary if the circuit is to be useful. Pretty soon, there are a lot of holes in our perfect shield; those allow radiated energy to "leak" into the box. A compromise between the perfect and the practical must be made. There are methods available to accommodate the holes and still have a pretty good shielded box design. Let's look at some of those methods.

An important consideration in shielded-box design is the size of the hole in the shield. At low frequencies, the wavelength of the EMI is large compared to the size of the hole. As the frequency increases, the wavelength decreases and the energy can leak through the hole and pass through the shielded box. That phenomenon can be observed the next time you ride in a car and pass under a metal truss bridge that has a number of openings formed by the metal members of the bridge.

With the car radio tuned to an AM station, around 1 MHz (λ = 300 meters), notice how the signal fades out or even disappears. The bridge structure is acting as a shield to the AM radio signal. Switch the radio to an FM station (88–108 MHz) where the wavelength is a fraction of the size of the openings in the bridge; the signal should be unaffected. The high-frequency FM signals pass unimpeded through the openings in the metal framework of the bridge.

Thus, to design a good EMI shielded box, keep the openings in the box as small as possible. For instance, ventilation holes can be covered with a screen mesh. Box seams should be soldered closed. Also, there should be good electrical contact across the seam, so remove the paint or non-conductive finish (such as anodization on aluminum) from the edges. The idea is to have, as much as possible, a continuously conductive surface.

In addition, there are numerous products available that can be used to maintain the integrity of the shielding. Those include conductive gaskets, which are fitted to seams and covers of shielded boxes to provide electrical continuity across the seam; shielded windows, which are made of glass or plastic panels in which tiny screen mesh is placed; conductive paints, which are sprayed on plastic enclosures for shielding purposes (many popular computers use conductive paints and coatings on their cabinets), and special shielded switches.

Thus far we have seen how proper grounding and shielding can greatly reduce the affects of electromagnetic interference. While those techniques are useful in eliminating problems that might appear, they are most useful if considered in the design stages of a project. By EMI-"proofing" your design in the first place, you will greatly reduce the chance that any unforseen problems will crop up later on.

Now that we have some idea of how to eliminate or reduce the affects of radiated electromagnetic interference, how do we do the same for conducted EMI? Obviously the methods and products mentioned thus far in this article are effective in fighting radiated EMI, but they will do nothing to eliminate the affects of conducted EMI (interference that enters the circuits via a power line or signal cable). To eliminate the problems caused by conducted EMI, other techniques are required. Among those is the use of filters designed to trap out the interfering signal. In the next part of this article we will look at those filters and how they work. We will also look at still more techniques for reducing the effects of EMI. **R-E**

Interference from amateur stations

2 — A discussion of the results of the RSGB investigation published in March

by I. Jackson G3OHX

Before discussing the answers to the survey questions certain points must be mentioned concerning alterations made to the figures given by some amateurs. These "corrections" were made for the following reasons:

In question 2 of section 1 a lot of amateurs gave answers in fractions of years (especially those where the answer was less than one year). To simplify matters these were rounded up to whole numbers.

In a few cases in section 2, the answer to question 1 was lower than any of the answers in question 2. This is not possible as it must at least be equal to the highest answer given in question 2 and could be the total of all three answers. To avoid possible exaggeration, the answer to question 1 was made up to equal the highest answer in question 2.

In cases where the answer to question 1 exceeded the total of the answers in question 2, some amateurs gave no figures for question 2 and the result was allowed to stand. This is reasonable because, in certain circumstances, the amateur might not be informed of all the facts, or even bother to find out.

Again in section 2, in quite a number of cases, the answer to question 7 exceeded that of question 6. As it was the intention that answer 6 should include the figures of answer 7, answer 6 was made to be at least equal to answer seven.

The first two and last two questions in sections 3 and 4 showed the same anomalies as in section 1, and the same corrections were applied.

Compilation of the results

The survey returns were separated into the three groups Class A, Class B and "Both A and B" amateurs. Each group was divided into wired and non-wired (to see if any great differences were apparent between amateurs in wired tv areas and non-wired tv areas).

Survey results

Questions are referred to in the following form where it is convenient to do so. For example, section 3, question 2b is 3.2b, etc.

A total of 1221 survey forms were returned. This represents about 9.5% of the RSGB licensed membership. Figures in *Radio Communication*, January 1976, assume that 60% of UK licensees are members. While returns could have been greater, it must be remembered that a fair number of licensees are permanently inactive. While some replies did indicate that the amateurs concerned were not currently operating, most suggested a reasonable level of activity. It is probable that the majority of replies came from fairly active amateurs. The return rate represents about 5.7% of all UK licensees.

The average time period covered by the survey was 6.54 years. However, operation ranged from over 40 years to just a few days. Of course, the average Class A figure is much greater than the others because of the relatively recent introduction of the Class B licence.

Thirty-six per cent of amateurs are "slightly worried" about interference. Those "not worried at all" or "moderately worried" are equal to 26%. Only 10% are "severely worried". Class B licensees are less worried than the others, even though 31% have problems on 144MHz (see results for 1.4).

Of the h.f. bands 1.8 to 28MHz, 1.8MHz is the least troublesome. This might be expected because of the low permitted power and great frequency separation from the tv channels. 7MHz is worse, but most interference occurs from operation on the remaining four bands where over 20% of amateurs are unable to operate freely. 21MHz is the worst band for the "A" class (this result may be influenced somewhat by past experience rather than by present troubles, although the question asks for the latter). The more recently licensed "A and B" class have relatively less trouble on 21MHz than "A". However, such differences are small.

The worst of the lower h.f. bands is 3.5MHz, probably because of its popularity in the evenings (and hence tv hours). Surprisingly, the new "A + B" group has less trouble than the older "A" group despite the recent growth of colour tv (which is maybe more susceptible to video frequency interference). 7MHz is not too troublesome. Technically this band is usually too high to cause direct video breakthrough and sufficiently low to avoid severe harmonic problems. It is also not very popular for evening use because of the level of interference from illegal commercial and broadcasting stations.

On the v.h.f. bands 144MHz is by far the most troublesome on average, but this is mainly due to the Class B licensees (for whom it is undoubtedly the most popular band). However, despite the prolific use of the f.m. mode (which is reputed to cause minimal interference) 31% of "B" amateurs cannot operate without problems. "A+B" amateurs also have considerable trouble on this band where 20% are affected — similar to the h.f. bands. 432MHz is troublesome mainly for Class B amateurs since it is probably the second most popular band for them. On 70 and 432MHz "A" and "A+B" results are similar. Having obtained their full licences, the "A+B" amateurs are likely to move to the h.f. bands (though not necessarily abandoning v.h.f.).

As question 4 asks for information pertaining to present problems (and not those in the past) it is probable that differences between "A" and "A+B" are due to reasons of band popularity. For similar reasons, the high incidence of trouble on 144MHz with Class B amateurs is not that they have problems peculiar to them — it is more likely the very high proportion of them on that band. Accordingly, they are the least worried group, even though about a third of them have problems (see 1.3).

The answers to question 5 follow the same general pattern as in 1.4 but the percentages are about one-half lower. However, there are exceptions. In this question results are likely to be influenced by lack of interest or popularity. Few Class B amateurs avoid the 144MHz band because their choice is obviously limited. The "A+B" group avoid 70MHz in disproportionate numbers. It is unlikely that this is only for reasons of possible interference, but rather that, having obtained a full licence, they choose to explore the new pastures of the h.f. bands.

Although there is a visible correlation between the expected troubles and the actual troubles in question 4, because of the other influences mentioned, maybe one should be a little cautious before concluding that any particular band deserves a bad reputation for interference problems.

No attempt has been made to correlate the incidence of t.v.i. and the tv channels received since, with the change to u.h.f., the answers would not be particularly meaningful if any deductions about v.h.f. tv were attempted. In addition, a high proportion of amateurs were very vague about which channels or transmitters were received in their area. Many did not give any answer, and some answers were obviously incorrect. It seems a waste of time piecing together these scraps of evidence to obtain a largely academic answer.

Regarding differences between "wired" and "non-wired" amateurs, the "wired" represented less than 10% of all the returns. There were no outstanding differences in the answers given by these two categories, so no attempt has been made to carry out detailed separate analyses.

Television interference

The amount of t.v.i. caused by each of the three groups, A, B and A+B, was found from 2.1 to be very similar. On average, each amateur has 2.65 cases of interference. Complete lack of t.v.i. may result from infrequent operating or when the amateur is lucky enough to live in an area of low housing density. If amateurs who have no t.v.i. are excluded, the average number of cases rises to 3.4. Of all classes of amateur, 17.36% have no t.v.i. at all.

Answers to question 2.2 showed that Band 1 t.v.i. affects Class A amateurs more than the others. This result probably reflects problems which occurred before the growth of the u.h.f. tv service, rather than present trends. When t.v.i. occurs these days, it is almost certainly a u.h.f. set which is affected. This is illustrated by the figures obtained for 2.2c.

Results for 2.3 indicated that the Post Office was involved in about 30% of the cases of t.v.i. known to the amateur, and again there is little difference between the three groups. Using the figures in "Technical Topics," September 1975 issue of *Radio Communication*, to obtain a yearly average of the number of cases of t.v.i. (1968 to 1974) with which the authorities dealt, it is possible to make an estimate of the number which actually do occur. The yearly average of investigated cases is about 1,044. If this represents 30% then 3,480 cases occur of which 2,436 are never reported to the Post Office.

Again in answer to 2.4 the results are surprisingly similar for the three groups and 46% of t.v.i. cases are cured by the amateur or other parties without the help of the Post Office. Working with a figure of 3,480 t.v.i. cases per year, the amateur cures 1,600 of them. Assuming that the Post Office cure all of the cases in which they are involved (maybe this is a little optimistic) and that no cures are effected without the help of the amateur or the Post Office, this leaves 836 cases of t.v.i. uncured each year (24%).

According to the results of 2.5 only 9% of the cases of t.v.i. were cured by modifications to the amateur station.

Answers to 2.6 showed that 58% of the cases of t.v.i. were cured by modifications to the tv installation. Comparing this answer with that of the previous question clearly illustrates that the amateur is usually not to blame for t.v.i. Of course, it is not possible to tell if the uncured t.v.i. cases would give the same ratio if sufficient work was done to effect cures. However, if all uncured cases were blamed on the amateur (highly unlikely) this still gives a result which shows that the tv installation is more to blame. The ratio is 58% to 33%. (Note: this adds up to 91% and not 100%, showing that one should be a little cautious in drawing conclusions from results of this type, unless the differences being discussed exceed the expected errors).

The results obtained for 2.7 indicated that 52% of tv sets were cured of t.v.i. by external modifications alone, that is there was no need to meddle inside the tv set. It is reasonable to conclude that, when t.v.i. occurs, the amateur has about a 50-50 chance of curing it by using a simple tv filter. Compared with the 58% cures recorded in the previous question, over 90% of the cures effected at the tv installation are by external filtering alone. Hence the amateur has a good chance of overcoming his problems without too much trouble.

It is interesting to note that only 17% of all amateurs recorded that they had no t.v.i. problems at all. Group B has the least trouble (24% free) and group A+B the most (13%). It is difficult to give an explanation for this. Perhaps group B uses f.m. more, while group A+B are keen to use the more interference-prone modes of the h.f. bands. It is likely that the A+B amateur, having taken the trouble to obtain a full licence, is more active than the ordinary Class A.

Seen from the pessimistic side, the average amateur has an 83% chance of t.v.i. problems.

Radio interference

Answers to 3.1 showed that the amount of broadcasting interference (b.c.i.) caused by each of the three groups is similar. On average, each amateur has 0.86 cases of interference. If amateurs who have no b.c.i. are excluded, the average rises to 1.9 of all classes of amateur. 56% of the amateurs have no b.c.i. at all.

On average, a.m. and f.m. radios are affected almost equally according to the results of 3.2. However, Class B amateurs cause twice as much b.c.i. to f.m. than to a.m. This is presumably because of the proximity of the 144MHz band to the f.m. broadcast band. Cheap a.m. portables tend to suffer from harmonic mixing problems and are prone to interference from h.f. transmitters.

The results from 3.3 indicated that the Post Office was involved in about 14% of the cases of b.c.i. known to the amateur. Using the figures in "Technical Topics" (see previous reference) the average number of cases of b.c.i. from 1968 to 1974 was 101 per year. Hence an estimate of the actual number is 721.

Answers to 3.4 showed that 28% of b.c.i. cases are cured without the help of the Post Office. Class B licencees solve more of their own problems. As they cause worst b.c.i. to f.m. radios, it is probable that, in many cases, a filter in the coax downlead effects a cure. With most a.m. radios there is no external aerial to filter, thus making the cure more difficult. The lower cure rate for radios probably reflects the reduced concern of the owners of the affected equipment. Working with a figure of 721 cases of b.c.i. per year, the amateur cures 202. Assuming all Post Office cases are cured (even less likely than for t.v.i.) this leaves 418 uncured each year (58%).

Only 5% of the cases of b.c.i. were cured by modifications to the amateur station according to the results of 3.5.

The results obtained for 3.6 indicated that 28% of the cases of b.c.i. were cured by modifications to the radio installation. Comparing this to the answer of the previous question indicates how seldom the amateur is to blame for b.c.i. Of course, it could be argued that the uncured cases are the fault of the amateur, but there is no reason that this should be so.

Answers to 3.7 showed that only 13% of radio sets were cured of b.c.i. by external modifications alone. This represents 46% of cures effected at the radio installation — a much lower proportion than for t.v.i. Some of this difference may be accounted for by the fact that many a.m. radios have no external aerial and are battery operated, thus there is nothing to filter externally.

The survey showed that 56% of all amateurs have no b.c.i. problems at all. As with t.v.i., the A+B amateurs have the most trouble. This may reflect the effects of somewhat greater enthusiasm on their part compared with the other two groups. Class B amateurs have the least b.c.i. Maybe this is due to the use of f.m. on 144MHz. A+B amateurs have the most b.c.i. cases.

Audio interference

The A+B group have somewhat more audio frequency interference (a.f.i.) cases than the others according to 4.1. The average number of cases of all the amateurs is 1.24. If amateurs with no a.f.i. are excluded, the average rises to 1.85. 33% have no a.f.i. at all.

A surprisingly high amount of Post Office involvement is recorded in 4.2 especially when considering that audio equipment is not protected by the Post Office. Presumably they become involved as part of investigations into b.c.i. problems. The three groups are again very similar.

Answers to 4.3 showed that 33% of a.f.i. cases are cured without the help of the Post Office.

On average, according to the results of 4.4, 4% of the cases of a.f.i. were cured by modifications to the amateur station. However, this is 10% for Class B alone — much greater than the others. It seems likely that, in most cases, such modifications involved the repositioning of the aerial to reduce the local field strength.

Results from 4.5 indicated that 33% of the cases of a.f.i. were cured by modifications to the audio installation. As an audio installation is not designed to receive radio signals, the amateur should not be blamed for such interference, especially if he has taken action to minimise his local field strength.

Answers to 4.6 showed that 18% of the audio installations were cured of a.f.i. by external modifications alone. It can be seen that the Class B amateurs are relatively least successful with external cures. This might be expected as interference pick-up via the external leads is more predominant on the lower frequencies. At v.h.f. the internal wiring is long enough to act as an efficient aerial. A proportion of audio equipment (record players, stereograms, etc) do not have any external wires, other than the mains lead. Thus it follows that most of the cures will be internal.

The survey showed that 33% of all amateurs have no a.f.i. problems at all. Class B amateurs have the least (39%) while A+B amateurs have the most (23%). As with t.v.i. and b.c.i. it could be that this is indicative of the level of activity and enthusiasm.

The results indicated that the percentages of amateurs having "no interference at all" were similar in each of the three groups. Class B amateurs have the least trouble (15% free) while the A+B group have the most (7% free).

Amateurs provided a variety of additional information on how interference affected them. Often the numerical answers in the preceeding sections were expanded. Case histories and tips on curing interference were also given. Several complimentary comments were received concerning the survey, the special interference issue of *Radio Communication* and the work of the RSGB Interference Committee. A few adverse comments criticizing the survey questions were also received. While there may have been a certain amount of justification, most adverse comment came from those who had apparently not read the questions correctly or who had mistaken the aims of the survey.

Summary

Although the results of each section have been discussed in detail, the following features are worthy of emphasis.

There are few outstanding differences between the three groups A, B and A+B. However, Class B licencees are less worried about interference. Indeed, this group has fewest interference problems of all kinds. Perhaps this is largely due to the extensive use of f.m. on 144MHz.

When the effects of band popularity are considered, no amateur band is outstandingly troublesome in causing interference. It is reasonable to conclude that it is not generally possible to choose a particular band with the certainty of avoiding interference.

The incidence of t.v.i. to u.h.f.-tv is considerable. It greatly exceeds that to Band I or to Band III. While this probably reflects the decline of the use of the old 405-line system, it also indicates that t.v.i. is certainly not on the decline, even though u.h.f.-tv is potentially more immune to interference. Similarly, v.h.f.-f.m. radio suffers as much as l.w./m.w.-a.m. radio.

The Post Office become involved in only a minority of interference cases, hence their yearly figures are substantially lower than in reality. A great deal of interference is cured by the amateur without the Post Office being informed.

Only a small proportion of interference is cured by modifications to the amateur station. A much greater proportion involves modifications to the affected tv, radio or hi-fi installation. External devices are effective in the majority of cures for t.v.i., but somewhat less so for b.c.i. and a.f.i.

Few amateurs have had no t.v.i. problems, although b.c.i. and a.f.i. are less troublesome. Even fewer have no problems of any kind.

Conclusion

It may be considered that more statistical data could have been derived from the results of this survey or that methods other than simple averages used. However, it must be remembered that the primary aims of the survey were strictly limited so that the results could be used to formulate definite courses of action rather than to obtain information of a largely academic nature.

It is certainly evident that the poor e.m.c. of domestic equipment is to blame for the vast majority of interference cases, rather than defects at the amateur station. It follows, therefore, that only an improvement of e.m.c. standards can bring about a significant reduction in the number of cases of interference which occur.

letters

RECTIFICATION

Regarding your article, "Audio Signals You Never Bargained For" in the April 1975 issue of **Radio-Electronics,** I felt compelled to write to you regarding detection of RF signals. I work as a technician for the Canadian Broadcasting Corporation here in Toronto and our radio studios are about 100 yards from:

CH 5 TV transmitter
CH 19 TV transmitter
CH 25 TV transmitter
FM station at 94.1 MHz

We originally had considerable interference from these transmitters and I thought you might be interested in our solutions.

For a transistor stage, the solution is shown in Fig. 1. The 1000-ohm resistor and 200-pF capacitor should be as physically close to the transistor as possible—preferably on the leads of the transistor itself. The 1000-ohm resistor is after the biasing network.

The rectification is normally *in the 1st stage* of the mike, phono or tape preamp but the same method should be applied to later stages if required. The 200-pF capacitor with ¼-in. leads has a series resonance of about 80 MHz but its very

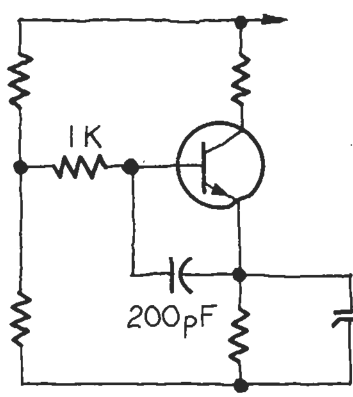


FIG. 1

broad and will cover TV channels 4 through 6 and FM band. I don't recommend going above 500 pF as the transistor could oscillate.

For AM band, change the 1000-ohm resistor to a 1-mH RF choke and the capacitor to 470 pF.

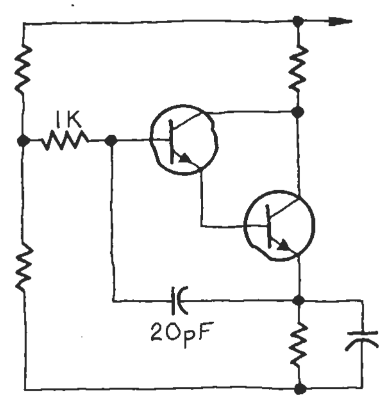


FIG. 2

For 30 MHz; leave the resistor at 1000 ohms (although a 20 μH RF choke may work as well) and change the capacitor

(continued on page 22)

(continued from page 16)

to 470 pF.

For UHF TV interference; try a ferrite bead in place of the 1000-ohm resistor and change the capacitor to a 10 pF ceramic.

For Darlington input stage—same method. (See Fig. 2.)

Now for the theory behind this. Consider a detector (base-emitter junction) and an antenna (See Fig. 3). If a capacitor

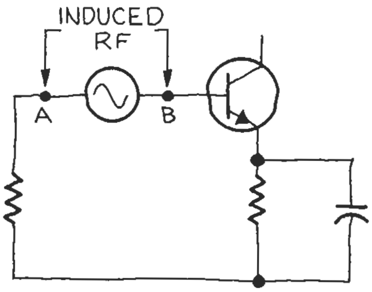


FIG. 3

is placed between point A and ground, the source is effectively shorted out as far as RF is concerned. This applies more RF to the base-emitter junction and makes matters worse! Connecting a capacitor to point B (close to transistor) and to ground is not doing the job either. The reactance of the emitter capacitor is very high to RF, so the emitter resistor is in series with the capacitor across the base-emitter junction (see Fig. 4). Obviously, the best solution is to put the capacitor directly across the detector (base-emitter junction). The resistor in series with the detector gives a further improvement.

It has not been my experience that the base-collector junction detects. Possibly

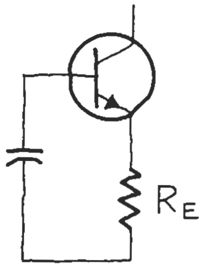


FIG. 4

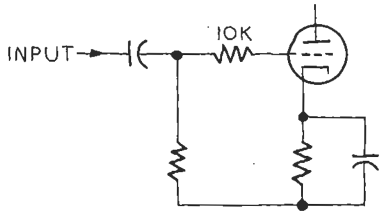


FIG. 5

because of the high reverse-bias. Old germanium transistors never give any trouble due to their high base-to-emitter capacitance (low high-frequency response).

For tubes, a 10,000-ohm resistor in the grid circuit once again, as close as possible to socket, usually works best. NO CAPACITOR. (See Fig. 5.)

The solution for integrated circuits is shown in Fig. 6. IC's are the hardest to

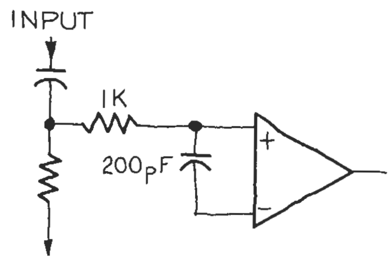


FIG. 6

debugg primarily because its not generally possible to get across the base-emitter junctions.

T. R. BURNS
Toronto, CANADA

In your April 1975 issue, you published an article by Len Feldman entitled "Audio Signals You Never Bargained For." The article came at an appropriate time as I was having this type of trouble and could not determine what was causing it.

I do quite a bit of tape recording of records as a retirement hobby. I recently constructed a single-channel 9-octave audio equalizer which I wanted to use while taping records.

I have a small Sony 8FS-50W stereo

(continued on page 28)

LETTERS

(continued from page 22)

AM/FM receiver thru which I can play and tape records but it is not equipped with tape monitor in and out circuit, so I constructed a separate phono preamp using an LM381 IC. Now when I connect the record player thru the preamp, then equalizer, to the tape recorder (Sony model TC-353), I can tape a record and monitor the taped result on my speakers. But at times while taping I'd hear interference—sometimes music, sometimes voices. Checking this out I found I was hearing an FM station and at times an Amateur would be heard.

As suggested by Mr. Feldman, I put a 250 pF capacitor across the input of the preamp and that helped considerably. I tried the capacitor and inductor setup suggested using first a 1.5 μH inductor and then a 5.6 μH, but it didn't seem to improve things. I was told that the shielded cables normally used are made with a spiral shield instead of braided shield. I had some single-conductor braided shield cable and tried that but it didn't help.

Mr. Feldman said if enough interest was shown he would have more information on this subject. Are more articles coming up? I would like to get all information available on this subject. I wrote to the local FCC but they were of no help. I am writing to EIA to see what they will do.

A. A. HOLLIGER
Los Angeles, CA

Mr. Feldman is patiently awaiting reader responses to determine if there is enough interest for a follow-up article. Your response has been taken into consideration.

How about the rest of our readers? If you know of any other sources of information on rectification, let us know so we can pass it on—Editor.

CLEARING HOUSE FOR SECURITY

I've been an avid reader of your publication for many years. I particularly look forward to the excellent articles on security systems and I am presently attempting to write a book on the subject. In reviewing the many articles you have presented over the years, I noted that a gentleman volunteered to act as a "clearing house" for your TV Typewriter. I would like to avail myself as a "clearing house" for security systems. Readers that would like to participate in exchanging ideas, approaches and problems can write to me at the following address: Don Johanson, 1860 Polk St., Concord, CA 94521. In turn I will compile the information and distribute it to those interested. (A self-addressed, stamped envelope will help.)

My book, when completed, will cover fire/intrusion detection, controls and alarms with sections on do-it-yourself circuits and low-cost measures that can be taken to reinforce areas of entry.

Keep the security articles coming—in these times we need them.

DONALD P. JOHANSON
Concord, CA.

R-E