HOW TO ELIMINATE HUM, SQUEALS AND MOTORBOATING

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STUDY SCHEDULE NO. 41

For each study step, read the assigned pages first at your usual speed, then reread slowly one or more times. Finish with one quick reading to fix the important facts firmly in your mind. Study each other step in this same way.

☐ 1. **Hum as a Service Complaint** . . . . **Pages 1-8**

This section answers the important question: "What causes excessive hum?" A review of power pack troubles is followed by practical examples of troubles which may arise within the receiver itself. Be sure to notice how the serviceman can unwittingly introduce excessive hum, so you can avoid these headaches.

☐ 2. **Localizing Hum** . . . . **Pages 9-17**

The type of hum automatically localizes the defective section, so we need only effect-to-cause reasoning, stage and part isolation. These procedures are given in detail for both steady hum and modulation hum.

☐ 3. **Residual Hum Problems** . . . . **Pages 18-21**

Once in a while you may be called on to reduce the residual hum level in a receiver. Hum-bucking circuits or changes in design are required, most of which take considerable time. These procedures should be tried only after reaching an agreement with the owner, as results cannot be guaranteed.

☐ 4. **Oscillations, Squeals and Motorboating** . . . . **Pages 21-28**

Oscillations occur only when there is a feedback path, a feedback with the proper phase and sufficient feedback energy. The cure is usually one of reducing the feedback energy or destroying the path. You will study the paths and then take up the methods of localizing the offending stage and curing the trouble.

☐ 5. **Answer Lesson Questions and Mail Your Answers to N. R. I.**

☐ 6. **Start Studying the Next Lesson.**

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HOW TO ELIMINATE HUM, SQUEALS AND MOTORBOATING

Hum as a Service Complaint

HUM is a very common service complaint. However, hum is not a trouble which is "there" or "not there". Only a battery operated set can be completely "humless"; there is always some residual hum in even the best receiver operating from a power line or power converter. Your object, therefore, in servicing a set for hum is not to remove the hum altogether, but to reduce it to an acceptable level. This lesson will teach you the many ways in which this can be done.

You can learn to recognize hum very easily. Just listen carefully to the output of any properly operating power line receiver when the surroundings are quiet and no program is coming through the loudspeaker. Turn the volume control to zero to eliminate stray noises and other signals. You will soon become conscious of a low-pitched humming sound if your ears can hear low frequency sounds. If the set is a standard a.c. receiver using full-wave rectification and operating on a 60-cycle power line, you will be hearing 120-cycle hum. (It is called 120-cycle hum because the fundamental frequency is 120 cycles; there are harmonics present also.)

Next, connect a headphone in series with a 10,000 to 50,000 ohm resistor, connect this combination across the filament terminals of any tube in an a.c. receiver except the rectifier tube, and slip on the headphones. You will hear 60-cycle hum. You should learn to distinguish the difference between 60- and 120-cycle hum, because this will be important in recognizing the source of hum in service work

▶ Usually the hum level is considered satisfactory if the hum is not noticeable when the device is in normal operation, but this standard allows wide variations in the amount of hum present. For example, an outdoor public address system can have more hum than a radio receiver, because in its normal use surrounding noises will make hum less noticeable.

Incidentally, there may be a considerable difference between the amount of a.c. hum *voltage* in the output circuit and the amount of hum *sound* which actually comes from the radio loudspeaker. Midget or table type receivers give relatively little hum output, because the design of the speaker and output transformer and the limited amount of speaker baffle do not favor the passage of low frequencies. As a result, half-wave rectification and less efficient filter designs are permissible in these sets because even relatively large amounts of hum voltage are not appreciably reproduced as hum sounds. On the other hand, even an extremely small hum voltage at the voice coil of a loudspeaker in a high-fidelity receiver may produce a relatively large amount of hum sound, both because the system is capable of reproducing low frequencies, and because the speaker baffle or speaker cone may have a response peak at low frequencies or have resonant points at or near the hum frequency.

Practical experience is the only guide to the amount of hum normally found in any particular kind of set. Make a point of noticing the hum level of radio receivers you service for other complaints, so you'll learn to know the amount of hum to expect in various models.

▶ Remember—the amount of hum permissible in a device depends a great deal upon the listener. Some ears do not hear low frequency sounds well. If you find you can't hear hum unless you bring your ear quite close to a loudspeaker, be careful about handling customer complaints—your customers may hear hum much more readily than you do.

Usually you will be asked to service a set for hum only if some defect or change in the circuit has raised the hum level to an abnormal degree. Surprisingly large amounts of hum may be tolerated by the receiver owner until his attention is called to the fact that the receiver is humming, or until some defect suddenly causes an even louder hum. But once he has become definitely conscious of the hum, he may then become so critical that he listens for the hum instead of the program.

▶ Incidentally, when you are working on a receiver with an elusive case of hum, you may yourself reach the point where even a normal hum level seems excessive. Getting away from the receiver for a while will frequently restore your sense of proportion. This will also often work for the customer—just keeping the radio in your shop for an extra day or two, so that he begins to forget the hum annoyance, may satisfy a customer if his radio is apparently normal and the usual hum elimination procedures do not lower the hum level. Of course, if the customer insists, and is willing to pay for the large amount of time that would be necessary, then there are some elaborate procedures which can be followed. These will be described in this lesson.

Before we study service techniques for reducing hum, let's review quickly the causes of excessive hum in radio circuits. This will make it easier for you to see just what must be done to localize and eliminate hum troubles.

Power Lines. We will assume a standard 60-cycle power line is used in the examples in this lesson. Should some other frequency line be used, then the frequencies will be changed. For a 25-cycle line, the frequencies will be 25 and 50 cycles instead of 60 and 120 cycles in these examples.

POWER PACK TROUBLES

Most a.c. receivers have a power supply like Fig. *1*, in which an a.c. voltage from the power line is rectified. The output of the rectifier contains a large amount of a.c. ripple, so it is passed through a filter before being used to supply the radio. Of course, if there is any defect in the filter, the hum level in the receiver will be abnormal. Let's see what can go wrong with a filter—starting with the condensers, as they are the most likely sources of trouble.

Filter Condensers. It is possible for a filter condenser to open, to short circuit, to develop leakage, to lose capacity, or to develop a high power factor. (A good condenser will have a low power factor, or low series resistance. As this resistance increases the capacity becomes less effective.) When a condenser is *open* the effect is the same as if the condenser were not present at all, so the hum level will increase. A *short-circuited* condenser will kill the receiver altogether instead of causing hum.

Leakage in a condenser has the same effect as connecting a resistor in parallel with the condenser. As this does not affect the capacity, a leaky condenser by itself will not cause hum, but may cause another part to do so, as we will show later.

Loss of capacity and high power factor may be caused in wet electrolytic condensers by evaporation of the electrolyte and in dry electrolytic condensers by drying out of the electrolyte. Either defect produces more hum, particularly if C_2 (Fig. *1*) is the offender.

Choke Coil. Excessive d.c. current through the choke coil, such as may be produced by a leaky output filter condenser, will saturate the choke coil core and thus reduce the effective inductance of the coil. Reducing the choke inductance of course lowers the filter effectiveness, so the hum level will rise. In this case the condenser is the actual cause of trouble but it is the change in choke characteristics that causes the hum. Replacing the condenser will allow the choke coil to resume normal operation.

As you know, choke coils have an air gap to prevent core saturation. The gaps of well-made chokes are filled with some non-magnetic material such as paper, cardboard, copper or brass spacers, etc. However, the gap of an inexpensive choke often has nothing in it; once in a while the gap of such a choke will close up, if the clamps holding the core happen to loosen. This permits core saturation which lowers the choke coil inductance and raises the hum level.

If some of the coil turns short together, the inductance of a choke will also be reduced, increasing hum. This difficulty is not common with ordinary choke coils, but does happen occasionally when a speaker field is used as a choke.

Rectifier Tube. A full-wave rectifier normally supplies current with a ripple frequency of 120 cycles. If the rectifier tube sections become unbalanced, so that one section passes more current than the other, the fundamental ripple frequency will change to 60 cycles because the output is more nearly like that of a half-wave rectifier. This often causes hum in the set, because a filter which is adequate for 120-cycle ripple may be unable to filter the 60-cycle ripple sufficiently. (Remember, a poor socket connection or a defective power transformer, in which only half the high voltage secondary supplies voltage, will also cause half-wave rectification and create hum. If the tube tests good, investigate these points.)

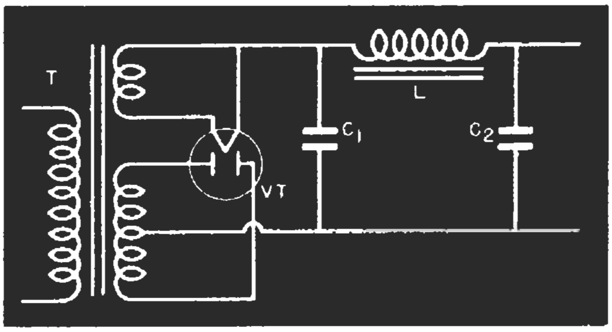

FIG. 1. Although this standard a. c. power pack is the type most commonly encountered, the same filter troubles described in the text will be found in a. c.-d. c. packs.

Sometimes a rectifier tube becomes gassy, due to a faulty tube or because of excess current flow. The high concentration of ions makes the tube continuously conductive, so it becomes an imperfect rectifier and passes some current on the reverse cycle. This again introduces 60-cycle a. c. in a circuit designed to eliminate only higher frequencies and may produce hum. Also, an r.f. oscillation may develop, producing hum modulation as we shall learn later. When you see the rectifier light up with a purplepink glow, and know it is not a mercury vapor tube, you're justified in assuming it is gassy. To cure the condition you must usually replace the tube. If there is an excess current flow, it must be reduced by replacing the defective part (usually leaky filter condensers).

Tuned Filters. Some of the older receivers have tuned filters. These are adequate hum eliminators as long as they stay tuned to the proper frequency, but are very difficult to retune if they drift off. If you find something wrong with a tuned filter nowadays, the easiest thing to do is to remove the tuning feature so the filter is no longer resonant, and replace the filter condensers with modern, high capacity electrolytic condensers. The hum reduction of the new filter will equal or better that of the tuned circuit.

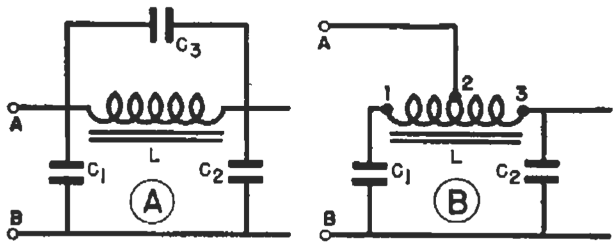

FIG. 2. Two common tuned filters.

To change over tuned filters of the type shown in Fig. *2A*, remove C_3 and increase the capacity of C_1 and C_2; to change over one like that in Fig. *2B*, move the wire coming from terminal *A* from point *2* to point *1* and increase the capacity of C_1 and C_2 each to 8 mfds. or more.

RECEIVER DEFECTS

Quite apart from the power pack, there are many possible sources of hum in the receiver itself. One of the most common is cathode-to-heater leakage in any tube in which the filament is operated from a.c. voltage directly. Normally, the cathode of such a tube is insulated from the filament. However, the cathode may short to the filament or leakage may develop between them. If either happens in a set in which the cathode is connected to the chassis through a bias resistor, a hum voltage may exist between the cathode and the chassis. (Cathode-to-heater leakage is not troublesome if self-biasing is not used and the cathode is grounded directly, as there is then no way of developing a cathode-chassis voltage.)

Cathode-to-heater leakage is most likely to occur in a.c.-d.c. receivers, where the difference in potential between a tube cathode and its filament increases as you progress along the filament string (see Fig. 3). For this reason, the first audio tube (the tube most sensitive to hum) is always placed first in the filament string of such sets, where the potential difference is least, to minimize hum.

A tube tester may or may not show up cathode-to-heater leakage, depending on the sensitivity of its leakage indicator. Try another tube when there is any doubt.

Decoupling Circuits. Figure *4* shows typical decoupling circuits used

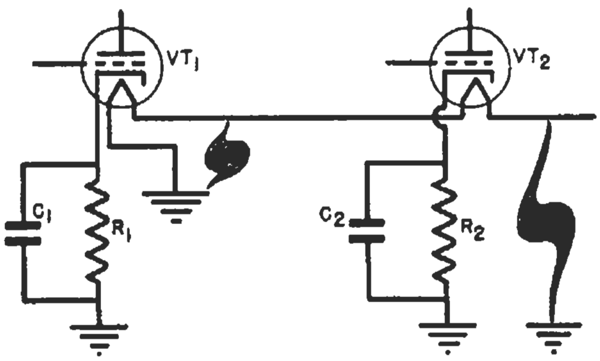

FIG. 3. The filament-to-ground voltage increases as you move along the filament string in a. c.-d. c. receivers.

in plate and grid circuits, particularly in audio stages. The filter R_4-C_4 is used in the plate supply. The combination normally forces signal currents through C_4, keeping them out of the power supply, and also acts as an additional filtering section between

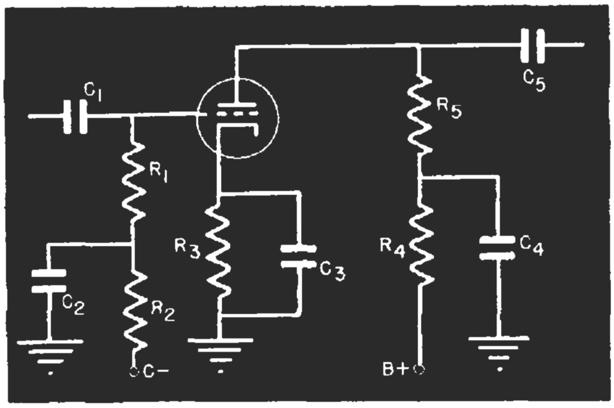

FIG. 4. Plate and grid decouplers.

the power supply and the tube. If C_4 should open, a certain amount of hum may get into the circuit from the power supply and be fed through C_5 to the following tube. It is also possible for signal currents to get out of the circuit and enter other circuits through the power leads; this may cause motorboating, or other difficulties.

▶ Similarly filter R_2-C_2 prevents signals from getting into the *C* supply and keeps hum voltages from getting into the grid circuit. If C_2 opens, hum voltages may be applied to the control grid.

▶ We don't ordinarily think the bypass condenser C_3 has much to do with

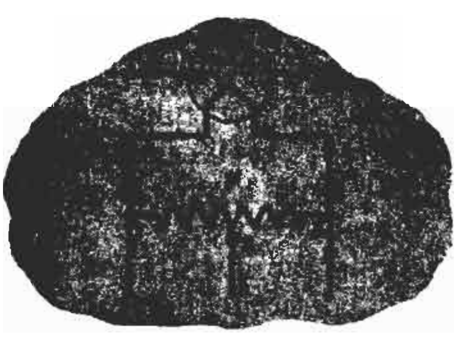

FIG. 5. How a hum balancer is connected to give the effect of a filament center tap.

the hum level. However, if there is even a very slight amount of cathode-to-heater leakage in the tube, there will be a small 60-cycle current flow from cathode to chassis. This will not cause much voltage drop across the low-reactance condenser C_3 as long as it is in good condition; but, if the condenser opens, the cathode-to-chassis impedance will rise to the value of R_3, and this increased impedance will cause a considerably higher hum voltage drop. Since this voltage will be between the grid and cathode, it will enter the stage and be amplified.

Hum Balancers. In a few radios, you may find a triode tube in the audio amplifier. The grid return to such a tube is made to some point representing the center tap of the actual tube filament. Sometimes a center-tapped resistor or potentiometer will be used as shown in Fig. *5*. The potentiometer *P* is normally adjusted so that hum is at a minimum. However, if this potentiometer burns out or becomes disconnected at *either* terminal *1* or terminal *3*, then it effectively just connects terminal *A* to one side of the filament. This will introduce hum, as will improper adjustment of the tap.

Grid Circuits. If the grid circuit of a tube (particularly a first audio

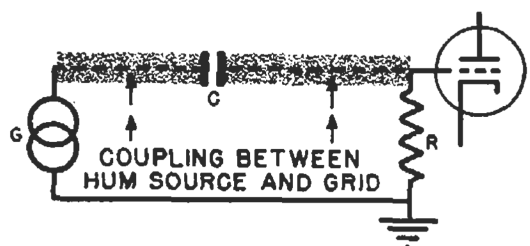

FIG. 6. Capacity coupling exists between grid wiring and the hum source.

tube) increases in impedance or becomes open, hum is practically certain to result. To see why, let's look at the circuit in Fig. *6*. Here the stray hum field is represented by a generator *G*, and the capacity between the grid wiring and the hum source by a a condenser *C*. Since *C* is of course very small, it has a high reactance.

Since the hum generator feeds into the voltage divider formed by *C* and *R*, the hum voltage divides between the reactance of *C* and resistance of *R*.

The larger R is, the more hum voltage appears across it between grid and ground, and the greater the hum output.

When the grid input circuit has low impedance (R is small), it takes a considerable amount of stray hum voltage to develop an appreciable hum signal. On the other hand, when the grid circuit has high impedance, very small amounts of stray hum voltage may cause trouble. Sometimes a set develops hum because of an increase in the grid circuit impedance; the most common cause of such an increase is a defective volume control. As the control wears, a poor contact develops between the rotating arm and the strip; causing an increase in the resistance between the grid and ground. In many types, the strip itself may wear out; this, of course, increases the resistance a great amount.

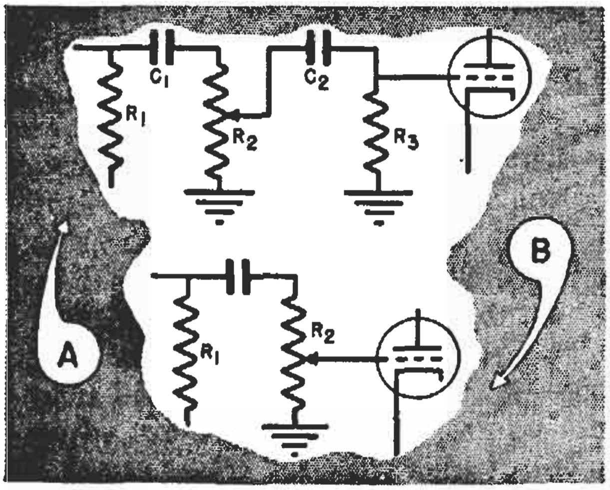

FIG. 7. Two methods of connecting volume controls. A defective control can cause hum in either instance.

This effect may even occur when the volume control is decoupled from the grid circuit, as in Fig. 7*A*. Here, the a.c. impedance between grid and ground is formed by R_3 in parallel with C_2-R_2, with the volume control in turn shunted by C_1-R_1. Since the condenser reactances are negligible, we have R_3, R_2, and R_1 in parallel when R_2 is set for maximum volume. If the control opens circuits at the ground end, the a.c. impedance between the grid and ground will increase because it will no longer be shunted by R_2.

In a circuit like that shown in Fig. 7*B*, where the volume control is right in the grid circuit, a defective control can break the d.c. path. The a.c. impedance rises to a high value, causing a loud hum. This open also produces a "floating grid" (no bias), and will frequently cause distortion in the set output as well as hum. In either case, the volume control will not properly control volume, which is an additional clue leading you directly to the trouble.

INDUCTIVE COUPLING

Iron core transformers and chokes have leakage magnetic fields which exist in the space about the devices and frequently travel through the chassis. Most of them use soft iron magnetic shields to limit this field, but even so audio transformers must usually be placed well away from power transformers and filter chokes to avoid hum pickup.

If you replace an iron core choke or transformer, you must take special precautions not to introduce hum in the receiver—unless you can get an exact duplicate, in which case there is no problem. If you must use one of the "universal" replacement types, or some other type having similar electrical characteristics, you may find after making the installation that the leakage magnetic field of this particular part is different, or the shielding poorer, so that some magnetic coupling exists to another circuit or part and hum develops. The amount of hum increase will usually be slight, but it may be noticeable to the owner of the receiver.

Frequently a simple change in the position of the part, such as rotating it or tilting it at an angle, will clear up this trouble. Usually, however, there are so many wires connected to such parts, and the mounting space is so limited, that this is not practical; if so, try using a shield. Soft iron is the best shield at these low frequencies. Make a practice of saving the cases from defective transformers for possible future use as shields for others.

Since both inductive and capacitive coupling can exist between wires, any wires carrying large amounts of a.c. current must be kept away from grid and plate leads to prevent hum. Often the filament leads are twisted together so that induction from them to neighboring wires is minimized.

Because of inductive and capacitive coupling, you may accidentally raise the hum level by moving the wires about while hunting for trouble or while making a replacement. Be careful about this. Before moving wires or parts, make a note of their exact locations, and return them to these positions when repairs have been made.

Set owners often tuck excess lengths of line cord into their radios. Watch out for this—it may bring the a.c. cord close to a grid, producing enough coupling to cause hum.

REVERSED HUM-BUCKING COIL

If you disconnect a speaker for any reason, be very careful when you connect it up again. It is very easy to make the mistake of connecting the hum-bucking coil up backward—even factory assembly workers have been known to do so.

This hum-bucking coil is a small coil wound next to the field coil. The field coil usually carries a certain amount of a.c. (particularly when used as a choke coil in the power supply) and induces some hum voltage in the voice coil, making the loudspeaker produce hum. The hum-bucking coil is arranged so that when it is properly connected to the voice coil, the voltages induced in the hum-bucking coil by the field cancel those induced in the voice coil. This prevents speaker field induction from causing hum. However, if the hum-bucking coil terminals are reversed with respect to the voice coil terminals, then twice as much hum current flows through the voice coil and the hum level increases considerably. Figure *8* shows how the hum-bucking coil is usually represented on diagrams. Here, L_1 is the speaker field, L_3 the voice coil, and L_2 the hum-bucking coil.

Even without a diagram, you can always tell when a hum-bucking coil is used by tracing the connections

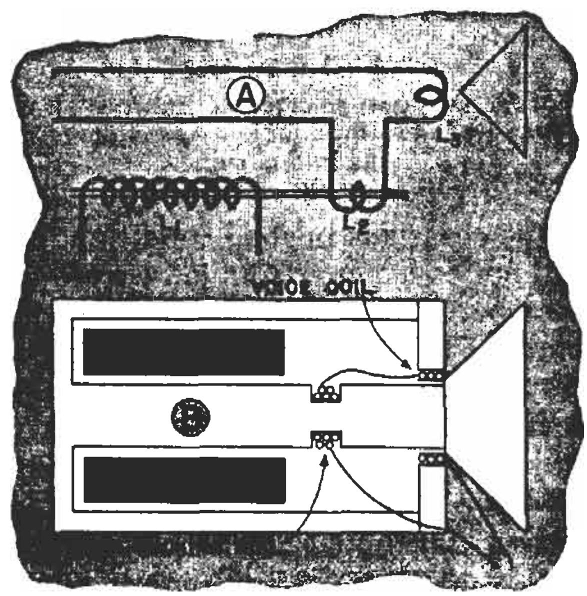

FIG. 8. The hum-bucking coil is placed between the voice coil and field, and is so connected that the hum voltage induced in it and the voice coil by the field are out of phase and cancel.

from the output transformer to the voice coil. If the two leads from the voice coil go directly to the output transformer, there is no hum-bucking coil. However, if one of the leads from the voice coil and one of the leads from the output transformer secondary go to a small coil in the field coil enclosure, a hum-bucking coil is used.

POOR CONNECTIONS

It is quite possible for a poor connection to cause hum, particularly when the joint is common to more than one circuit, as in Fig. *9.* Here the grid resistor *R* and one filament terminal must both be grounded. As it is difficult to solder to the chassis lug *G* with parts in the way, *G* is connected to terminal *7*, and the resistor is then connected between terminal *7* and terminal *5*. Now, as long as the ground

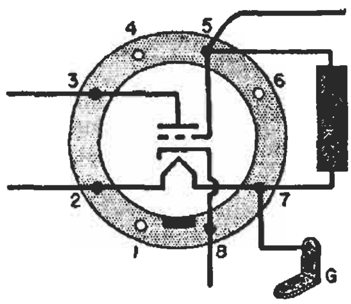

FIG. 9. A poor connection between 7 and grounding lug G introduces a hum voltage into the grid circuit.

at the chassis is in good condition, this will not cause any trouble because the wire between *7* and *G* is usually too short to have appreciable resistance. However, suppose a poor connection develops at *G*. This is the same as adding a small resistor in the circuit between *7* and *G*. The a.c. filament current flowing through the resistance of this poor connection causes a voltage drop; tracing from the grid to ground, you can readily see that this a.c. voltage drop will be introduced into the grid circuit. Feeding directly into the grid circuit like this, even a small hum voltage may produce a very loud hum. You can cure such a condition, after isolating its source, by resoldering the connections or by using a different ground for the grid return.

Hum may also be introduced into a circuit by a poor ground connection to a shield. A wire in a circuit critical to hum pickup is often shielded—particularly a grid lead which must be run any great distance. The shield around such a wire must be grounded to be effective; if the ground connection is poor or non-existent, the effect of the shield is lost and hum can be introduced into the shielded wire.

Sometimes the shield must be grounded at both ends, as in Fig. *10,* to reduce the hum level. A poor ground at either end of the shield permits the shield itself to pick up hum voltages and transfer them to the wire within.

MECHANICAL HUM

All the examples so far discussed are classed as electrical hum, because they cause a hum voltage which is reproduced as sound by the loudspeaker. Hum may also be caused mechanically by a vibrating part which produces sound directly. Almost invariably, mechanical hum is

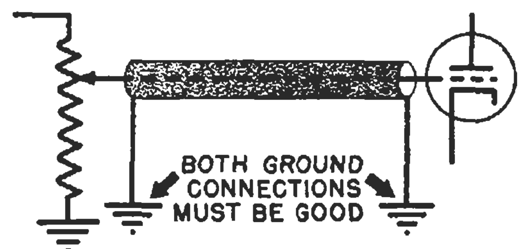

FIG. 10. Watch for poor grounds.

produced by an audio or a power transformer whose laminations are so loose that the transformer core can vibrate under the influence of the varying flux.

The source of mechanical hum can easily be discovered by careful listening. You can remedy the condition just as easily, either by tightening the clamping bolts or by driving a small wedge between the transformer laminations. Either method will usually secure the core so that it cannot vibrate.

Localizing Hum

The same general procedures are used to locate the source of hum as are used to localize any other radio trouble. Your first step should be to confirm the complaint. Next, use effect-to-cause reasoning—which can eliminate many localizing steps. For example, the manner in which the hum is reproduced will let you determine at once the section of the receiver in which the hum originates.

If the hum is produced steadily, whether a program is tuned in or not, then the hum *must originate in the power supply or in the audio amplifier,* since an audio frequency voltage cannot travel through the r.f. amplifier by itself. Of course, the hum will be more evident when you are tuned off a station, because then there is no program to mask or drown out the hum.

On the other hand, if the hum is tunable (is heard only when a signal is tuned in) then we have *modulation hum, due to hum voltages entering a defective r.f. or i.f. stage, or due to modulation outside the receiver.*

Let's repeat these two important facts, to fix them firmly in your mind:

Steady hum originates in the power supply or a.f. stages.

Modulation hum originates outside the receiver or because of modulation in an r.f. stage.

Since steady hum is the complaint you'll meet most often, we'll study it first. Modulation hum will be taken up later in this lesson.

STEADY HUM

Let's assume the power line frequency is 60 cycles. Suppose you are asked to service a standard a.c. receiver with full-wave rectification, and a case of steady hum. You know at once that the cause lies somewhere in the power supply or a.f. circuits. Next, ask yourself some mental questions about the operation of the receiver.

Is the hum accompanied by any other complaint? How loud is the hum? Is it 60-cycle or 120-cycle hum?

The answers to these questions will help you greatly in localizing the source of hum. Let's see what some typical answers reveal.

▶ A steady 120-cycle hum of medium loudness, accompanied by weak reception and possibly distortion, may indicate the input filter condenser is open, has lost capacity, or has developed a high power factor. Any of these conditions will lower the operating voltages, causing weak reception. The fact that the hum is only of medium loudness shows the following choke-condenser sections are still effective.

The same combination of defects may also mean the output filter condenser is leaky. This causes an excessive voltage drop in the choke, and therefore lowers the operating voltages supplied to the set.

You can be reasonably certain a filter condenser is causing this sort of hum if you find a condenser with a swelled-up container, or one which grows hot after a few minutes' operation—or if you discover a deposit of white chemicals about the vent on a wet electrolytic. Replacing a suspected condenser with a good one and listening to see if the hum is reduced is often a simple way to confirm your diagnosis. If you believe the condenser is open, has lost capacity, or has increased in power factor, shunt it with a good one (watching polarity, of course, if you use an electrolytic). If you suspect leakage, however, you must disconnect the original condenser before trying another one in its place.

The choke coil will probably overheat if you have a leaky output condenser. However, this is not a very helpful clue, since it's hard to tell just how much heat should be developed in a choke coil or speaker field. Speaker fields are frequently quite warm to the touch, even during normal operation. If you know the voltage drop which should exist across the field or choke, and measure a voltage which shows that the drop is considerably higher than normal, then you do have an indication of excess current through the field or choke coil.

▶ A very loud 60- or 120-cycle hum, accompanied by weak reception or a dead receiver, usually indicates an open grid circuit, particularly in the first audio stage. The hum frequency depends on the source of the stray field; the power transformer would induce a 60-cycle voltage while the filter choke would cause a 120-cycle hum. Watch for grid caps off tubes or on the wrong tubes in such cases. The hum will be especially loud if the open is near the grounded end of the input device, because the parts and leads still connected to the grid will help pick up stray fields.

A very loud 120-cycle hum with a loss of low frequency response, possibly accompanied by oscillation, motorboating, or distortion, usually means an output filter condenser is open or has lost capacity.

▶ A 60-cycle hum, in a standard receiver using full-wave rectification, usually indicates cathode-to-heater leakage in an audio tube. The loudness depends on which tube has the leakage, since tubes near the input of the amplifier cause more hum than those farther along in the amplifier.

Remember that a hum voltage is amplified just like a signal voltage, so even a small amount of hum originating in the first audio stage can cause more hum output than a large amount of hum in a tube further along in the amplifier. From this you can see, except for the power supply, the first audio stage is the one most likely to be the source of abnormal hum.

▶ A push-pull output stage will tend to cancel any hum voltage coming from the power supply to that stage alone. (The two tubes draw equal plate currents in opposite directions through the output transformer, so any ripple introduced in this plate supply will cause opposing fluxes in the output transformer which tend to cancel the hum.) Many receiver manufacturers, taking advantage of this fact, obtain a higher plate voltage by connecting the plate supply for the push-pull stage at a point in the filter circuit where there is less filtering. This is safe enough as long as the push-pull tubes stay balanced, but the hum level will rise as soon as they become unbalanced.

Finding tubes which will balance is often something of a problem. Since the push-pull tubes are power tubes and so draw high currents, a tube tester will often not show up an unbalance unless the tubes are radically different. Sometimes the only way you can find two tubes which draw approximately equal plate currents, and so minimize hum, is to keep trying tubes in the set or to insert a plate current meter in each tube circuit.

Defective Stage Isolation. Almost always, proper effect-to-cause reasoning and a few tests will lead you immediately to the source of steady hum. This is particularly true of modern receivers, where there are rarely more than two audio stages and usually only two or three filter condensers. These few items can be checked quickly and the source of hum located in a few minutes. However, if there is some rather unusual steady hum condition (particularly in an elaborate receiver), some of the following methods of further localization may have to be used. Before trying any of these methods, tune away from any signals or turn the volume control to zero volume, so you can concentrate on the hum.

▶ The stage interruption test is an easy way to localize the hum-producing stage. This method consists of blocking the circuits, one at a time, to determine which is causing the hum. To apply the method to an a.c. receiver, start at the input of the amplifier and pull out the tubes one at a time, moving toward the output each time. (Of course, you must replace each tube before pulling out the next.) If pulling out a particular tube makes the hum disappear, then the hum is originating in that stage or in the preceding coupling device.

If you notice that pulling out tubes one at a time makes the hum decrease each time, but does not stop it altogether, then probably the hum is getting into all the stages simultaneously. This immediately indicates that the trouble is in the power supply common to all the stages.

The tubes in universal receivers can't be pulled out to perform the stage interruption test. It is possible to short circuit the input of each stage, however, and achieve the same result. If one end of the input part (across which the signal appears) is connected to the set chassis, you can short it out by touching the control grid terminal and the chassis with the probes of a test lead. Move from stage to stage, toward the output. However, you should not do this if bias sources are placed in the grid circuit between grid and chassis, because your test lead will short out the bias. (An example is shown in Fig. *11*, where VT_3 gets bias from the tapped choke L_4.) Instead, hold the test lead right across the input device itself (R_8 for example). This blocks hum signals from preceding stages but will not stop hum coming from the bias source, such as might be caused by an open C_7.

If the set chassis is not part of the circuit, then you must identify the B— return lead and short the grid terminal to it, or else short across the input part itself.

▶ A signal tracer is very useful in localizing hum sources. If the tracer has an audible output indicator, all you have to do is connect it to the output of each stage in succession and listen for the hum. Moving from input to the output, the first stage you encounter having hum is the source. Remember, this hum will get louder as you move toward the set output. If the signal tracer has only meters or electric eye indicators, with no provision for phones or loudspeaker, then you may find it more difficult to locate a relatively low-level hum source.

A pair of headphones in series with a blocking condenser can be used as a signal tracer, moving from input to output in the a.f. stages.

▶ There are a few precautions to observe in using either a signal tracer or a pair of headphones. Either device may be more sensitive to hum voltages than is the amplifier. Since the headphone is bound right to your ear, hum levels will always sound louder than those normally produced by the loudspeaker, so even the normal residual hum level may sound high when you are listening directly to the receiver stages. Be careful not to confuse this hum level with the abnormal hum for which you are looking.

▶ The c.r.o. is useful as a signal tracer if the hum level is high enough to give a noticeable deflection. By using a 60-cycle sweep, and noticing whether you have a one- or two-cycle pattern, you can tell whether you have 60- or 120-cycle hum.

Defective Part Isolation. Once the defective stage has been isolated, hum localization is relatively easy. Naturally, the first step is to test the tube in the defective stage, or try a new one. If this gives no result, a careful check of the grid, plate and other electrode circuits will show the part which is causing the trouble.

▶ If there is any evidence that the wiring has been changed about during previous servicing, try shifting the wires in that stage with a non-metallic rod. If you find any wire causes variation in the hum level as it is moved, move it carefully to the position of least hum.

It is usually possible to break circuits in a manner which will help in localizing hum. For example, you may hear hum when a signal tracer is connected at terminal *5* of Fig. *11*. You cannot tell whether this hum originates in the grid circuit of VT_3 or in the plate circuit of VT_2. By disconnecting condenser C_6, however, and listening between terminal *5* and the chassis, you can definitely tell where the hum is getting in. If you hear it between *5* and ground with condenser C_6 disconnected, then it must be getting into that grid circuit; the most logical cause of this would be an open condenser C_7. (Notice that C_7 and resistor R_7 are used as a decoupling filter in this grid circuit.) Of course, disconnecting C_6 effectively raises the grid circuit impedance by removing the shunting effect of R_5, and so may make the residual hum level rise at the VT_3 grid. Remember to make allowances for this.

Disconnecting C_6 while listening to the output of the set will also help point out the hum source. If the hum decreases or vanishes, then it must originate in some previous circuit; if it remains or increases, it is being developed in the output circuit, the power supply, or the loudspeaker.

▶ You can connect a signal tracer across a possible defective part and listen for excessive hum. For example, if you are suspicious of condenser C_7, connect a signal tracer between terminal *8* and chassis. Any appreciable hum at this point indicates an open condenser, because a good condenser would practically short circuit hum voltage between these two points. Similar use of the tracer will show you whether condensers C_{10} and C_5 are defective.

▶ In the same way, you can separate the circuits of VT_1 and VT_2 and discover which is causing hum by unsoldering condenser C_4. Again, remember to make allowances for a possible rise in hum caused by disconnecting the shunting resistor R_2 from the grid circuit of VT_2. If the hum source is in the VT_2 grid circuit, the most logical suspect would be the volume control.

▶ To separate circuits which are transformer coupled instead of resistance coupled, disconnect the primary winding and leave the transformer connected to the following grid circuit. Assuming the hum is present at the grid, and remains with the primary disconnected, the transformer is probably picking up the hum inductively. This means you will either have to move the transformer to a different location or shield it.

Practical Hints. When filter condensers are mounted in a common block, you will frequently find that only one or two of the condensers are defective. However, it is best to replace them all, because when one condenser in a block goes bad, the others will usually soon follow. (This is not so true of condensers that are separated from each other.) Many servicemen make a practice of replacing electrolytic condensers rather generously, particularly if the receiver has

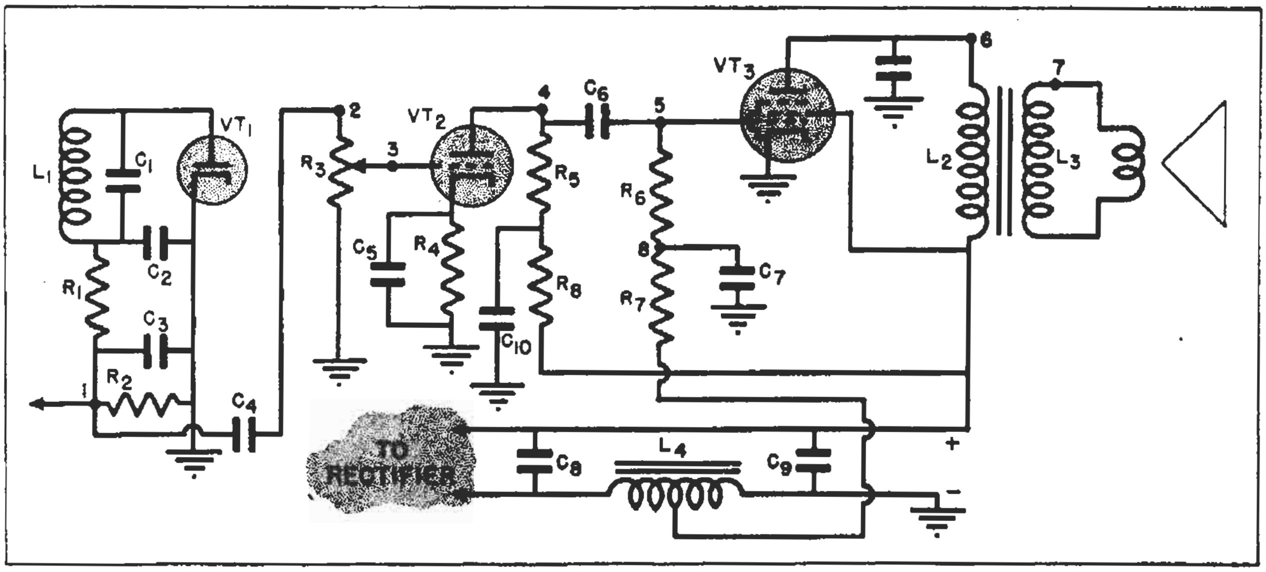

FIG. 11. Here are the testing points for localizing hum.

been operating for several years with no condenser replacement. It is gradually being recognized that condensers, like tubes, can wear out.

When replacing condensers, be very sure to make the proper connections. See that the replacement condenser has ratings like those of the original, and that the replacement is connected with the proper polarity and between the right points.

▶ An unusual source of hum is found in some receivers in which the filter condenser block is made up of dry electrolytic condensers contained in a waxed cardboard container, and is mounted on the set chassis by means of a metal strap around the block.

If the filter choke is in the negative side of the circuit, the negative lead of one of the condensers will not go directly to the chassis (see Fig. *12A*). If leakage develops between the ungrounded negative terminal of the filter condenser and the grounded mounting strap, the choke coil will be shunted by the leakage resistance *R*. This will reduce the effectiveness of the choke coil and introduce hum.

If the set has a common bus or lead as the B— return so the set chassis is not a part of the circuit (see Fig. *12B*), none of the negative leads of the filter condensers will go to the set chassis. Leakage between any condenser section or lead and the chassis through the strap will set up hum currents in the chassis between the leakage point and the C_3 return, thus providing chassis voltage drops which may link with other circuits.

To stop hum in circuits like these, either replace the condenser block or

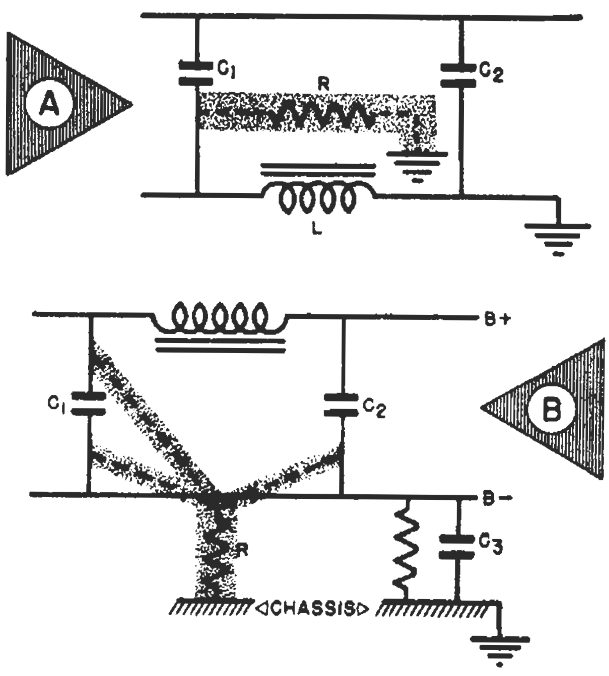

FIG. 12. Leakage to chassis through the cases of filter condensers is a source of hum in many a. c.-d. c. receivers.

cut the strap and make the condensers self-supporting.

MODULATION HUM

Modulation hum develops in the r.f. amplifier or outside the receiver. Since an audio signal will not travel through the r.f. or i.f. stages by itself, it must be mixed with or modulate an incoming carrier to cause hum. Hum of this sort is more evident when a station is temporarily not modulating, as during the silent period between programs, *but you can hear it only when you are tuned to a station.*

The fact that mixing is necessary for modulation hum to exist means that there must be both a hum voltage and a curved tube characteristic in the stage where the hum is introduced. When an r.f. amplifier has a linear Eg-Ip tube characteristic, the presence of both r.f. and hum voltages will not produce hum. If you were to take a cathode-ray oscillograph picture of the plate current when both the ripple and r.f. components exist in a stage operating as a linear amplifier, the pattern would be as shown in Fig. *13A*. As you can see, the hum signal is varying the r.f. signal, but the amplitude (height) of the r.f. pulses remains exactly the same. (That is, if you measure the distance between points x and y and compare it with the distance m-n, or the distance s-t, you will find they are the same.) This means we have both an audio and r.f. voltage existing together, but they are not modulated. In the plate circuit of this stage, the tuned circuit will pick out the r.f. voltage, and the audio voltage will be ignored. Thus, a hum voltage introduced in a linear r.f. amplifier will not be passed on to the next stage.

This does not mean, however, that only a detector stage can give hum modulation. The Eg-Ip characteristics of all amplifiers, including those in the radio frequency system, are not perfectly linear, so in practice we may get modulation hum from any amplifying stage.

Operating an amplifier at a point on the curved region, as shown in Fig. *13B,* permits normal variation in one direction but tends to cut off variations in the other direction. This does not greatly matter to the incoming signal, since the flywheel effect of the following resonant circuit will restore the original wave shape. However, if hum is introduced, the plate current will have the appearance shown. Comparing the x-y distance with the m-n or the s-t distance in this figure shows you that the amplitude of the r.f. signal has been changed by the hum voltage—in other words, a modulation has occurred. The following tuned circuit will now reconstruct a completely modulated wave like Fig. *13C,* so the hum voltage will be carried along on the r.f. voltage just like any original modulating signal.

Effect-to-Cause Reasoning. When you are tracking down modulation hum, notice whether it is heard on all stations, only on certain stations, or just on one. These are important clues.

▶ Usually, if the source is within the set, you will notice that the modulation hum is heard on all reasonably strong local and distant stations. The most common sources of such hum are cathode-to-heater leakage in a tube or a defective filter system in the plate supply for the oscillator of a superheterodyne. (Very frequently a separate condenser-resistor filter combination is used in the oscillator plate supply, because any hum in this supply will modulate the oscillator voltage and so be mixed with the incoming signal in the first detector.)

If these points appear normal, then check operating voltages carefully, noticing in particular the grid bias voltages developed for the r.f. amplifiers. In addition, a lower than normal screen grid voltage will cause operation on a curved characteristic just as excess bias will—so changes in the values of bleeder resistors, or leakage in a screen-grid bypass condenser, can cause modulation hum by producing a curved characteristic in an amplifier.

▶ If modulation hum appears to be stronger at one end of the station dial (usually the high frequency end), often some stage is in a regenerative state which allows it to be easily affected by stray hum fields or hum voltages. Eliminating the excessive feedback in such a case will frequently remove the modulation hum. This condition sometimes means that realignment or a check of the bypass condensers is needed.

▶ If the modulation hum appears only on the stronger local stations, it may be originating outside of the receiver. The power line picks up a considerable amount of r.f. energy; if the antenna or ground installation is in poor condition, this power line r.f. may feed through the chassis to the input of the set. As the power line may have non-linear characteristics, it is quite possible for these r.f. signals to arrive with a hum modulation. Also, if the antenna is near power lines, a poor joint may cause rectification and mixing right in the antenna system. The cure is to restore the antenna and ground to full effectiveness, and, if necessary, to bypass the power line connections at the set with a small condenser. One condenser from each side of the power line to chassis, which in turn is grounded, is effective. (A separate ground cannot be used on an a.c.-d.c. universal set unless a ground terminal is provided on the set by the manufacturer. Don't connect a ground to the chassis of such receivers.)

Sometimes you can make the modulation hum disappear just by reversing the power line plug in the wall socket. If this reversal also changes the apparent strength of the signals, then you have a definite indication of a poor antenna or ground installation.

▶ If modulation hum is heard on only one station, the signals from that station are strong enough to drive one of the tubes into the curved region of its characteristic, external hum modulation occurs, or else the hum is originating in the station itself. Station hum

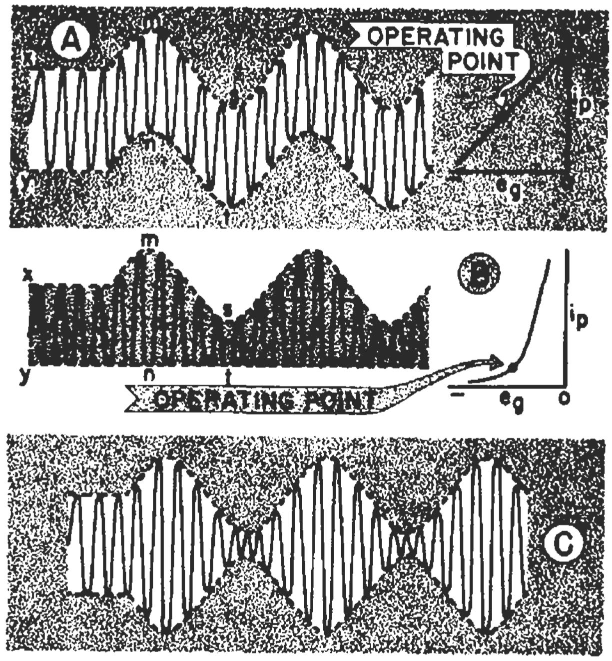

FIG. 13. How modulation hum occurs.

is much more noticeable on high-fidelity receivers where there is a greater response to low frequencies. To determine which of these possibilities exists, try another receiver at the location or move the defective receiver to your shop. If hum is heard regardless of location or changes in antenna, then the station is to be suspected. If the test receiver hums at the location of the defect, overloading or external hum modulation is occurring.

If some nearby station or some very powerful station actually drives a tube into detection, usually a wave trap tuned to that particular frequency will reduce the incoming signal level enough to prevent hum modulation.

Defective Stage Isolation. When you are tracing a steady hum, all interfering signals must be tuned out. However, when you hunt for the source of modulation hum, you need an r.f. voltage source. To isolate a defective stage, you can use a broadcast signal and a signal tracer with an au-

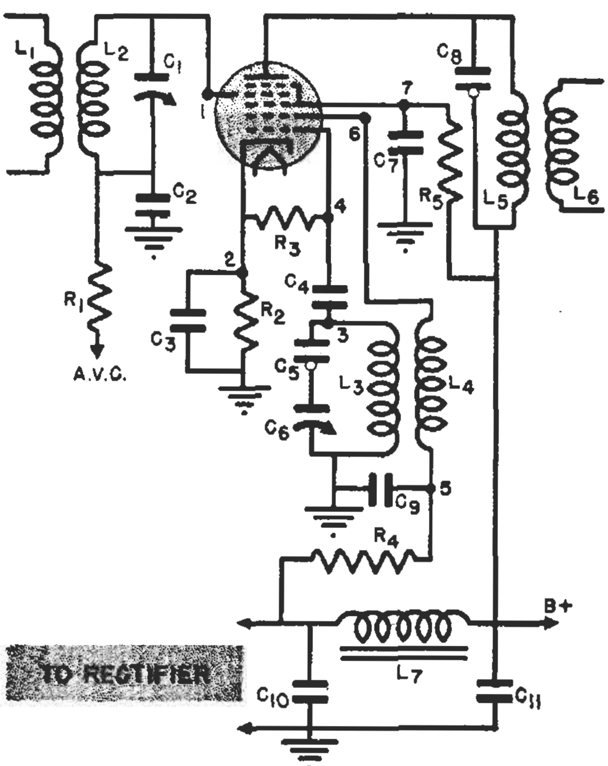

FIG. 14. There are several possible causes of modulation hum in the frequency converter stage.

dible output indicator, or you can make use of a signal generator.

▶ If you use a signal tracer, first tune in some signal which has the modulation hum. Then, start at the input of the receiver and move toward the output with the signal tracer, listening to each stage. As you move toward the output, the signal will be hum free until you pass through the stage where the hum is introduced. The signal tracer must be tuned to the frequency of the incoming signal until you pass the first detector, at which point you should change to the intermediate frequency of the receiver.

If you use a signal generator, start at the second detector and move back toward the input, feeding the signal into the stage being tested and listening to the output of the receiver. Use the audio modulation of the signal generator to make sure you are tuned to the proper frequency, then turn the modulation off so you can hear the hum. As you move back toward the input with the *unmodulated* signal generator, you will not hear hum until you have passed through the defective stage—provided no stage is overloaded. Of course, the signal generator will be set at the i.f. value until you pass the first detector, moving back toward the input.

As you move toward the input, the signal strength increases; this may overload some stage previously passed through, causing another modulation hum to be set up. To prevent such overloading, reduce the output of the signal generator enough as you move back so that the output of the set, shown on the tuning indicator, will be approximately constant. Use a d.c. type v.t.v.m. across the a.v.c. leads if no indicator is on the set. An audio indicating device would not show up the overloading.

When you reach the input of the first detector, be sure to change the signal generator to the frequency for which the receiver dial is set.

Defective Part Isolation. Suppose your stage isolation tests show that the modulation hum arises in a frequency converter stage like the one shown in Fig. *14*. Let's see how the defective part may be found.

The most logical causes of hum in this circuit are cathode-to-heater leakage in the tube or hum voltages in the oscillator circuit caused by a defective condenser C_9. (Notice that C_9 and R_4 act as a filter.) It is also possible for condenser C_7 to be open, permitting hum voltage to get into the screen grid circuit; usually, however, an open in this condenser would cause lower than normal volume. This open would cause oscillation if it occurred in an r.f. or i.f. stage, but might not do so in a converter as the output is not tuned to the same frequency as the input.

First, check the tube and try other condensers across the suspected ones. If tests show these parts are normal, next use an *audio* signal tracer to listen in the grid circuit between terminal *1* and ground, in the cathode circuit, and in the other element circuits, to determine just which one is introducing the hum. A station should not be tuned in, since you are looking for an audible hum voltage. Of course, the hum level may be too low to be heard directly; if so, the easiest procedure is to substitute good parts for logical suspects.

▶ Hum does not often enter the grid circuit of a first detector or an r.f. stage, but it may get in if the grid circuit opens up—because, say, of a defective wave band switch arrangement—or if some hum-carrying wires develop leakage to the grid circuit. Capacity coupling between hum-carrying wires and the grid leads is usually kept at a minimum by the normal arrangement of the grid circuit. Similarly, stray hum fields from the power transformer or filter choke will not usually induce hum voltages in a radio frequency coil.

COMMON CAUSES OF HUM

This table covers only the more usual causes, with the most common first. Use it as a guide or memory refresher. Make localizing tests first, unless you are led directly to one of these troubles by the symptoms.

Type	Location	Causes
Steady, 120 cycle (or 60 cycle, if set uses half-wave rectification)	**1. Power Supply**	**Open, low capacity or high power factor filter condensers; leakage causing choke saturation; gassy rectifier tube.**
	2. A. F. Stages	**Open decoupler condenser; open grid circuit; reversed hum-bucking coil; poor connection.**
Steady, 60 cycle	**1. A. F. Stages**	**Cathode-to-heater leakage in tube; open grid circuit; hum adjuster unbalanced (where used); poor connections.**
	2. Power Supply	**Defective rectifier tube; open in half the high voltage secondary or in connection to tube. (Full-wave rectification only.)**
Modulation Hum	**1. R. F. Stages**	**Cathode-to-heater leakage in tube; open decoupler condenser; reduced screen grid or plate voltage; excess bias; poor connections.**
	2. Outside Set	**Poor Antenna or ground; power line modulation; defect at station.**

Residual Hum Problems

Residual hum problems may arise if the original receiver design was poor or overall aging of the receiver has caused an increase in the normal hum level. Assuming you have checked for all the usual causes of abnormal hum, your next step will be to see what changes may be made in the design of the set to decrease the hum level, provided the receiver owner is willing to foot the bill for the time required.

Before beginning such a procedure, be sure to find out if the receiver was repaired just before the hum was first noticed. If so, the hum level may have been raised by the repairs—or you may have run into an owner who has become critical of the normal hum level of the receiver, which was called to his attention by the previous trouble.

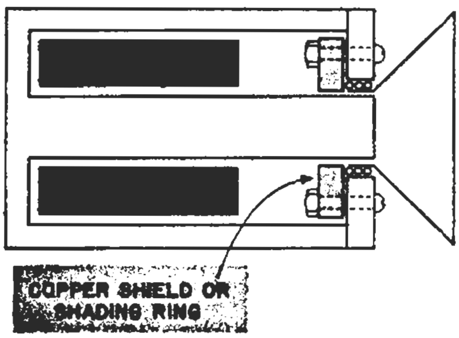

FIG. 15. Eddy currents induced in a heavy copper ring cut down the hum induction from the field into the voice coil.

Remember that the design of the receiver was carried only to the point where the hum level was considered acceptable. This usually means that not everything possible was done to reduce the hum, so going over the circuit carefully will probably prove helpful.

HUM-BUCKING

The simplest initial step is to try hum-bucking in the circuit if the normal hum-eliminating procedures are not helpful.

First, find out if the loudspeaker is adding to the residual hum level. Short the primary winding of the output transformer with a test lead; if you hear hum, it comes from the speaker. Next, see if the loudspeaker uses a hum-bucking coil (Fig. *8*). If not, see if a shading ring is used, like the one in Fig. *15*. (This ring is between the front pole plate and the field coil, so it can be seen only in speakers having an open "pot" field enclosure unless you take the speaker apart.) This copper ring uses eddy currents to reduce the hum induced in the voice coil.

If the speaker has neither a shading ring nor a hum-bucking coil, replacing it with one having a hum-bucking coil will usually reduce the hum level considerably. Some reduction may be obtained by such a replacement even if the old speaker has a shading ring. Be sure the replacement speaker matches the voice-coil impedance and the field resistance of the original speaker.

▶Fig. *16* shows two ways to buck or cancel out hum by deliberately introducing an out-of-phase hum into the hum-producing circuit.

The method shown in Fig. *16A* involves feeding a hum voltage from some source (such as the input of the filter in the power supply) into the cathode bias resistor of the hum-producing stage. If the cathode bias resistor is normally bypassed, the bypass should be removed. Then, the resistor R_2 is added and varied until hum is minimized. The .5-mfd. condenser C_3 is used in series with resistor R_2 so there will be no d.c. current flow to upset the bias.

A somewhat similar scheme is shown in Fig. *16B,* which can be used in any screen-grid or pentode tube stage producing hum. Condenser C_3 is connected across the screen-grid voltage-dropping resistor R_2, forming a hum voltage divider with condenser C_2. Any hum which is in the plate supply will then be fed to the screen grid, where it will be out of phase with that in the normal plate circuit or grid circuit of the tube. By choosing the size of C_3 properly, the circuit can be balanced and hum minimized.

▶ Of course, these methods of hum-bucking should never be used if there is any actual defect in the radio. Such methods should be employed only when you are attempting to reduce a normal residual hum level. If the

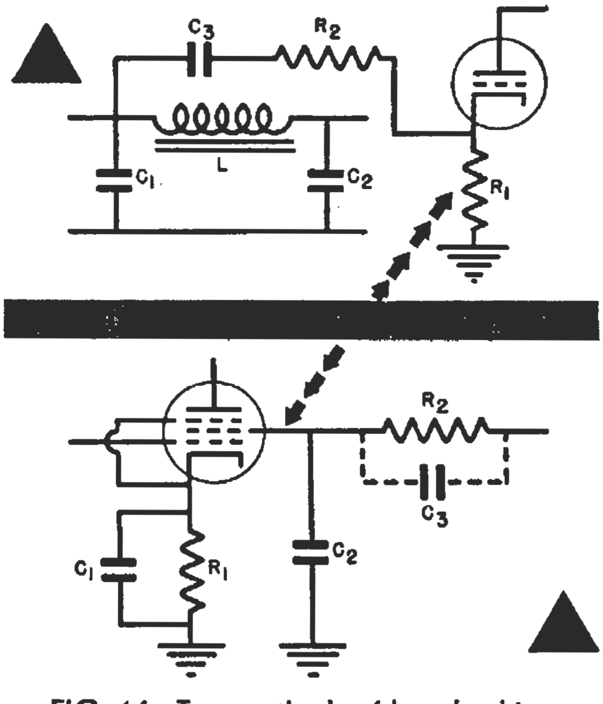

FIG. 16. Two methods of hum bucking.

residual hum level appears abnormally high, almost always some defect exists which you can—and should—find and correct by the basic methods given in the earlier part of this lesson.

REDUCING RESIDUAL HUM

As you carry out the following hum-reducing steps, you may find each one individually results in very slight reduction in the hum level. In fact, you may have to use a sensitive output indicator to determine whether you are getting any drop at all. Make measurements with care, because it will take a number of small reductions to decrease the hum level appreciably.

▶ Increasing the filter condenser capacities will frequently work wonders,

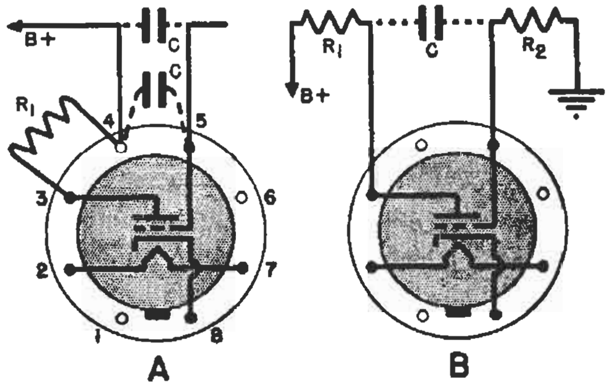

FIG. 17. Parts and lead placement contribute to the residual hum problem by providing capacity coupling.

particularly on some of the older receivers. Values as high as 16 to 30 mfd. can be used satisfactorily.

▶ As you learned earlier in this lesson, inductive and capacitive coupling between wires often causes hum, especially if the wiring has been changed about. It is important that plate and grid wires, particularly in the first audio stage, be kept well away from supply leads.

Fig. *17* shows two examples of how the mounting of parts may cause stray hum pick-up. It is common practice for manufacturers to wire up circuits in the easiest possible manner, using blank socket lugs for mounting. The plate resistor R_1 in Fig. *17A* may be mounted as shown, between socket terminals *3* and *4*. Using terminal *4* brings one end of this resistor and its supply lead close to grid terminal *5*, so that capacity coupling can exist between the grid lead and both this supply lead and the end of the resistor. Moving the resistor so it is between terminals *3* and *1* brings the *B+* lead to terminal *1,* which separates the resistor and supply lead from the grid and reduces the coupling.

In Fig. *17B,* the resistors R_1 and R_2 may be lined up on a terminal strip. Here, moving either of the resistors or reversing the connections to resistor R_2 so as to move the grid lead away from the plate resistor may prove helpful.

▶ Stray hum currents in the chassis add to the residual hum level, par-

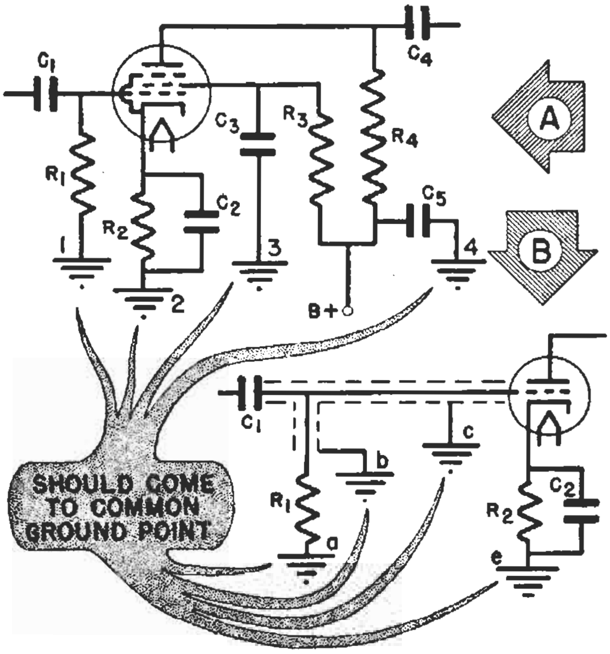

FIG. 18. Using a common ground point in a stage prevents hum currents in the chassis from producing hum voltages in the stage.

ticularly if the manufacturer has again followed the easiest procedure and grounded parts to different points on the chassis. For example, in Fig. *18A,* terminal *1* and terminal *2* may not be grounded to the same point on the chassis. If so, any stray hum currents between these points will produce a voltage drop in the chassis, which is effectively in series with the grid circuit and can cause hum.

There are four ground symbols shown in Fig. *18A;* it is desirable to have all of these grounded parts in a single stage come to a single ground terminal. This sort of connection will remove the effects of stray chassis currents. Of course, these four terminals must each make good contact to the ground point, without any common lead, so as to avoid the situation pictured in Fig. *9.* (In Fig. *9,* the resistor *R* should be brought to the ground lug *G* directly instead of to terminal *7.*)

Three separate grounds may be used in a circuit like that shown in Fig. *18B.* If hum is traced to such a circuit, grounding terminals *a* and *b* to the same point will prove helpful. If the hum comes from stray chassis current, removing ground *c* altogether may help.

▼ You might try shielding wires subject to hum pick-up to reduce the amount picked up. Shielding must be used judiciously, however, as there

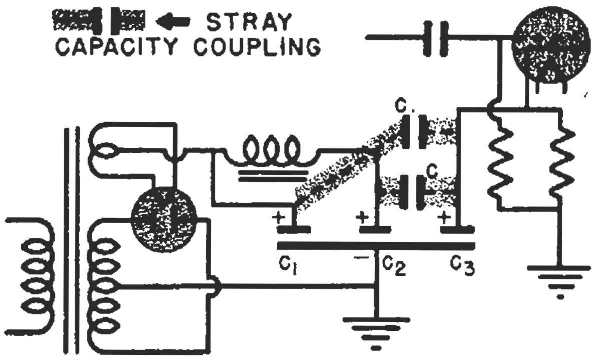

FIG. 19. Condensers in a common block or case will have capacity coupling between leads and sections which can contribute to the hum level.

is a considerable capacity between a wire and its shield. This capacity shunts the circuit and will lower the high frequency response of an audio amplifier considerably. Therefore, use no more shielding than absolutely necessary and use low-capacity cable if space permits. (This type of cable has a large amount of insulating material between the inner wire and the shield, thus reducing the wire-to-shield capacity by increasing the spacing between them.) Sometimes shielding can be avoided altogether by re-routing wires.

Stray capacity coupling may also prove annoying if you have filter condensers and a cathode bypass condenser in the same electrolytic condenser block, as in Fig. *19*. The cathode bypass condenser normally will be about 10 mfd., and so will have an impedance of about 130 ohms to 120-cycle ripple. However, if there is sufficient capacity coupling between the filter condenser leads and this condenser, an appreciable hum level may appear. This will certainly be true if the condenser loses capacity or develops a high power factor. In such cases, using separate condensers will help considerably in lowering the hum level.

Oscillations, Squeals and Motorboating

A certain amount of feedback takes place in practically all radio tube stages. This feedback may be in phase with the input signal, causing regeneration, or out of phase, causing degeneration. The amount of feedback is one of the limiting factors in radio design. A certain amount helps to obtain desired characteristics. Regeneration increases the sensitivity, while degeneration in an audio amplifier increases the fidelity by flattening the response characteristics. However, if either kind of feedback gets out of hand, undesirable effects result. Excessive degeneration lowers gain, while excessive regeneration makes the receiver unstable.

As regeneration increases, the set becomes much more critical in its operation. Sensitivity and selectivity increase abnormally and the receiver response becomes very erratic. Small changes in humidity (affecting circuit Q slightly) will have such great effects on the response that the receiver will seldom act the same from day to day. When regeneration is carried too far, oscillation occurs. (There is so much feedback that the stage sustains oscillation by itself). Then radio reception is blocked entirely, or is accompanied by squeals, whistles, rushing noises, or motorboating sounds.

Before we learn how to localize oscillation, let us see just how feedback can occur.

FEEDBACK PATHS

Fig. *20* shows a typical i.f. amplifier stage. As in all radio stages, there is a certain amount of grid-plate capacity. This can act as a feedback path—even in modern pentode tubes, in which the screen grid and the suppressor grid both tend to reduce this grid-plate capacity to a very small value. In addition, there is capacity coupling between grid and plate leads, as well as possible inductive coupling between the input and output tank circuits.

Since it has a path for feedback, and resonant grid and plate circuits, you can see that this circuit contains all the elements of a tuned grid-tuned plate oscillator. If the plate tank circuit is tuned so that the plate load is inductive (the tank circuit is tuned above resonance), then the feedback will be in phase with the input signal, will aid it, and may cause oscillation.

Of course, oscillation will develop only if there is enough feedback. This will depend on both the amount of voltage in the plate circuit available for feedback, and upon the effect the feedback has in the grid circuit. If the stage has high gain, and if the plate tank circuit has a high Q factor (thus acting as a high impedance load), there will of course be more voltage in the plate circuit available for feedback than if the stage had low gain or the tank circuit a low Q factor.

The Q factor is also important in the grid circuit; for the same amount of feedback, a grid circuit with a high Q factor will have more voltage across it than one with a low Q factor. (The reason is that the feedback capacity or inductance is in series with the grid impedance, forming our old friend, the voltage divider. The feedback voltage must divide between them; naturally, the higher the impedance of the grid circuit, the greater the percentage of the feedback voltage that will appear across it.)

Thus, problems caused by feedback will always be most frequent in high gain stages where tuning circuits of high Q are used. The more sensitive the receiver, the more you can expect oscillation troubles.

▶ Incidentally, proper alignment may clear up oscillation in a circuit like that in Fig. *20*. If the tank circuit C_1-L_1 is far off resonance, the reflected effects on C_2-L_2 are reduced, so the Q factor of the latter circuit will rise. Similarly, if tank circuit L_4-C_4 is far off resonance, the impedance of tank circuit C_3-L_3 will rise. Either condition may produce instability and oscillation. When the circuits are all correctly aligned, the reflected effects will load the tuned circuits in the offending stage and reduce their Q. Further, if the plate tank circuits are carefully tuned slightly below resonance (using an increased trimmer condenser capacity setting), then there is little chance for feedback to produce oscillation.

▶ To sum up, oscillation can occur only if there is: 1, a feedback path; 2, feedback of the proper phase to *aid* oscillation (regeneration); and 3, the strength of the feedback is sufficient. Usually you will try to cure oscillation by blocking or removing the feedback path or by reducing the amount of feedback; changing the phase of feedback is not usually possible unless the feedback is caused by circuits whose alignment may be corrected.

Feedback Examples. Fig. *21* shows several more examples of circuits in which feedback can occur. In *21A* the plate load is inductive (unless the reflected effects from the tuned circuit L_4-C_2 cancel all inductance in the plate circuit), so feedback from it will be in phase with the input signal and so may cause oscillation. In addition to the usual feedback paths, coupling may also exist between the tuned circuit L_4-C_2 and the antenna lead—especially if an excess length of antenna wire has been tucked into the radio. Feedback along this path may cause oscillation if it has the proper phase and is sufficiently large.

In an audio stage like that shown in Fig. *21B,* oscillation might occur but usually does not. The effectiveness of the capacity coupling is relatively small, as the capacitive reactance of such small capacities is very high at audio frequencies, so most of the feedback energy is dropped in the coupling. In addition, the audio transformers usually have appreciable d.c. resistance. Thus, although they resonate with their distributed capacities, the Q is very low, so rather large feedback voltages are necessary to cause oscillation.

Of course, if another stage is added, the increased amplification makes it possible for the feedback voltage to be considerably higher; if sufficient coupling exists between the input and output of the two stages, there may be enough feedback to cause oscillation.

Also, inductive coupling between transformers may cause trouble unless they are placed so minimum feedback can occur.

▶ Since each of the resistance-coupled stages of Fig. *21C* inverts the signal 180°, two of them cause a 360°

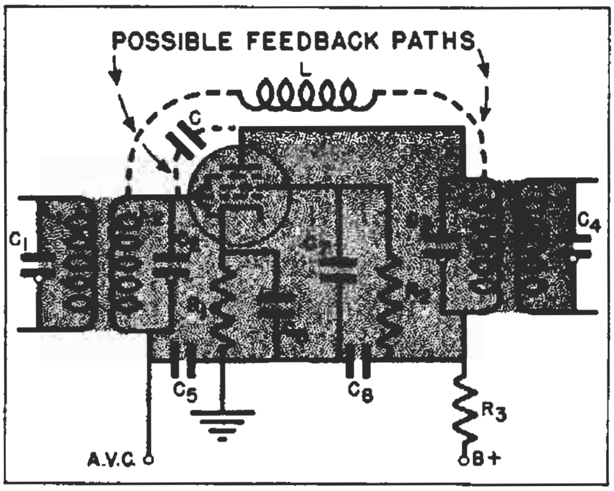

FIG. 20. This i. f. stage can have either inductive or capacitive feedback paths between grid and plate circuits.

change. Therefore, if there is any stray coupling between the grid circuit of VT_1 and the plate circuit of VT_2, the feedback voltage will have the proper phase to cause oscillation. Whether or not oscillation will occur then depends on the amount of coupling, on the amplification (which determines the amount of feedback voltage) and on the size of the grid resistance (which determines the proportion of feedback dropped across the grid circuit). The larger the grid resistance R_1, the greater the drop across it and the greater the likelihood of oscillation.

Low-Impedance Paths. In each of the foregoing examples, the feedback voltage is part of the rather high voltage developed across a high-impedance circuit or part. It is also possible for a voltage developed across a low impedance to cause feedback. For example, the a.c. plate circuit of the output tube in Fig. *22* traces from the plate, through the primary of transformer *T*, through condenser C_5, and then through C_3 back to the cathode. Therefore, audio variations in this plate circuit will create a voltage drop across C_5, the amount depending on the strength of the variations and on the reactance of C_5. Since C_5 is the output filter condenser of the power supply, this audio variation is impressed on other tube plate circuits.

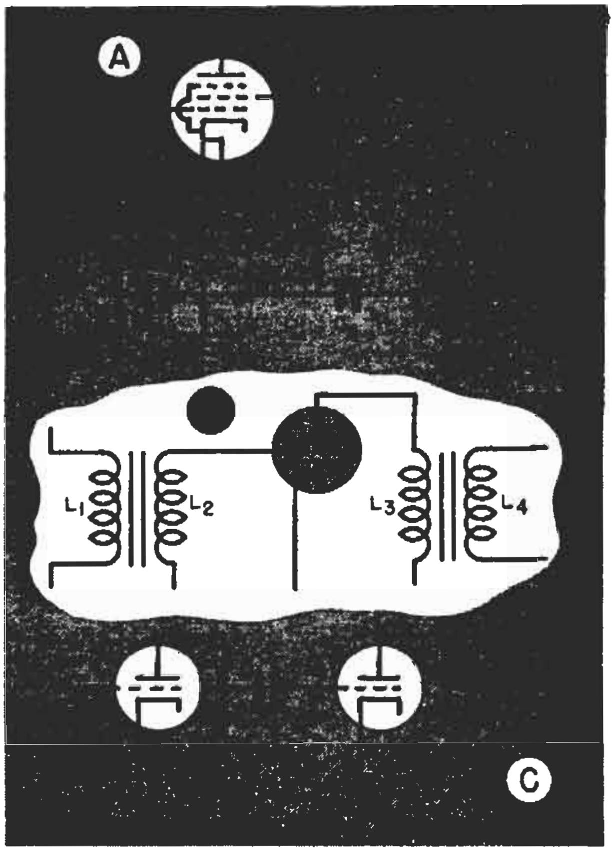

FIG. 21. Examples of stages where feedback can cause oscillation.

The plate supply of tube VT_1, for example, may thus be varied at an audio rate.

Such variations introduced in the plate supply of tube VT_1 are passed through the intervening stages and applied to the grid of tube VT_2. If there are enough stages, these variations may arrive back at the grid circuit of VT_2 in phase with the plate variation and thus provide regenerative feedback and oscillation. On the other hand, if VT_1 is coupled directly to VT_2, the feedback will be degenerative. Therefore, such oscillation will usually occur *only if* there are three stages in the audio amplifier. This kind of low-frequency oscillation is usually called "motorboating", because it has a "put-put-put" sound.

If condenser C_5 loses capacity, its reactance will increase, and the amount of feedback will be greater. Motorboating can therefore be minimized by replacing C_5 with a higher-capacity condenser. Incidentally, most receivers have additional filtering (represented by R_6-C_6) in the plate circuit of the first tube, which tends to remove such audio feedback and thus prevent motorboating.

▶ If either condenser C_2 or C_3 in **Fig.** *22* opens, the variations in the plate current in that stage will develop an a.c. voltage drop across the cathode resistor. This drop will be introduced in the grid circuit; it will be out of phase with the grid voltage, and so will be a degenerative feedback. Such degeneration does not cause oscillation—in fact, it suppresses it. Manufacturers sometimes deliberately introduce this degeneration both to control oscillations and to flatten out the response characteristics of the amplifier. This must be done carefully, because too much will cause an excessive reduction in gain.

Parasitic Oscillation. Any unwanted (or unintended) self-sustained oscillation is a parasitic oscillation, because it "lives off" the stage. However, servicemen and technicians usually use this term only to describe oscillations which occur at some frequency to which the circuit is not tuned or which is outside the normal frequency band of the offending stage.

In radio receivers, this trouble is usually limited to the output audio stage, because this is usually the only stage where enough power is available to sustain the oscillations. A pentode output stage is particularly subject to these oscillations, because such a stage has high gain, has a tube with a relatively coarse screen grid structure (so that the inter-electrode capacity is high), and uses circuit elements which readily permit parasitic oscillations. This trouble is most common when the output stage is run as a class AB or class B push-pull amplifier, where a low-resistance input transformer must be used. A typical circuit is shown in Fig. *23*.

The oscillation occurs at frequencies where the leakage inductance and distributed capacity of the transformers form resonant circuits, or where the transformer capacities remove the inductance effects, leaving the grid and plate leads to act as transmission lines due to their distributed inductance and capacity. The circuits act as tuned-grid tuned-plate oscillators which may produce oscillations well up in the short waves.

This parasitic oscillation does not occur in every circuit, of course. It may occur, however, in any circuit in which enough power is available, in which enough feedback exists, and in which the grid inductance and capacity can form a resonant circuit.

Parasitic oscillation causes severe distortion, weak reception, and perhaps a rushing noise or exceedingly high frequency whistle. The large amount of power consumed lowers all operating voltages. The output tubes may glow blue or even get so hot their elements melt. The rectifier tube, filter choke, power transformer and output transformer will be passing excessive current, so will overheat.

The condition may be cured either by introducing suppression, making the plate circuit bypass condenser more effective, or else by shortening the effective length of the grid leads so much that the tube will not be able to oscillate.

▶ As you have learned, a low Q factor tends to suppress oscillation. Therefore, one of the most effective cures

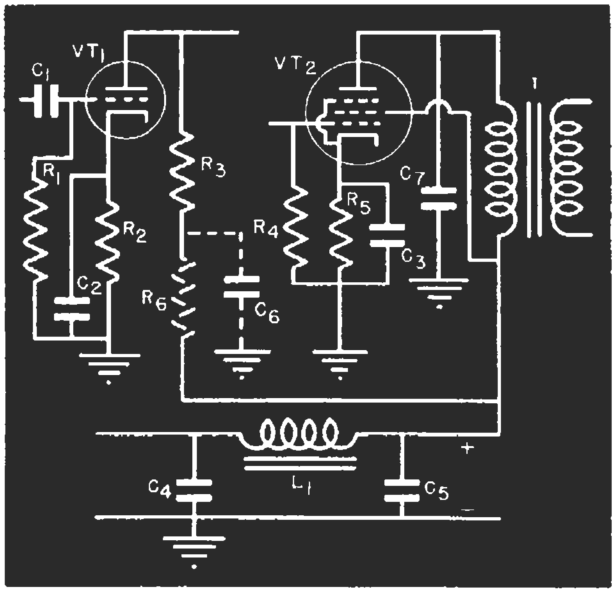

FIG. 22. Motorboating usually occurs in an audio amplifier which does not have decouplers R_6-C_6, or where this filter is ineffective.

for parasitics is to insert suppressor resistors right at the grid terminals of each tube, as shown in Fig. *24*. Resistors R_2 and R_3 should be between 100 and 1000 ohms. Use the smallest size which will eliminate oscillation.

In a Class *B* output stage, grid current will cause distortion if values above 500 ohms are used. Hence, if larger suppressors are needed to stop oscillations, use about 200 ohms and consider the following procedures.

▶ Manufacturers generally use condensers such as C_2 and C_3 of Fig. *23* in circuits where parasitics may develop, to make the plate load more capacitive. Such condensers should be right at the tube socket, a position which makes the effective length of the plate leads shorter, reducing further the inductance effects as well as the ability to feed back.

In the circuit shown in Fig. *23*, the bypass paths from the plates run through condensers C_2 and C_3 to $B+$, from $B+$ to $B-$ by way of the output filter condenser, and then to the cathode through condenser C_1. Bringing C_2 and C_3 directly to the cathode, as shown in Fig. *24*, eliminates a great deal of this path, and so makes parasitic oscillations less likely. If C_2 and C_3 are used in this manner, they must have voltage ratings of 600 volts or higher.

▶ As an additional measure, grid condensers of about .0005 mfd. each can be installed to change the grid resonant frequency, as shown by C_4 and C_5 in Fig. *24*. (Sometimes they are installed by the manufacturer.) If used, C_4 and C_5 should return to the same cathode point as C_2 and C_3.

▶ Remember that an electrolytic condenser makes a very poor r.f. bypass condenser because its induc-

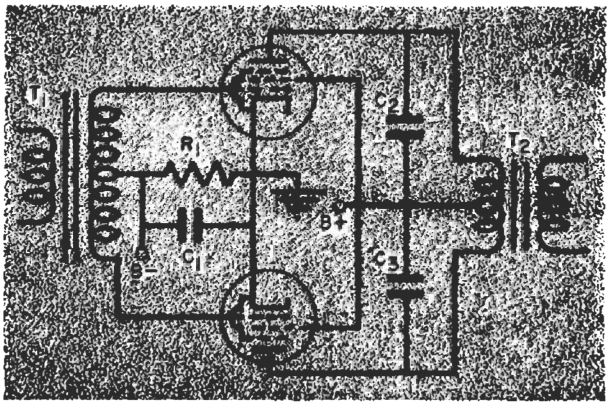

FIG. 23. A typical push-pull output stage.

tive winding limits its effectiveness at high frequencies. For this reason, a paper bypass condenser is connected across the output filter condenser in many receivers; sets without this feature frequently prove unstable. Never assume that an electrolytic condenser is an adequate bypass for all frequencies which may be present.

EFFECT-TO-CAUSE REASONING

As you have learned, oscillation may occur in a single stage of a radio receiver or may be the result of feedback across several stages. Your first problem is to localize the trouble, then you must cure it, generally by reducing the gain of the stage, by restoring bypass facilities to normal, or by blocking feedback paths.

▶ Oscillations may be audible or inaudible, and may occur anywhere in the radio. *If the oscillations are audible, whether or not signals are tuned in,* they are audio signals and in all probability originate in the audio amplifier. The only usual exception occurs when an a.v.c. controlled stage is oscillating and blocking simultaneously—that is, the circuit starts to oscillate, but sufficient grid bias is developed (particularly across a.v.c. resistors) to block oscillation at an audio rate. Motorboating can be caused once in a while by this particular combination of conditions.

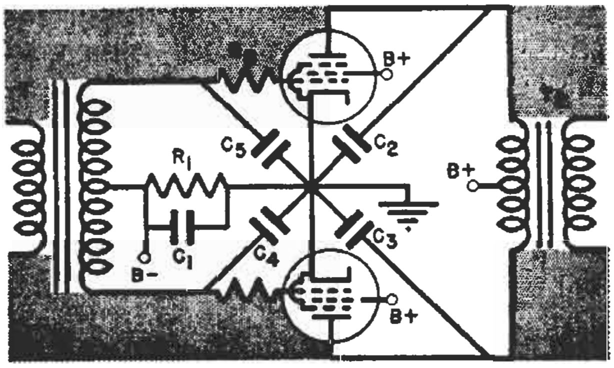

FIG. 24. Here are pictured the cures for parasitic oscillation in an output stage.

To tell whether a steadily produced whistle or "put-put" is in the audio system or in the last i.f. stage, turn the volume control to zero output. In most modern receivers the volume control is at the input of the audio amplifier. If a volume control adjustment will stop the sound coming from the speaker, then it is originating ahead of the control and is probably in the i.f. amplifier. On the other hand, the oscillation is probably originating in the audio amplifier if moving the control does not affect the oscillation.

If the feedback occurs *in or through* the circuit containing the volume control, varying the volume control will vary the amount of feedback and throw this particular circuit in and out of oscillation. If the set has a tuning indicator, notice whether the volume control adjustment stops the tuning indicator deflections as well as the sound output. If the tuning indicator continues to deflect in step with the oscillations, even when the volume control is at zero, then one of the r.f.-i.f. stages is oscillating.

If no indicator is used, pull out the last i.f. tube. If this stops the sounds, the trouble is in the r.f. section; otherwise, an audio trouble is present.

▶ If oscillations occur only when a station is tuned in, then they are undoubtedly starting in the r.f. or i.f. stages. In a set with this trouble, you will notice a loud whistle or squeal as you tune in a station; then as you tune slowly through the proper dial setting, the squeal will first drop to zero frequency and then increase in pitch again on the other side of the correct dial point.

If the ability to oscillate appears greater at one end of the dial than the other, an r.f. stage is probably to blame. In this case, the variation is caused by the fact that different frequencies will vary the amount of feedback and may, because of differences in alignment, vary the input and output impedances of the offending stage.

Be careful in making this check for suspected oscillation not to confuse these noises with whistles due to oscillator harmonic interferences, second harmonics of the i.f. amplifier, and similar causes, which have been discussed elsewhere. These last interferences will show up only at certain particular spots on the dial or only on certain stations, rather than over the entire dial or a large portion of it.

▶ Parasitic oscillations are not usually audible except as a sort of rushing noise. To help yourself diagnose them, remember that the great amount of power taken when these oscillations occur lowers the voltages throughout the receiver, so that weak or badly distorted reception, or possibly a dead receiver, may result.

LOCATING THE DEFECTIVE STAGE

The most common sources of trouble are missing or poorly connected shielding, and defective condensers in supply circuits common to more than one stage. The condensers most likely to cause oscillation, arranged in order with the most common troubles first, are:

1. Open screen grid bypass.
2. Open or low-capacity output filter.
3. Open or low-capacity plate decoupler.
4. Open cathode bypass.
5. Open or shorted grid decoupler (a shorted one removes bias).
6. Open bias supply bypass.

To make a quick check, first inspect the shielding visually, then tune in a signal and try a good bypass condenser across those listed in *1* and *2* above. If the oscillations continue, it is best to localize the defective stage.

A simple way to localize the trouble is to tune in a signal, and bring your hand near one tube at a time. As you approach the offending stage, you will change the pitch of the whistle or squeal.

▶ If you have a signal tracer, use it on each stage in turn (starting at the input and moving toward the output) with no signal tuned in. Since oscillations produce r.f. voltages, you will find an r.f. voltage present when you enter the defective stage. Sometimes this procedure will not work satisfactorily, because connecting the signal tracer or bringing your hand near the offending stage may stop it from oscillating. You will then probably pass over the offender, find the signal in the next stage, and believe that it is the defective one.

▶ In the audio stages, you can test each stage with an audio signal tracer, starting at the input and moving toward the output. Here again, you may stop the oscillation when you connect the tracer.

▶ The fact that your tests may stop the oscillation temporarily makes it rather difficult to do more than locate the defective stage with test equipment. If an open bypass condenser is suspected, you will have to hold a good condenser across each section you want to test. Remember, particularly when working with r.f. stages, that long leads cannot be used—you must hold the replacement condenser directly across the suspected one. Bend the test condenser leads so you can touch the proper points.

If the oscillation stops when you make such a condenser test, remember that it may do so because of the presence of your hand, not because of the condenser. If this happens, you will find it out quickly, because oscillation will usually start again as soon as you finish putting in the new condenser and remove your hand. It is usually a good idea to temporarily solder the trial condenser across the suspected one, then take your hands away to see if oscillation has stopped, before making a permanent replacement.

You should, of course, check an oscillating set to make sure that all tube shields for which provisions are made are actually used. But don't assume that the shielding is satisfactory just because they are all present

—remember, a poor contact between a shield and the chassis may make the shield ineffective. Try grounding such shields to the chassis with a short test lead or screwdriver blade. If this helps, sandpaper the edges of the shield and tighten the screws or rivets used to ground it. Since rivets sometimes corrode, replacing them with screws may prove helpful.

▶ Oscillation in an r.f. stage may be caused by a poor contact to the tuning condenser rotor shaft if the resistance of the contact provides a common coupling between condenser sections. Be sure to clean and tighten wiping contacts if trouble is localized in this section of the set.

▶ Remember that abnormal feedback must occur in the set to cause oscillation. To cure the condition, you must either block the feedback path or make circuit adjustments to cut down the amount of feedback. If you can find nothing out of the ordinary which could provide a feedback path, see if the stage has exceptional gain. Since this can easily be caused by higher-than-normal screen grid voltage or by lack of proper bias voltage, a short-circuited bias supply or an open screen bleeder may be the cause of the oscillation.

▶ Misplaced wires are a frequent cause of oscillation. Always look for them if an oscillating set shows evidence of a previous repair. If you find that moving a wire causes a change in the pitch of the oscillation, move both this wire and its neighbors carefully until you find a position which will give minimum feedback.

The manufacturer's service information is frequently helpful in finding this position. In all sets in which regeneration is allowed to exist to a considerable degree—small a.c.-d.c. receivers. for example—misplaced leads can easily cause oscillation. The manufacturer of such sets will frequently give information on "lead dressing," that is, how to position leads with respect to each other and to the chassis to prevent oscillation.

COMMON CAUSES OF OSCILLATION

This table covers only the more usual causes, with the most common first. Use it as a guide and memory refresher. Localize the trouble first, then check for these probable causes.

Condition	Location	Causes
Audible at all times.	Audio Stages	Defective filter or bypass condensers.
Squeals only when station is tuned in. Occurs on all stations.	I. F. Stages	Open bypass condensers; shielding missing or making poor contact; alignment off; excess screen grid voltage; low bias; leads improperly placed.
Squeals only when station is tuned in. Occurs mostly at one end of tuning band.	R. F. Stages	Open bypass condensers; shielding missing or making poor contact; poor contact at tuning condenser rotor shaft; excessive screen grid voltage; low bias; alignment off; leads improperly placed.

Lesson Questions

Be sure to number your Answer Sheet 41RH-2.

Place your Student Number on *every* Answer Sheet.

***Send in your set of answers for this lesson immediately after you finish them,* as instructed in the Study Schedule. This will give you the greatest possible benefit from our speedy personal grading service.**

1. Will a shorted filter condenser cause hum?
   Yes
2. What quick check can be used to determine if a suspected condenser is open or has high power factor? Shunt the suspected condenser with a good one
3. Excluding the power supply, what stage in a radio is the one most likely to be the source of hum?
4. Is the temperature of a speaker field, used as a choke, a reliable indication of excess current flow?
5. If the complaint is a loud 120-cycle hum, with a loss of low-frequency response and oscillation, what filter part would you suspect?
   The output filter condenser.
6. A 60-cycle hum is heard from a receiver using full-wave rectification. Which *two* of the following can cause this hum: 1, shorted filter choke; 2, cathode-to-heater leakage in a tube; 3, open output filter condenser; 4, open in one of the rectifier tube plate circuits; 5, reversed hum-bucking coil.
7. Does capacity coupling to a grid circuit cause more hum in: 1, a high-impedance grid circuit; or 2, a low-impedance grid circuit?
8. What three conditions are necessary for oscillation to occur?
   P22
9. Suppose motorboating is heard and the tuning eye deflects in step with the oscillations. Turning the volume control to zero output stops the sound from the speaker but the tuning eye continues to deflect. What section would you suspect is the source of the motorboating? One of the r.f. or i.f. sections
10. Name three procedures used to stop parasitic oscillations in an audio output stage.

P24