HUM ELIMINATION

Some New Ideas on an Old and Important Subject

By J. C. HOADLEY

HUM, that bane of every engineer's existence, the spoiler of recorded and transcribed music, can be eliminated. It merely requires careful analysis and a large dose of common sense. There is a myriad of ways that this insidious nuisance can creep into an otherwise well-designed piece of equipment, either through faulty design or from aging or faulty components.

First, hum may be eliminated through proper design. One of the most violent sources of hum is lack of filtering. Proper filter components are arrived at by designing the power supply—for the unit under consideration—to have a certain percentage ripple when loaded with the load the unit will draw. This is not always enough. It is sometimes necessary to utilize a voltage-regulated power supply to reduce the ripple to the desired amount. This may take the form of the well-known RCA circuit which uses a sharp cut-off pentode to receive the variations in the D.C. output voltage and with a resistor in its plate circuit to influence the grids of several power tubes such as 6B4G or 2A3's, connected in series with the power supply. Their resistance is increased or decreased, and, thereby, the voltage held constant and the ripple wiped out. For smaller loads, a gaseous regulator of the VR-150 type may be employed.

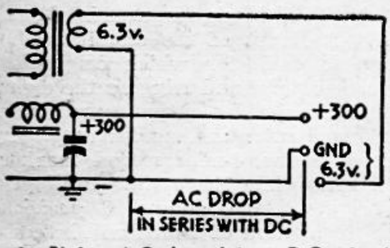

Fig. 1—Piping A.C. hum into a D.C. circuit.

In the former case, the regulator may function well with a resistive load, but when coupled to the circuit it is intended to power, ripple develops. This may be caused by several things. First and foremost is the shielding of the grid circuit of the pentode which controls the regulator tubes. If 60 cycles is introduced at this point, the tube will amplify the 60 cycles and swing the D.C. voltage at this frequency. Secondly, *this type of power supply cannot be overloaded*. It must be designed to handle the maximum current to be delivered. The regulation and ripple increase very rapidly after its maximum output has been reached.

If a VR tube is used as a regulator, its current range cannot be exceeded. This tube must be supplied with a minimum of 5 milliamperes, else it will not remain in a conducting condition. It must be remembered that the line voltage may change, so a low line voltage condition should be used to figure the minimum current value and the highest line voltage for the maximum current value. This current should not exceed the current rating for the tube.

These tubes under certain conditions will oscillate. This condition may be cured in some cases by inserting a series resistance of about twenty ohms between the VR tube and ground. It is interesting to note that VR tubes have an effective resistance in the order of 40 ohms.

MAGNETIC FIELD COUPLINGS

The power supply should be laid out with the fields generated by the power transformer and chokes properly oriented. The chokes and power transformers should be magnetically shielded and placed so their cores are at right angles to each other, as there is no point in building a good low-ripple power supply and then inducing a volt or so of 60 cycle from the power transformer into the chokes. This hum source will cause even more trouble if audio transformers are involved, as there is usually a considerable amount of amplification following these items and the induced hum is amplified accordingly.

Audio transformers should of course be kept away from power transformers and chokes and should be oriented properly as well. If these components are mounted on a common iron or steel chassis, their cores should be kept away from the chassis by mounting them on aluminum or brass bushings, as the magnetic chassis becomes a common lamination in the core of each transformer and comprises a convenient path for the transference of magnetic fields.

In general, the smaller an audio transformer is, the fewer external magnetic lines will cut it and, consequently, the less it will be bothered by external fields.

Remember that the field around a conductor is proportional to the current that conductor is carrying, so be very careful with leads such as supply lines for the power and filament transformers, and filament wiring which supplies a large number of tubes. Grounding one side of the heater winding on the filament transformers *in one place* is helpful, but keep the filament wiring to itself. This, of course, applies also to high voltage wiring to the rectifier tubes. Don't forget to shield all mercury-vapor rectifiers.

"GROUND" CIRCUIT COUPLINGS

Where the power supply and the unit to be powered are separated, do NOT run the negative B voltage and the grounded side of the filament through a common wire, because (as a look at Fig. 1 will show you) you will effectively connect an A.C. voltage in series with the D.C. supply which you consider hum-free. Although this voltage is small, being due to the filament current, it may be amplified many times by several tubes and assume much greater proportions in the output of your device.

It is somewhat risky to ground the filaments of high-gain amplifiers in several places or depend on the chassis to carry one side of the filament current. This is quite all right from the current standpoint, but if a previous plate is by-passed at Point A in Fig. 2 and a subsequent grid is returned to point B, then a hum voltage may be placed in series with the grid of the second tube. Even though this voltage is in the order of .01 volts or smaller, if that tube is a pentode with an amplification of several hundred followed by several more amplifier stages, as in a microphone amplifier, then this hum voltage can be very appreciable.

In high-gain stages, incidentally, hum

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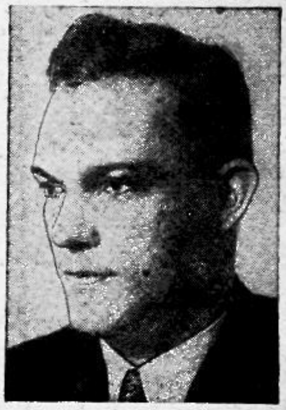
J. Carlisle Hoadley was born in Washington, D. C., November 22, 1916. Began his radio career at the age of ten, and was president of his High School radio club (McKinley Tech) a few years later.

After ten years in the servicing and sound apparatus business, sometimes with repair organizations and sometimes on his own, Mr. Hoadley went to the Naval Research Laboratories at Anacostia, D.C., as a radio engineer. Was engaged on pre-Pearl Harbor radar research, later studied captured enemy equipment and ran tests on Navy gear.



Went to the Bryant Chucking Co. of Springfield, Vermont, as Electronics Engineer, in 1943. At completion of the project on which he was engaged, he accepted a position with the Raytheon Manufacturing Co. of Waltham, Mass., as engineer on design and development of radar apparatus.

Started radio writing while at Springfield, Vt. Still spends most of his waking hours in his radio laboratory. Engaged at present in high-fidelity reproduction of music.

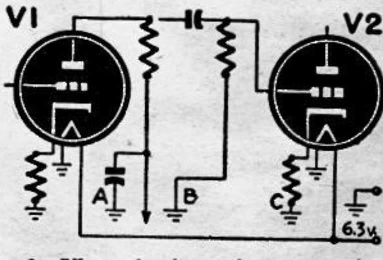


Fig. 2—Effect of voltage drops on a chassis.

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may be caused by emission from the heater to the cathode, or emission from the cathode to the heater. This condition may be reduced or eliminated, in the first instance by applying a positive voltage on the heater, sufficient to make it as positive as the cathode. In the second instance, the application of a negative voltage on the heater sufficient to make the heater-cathode voltage difference small is the remedy.

It must be remembered that although a tube is supposedly cut off by the application of bias to the cathode, the cathode does not always cover the heater completely, and that emission can occur from the heater to the plate. If this emission takes place from one exposed heater wire, said emission will not be from an equipotential surface and will vary as the heater supply frequency.

It is best, in audio amplifier design, not to rely on multiple grounds to the chassis. It is better to carry the ground circuit from point to point with a heavy copper wire, and this ground, insulated from the chassis, should be grounded in one spot only. This spot will have to be found by trial and error. This is particularly effective in high-gain amplifiers. A spot will be found at which the hum will drop appreciably and even reduce to the vanishing point.

RESISTANCE-CAPACITY FILTERS

It sometimes becomes impractical from an economic standpoint to use brute force methods, such as complicated filters and regulators, to effectively filter the entire power supply, when the addition of an RC network, in one or more circuits, will accomplish the desired result. This may be either keeping the supply ripple from this stage, or isolating the plate excursions of this stage from the power supply RC filter networks are usually figured on the basis of $T = RC$ (see Fig. 3) where T is the time in seconds, R is the resistance in ohms and C is the capacity in farads.

It might be pointed out that a lot of time can be saved and time-constant problems can be worked in the head, if you remember that microseconds equals ohms times microfarads or that microseconds equals megohms times micro-microfarads. One of these formulas puts the parameter you want in the terms that you want it and eliminates converting farads, for instance, to microfarads or micro-microfarads, or ohms to megohms. This will also eliminate the possibility of error in adding and subtracting negative and positive exponents.

This formula states the time, T, it takes the voltage across the Condenser, C, to charge to 2/3 of its full value or to discharge to 1/3 of its original value. These fractions are approximate, as the exact amount that the value C charges to is equal to $1 - \frac{1}{\varepsilon}$ and the value it discharges to is $\frac{1}{\varepsilon}$.

The condenser charges or discharges according to an exponential function so that it takes a much longer time to change even a much smaller additional amount in the direction we are considering. (See Fig. 4.) It is interesting to note that C may charge to 95% of its maximum in 3RC (seconds) or it will discharge to 5% of its total

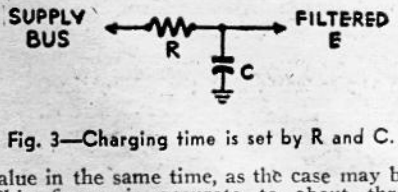

Fig. 3—Charging time is set by R and C.

value in the same time, as the case may be. This figure is accurate to about three decimal places.

If we compute our RC value on the basis of $T = RC$ in an isolation filter, we will still have 1/3 of the original amount of ripple left, which in most cases is not reducing it to a sufficiently low value. We could compute the necessary RC to reduce the ripple to any premeditated value but

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Spell radar backward and you get confusion, says Frederick C. Othman, newspaper columnist. He refers to the confusion surrounding both the early censorship of the subject and the subsequent "revelation," which was not entirely revealing.

Possibly to illustrate the confusion, the distinguished columnist goes on to declare: "My professor says that radar some day will become television, without scanning discs, synchronous motors and all the other complicated innards now in use."

The ghost of Nipkow will be pleased to hear that in this day of cathode-ray tube television, the scanning disc is still referred to, even if the reference *is* due to confusion caused by publicity on radar.

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for a reasonably close estimate we may use the formula $T = \frac{RC}{25D}$ where D is the duty cycle expressed in a fraction of one. This will yield an RC filter which will reduce the ripple to approximately 1% of its unfiltered value. The duty cycle is the ratio of time of duration of a wave form to the period of successive wave forms. In the case of a sine wave these values are equal, so D will equal .5.

Remember when using RC filters that the choice of R is limited to the largest value that will give the required filtering but which will not drop the average DC potential on the tube plate to a value lower than the value which was used in designing the components for that stage.

The importance of this factor "D" will be more evident when a non-sinusoidal circuit is to be decoupled. For instance, a multivibrator which produces a square wave ten microseconds wide and then rests for ten thousand microseconds will draw current for 10 µsec., whereas one which produces a square wave three thousand µsec. wide and rests for seven thousand µsec. will draw current for 3000 µsec. and will, therefore, discharge our C to a much lower voltage, indicating the necessity for a bigger C or a larger R.

In any event, when unequal wave forms are considered, it is more convenient to consider time constants rather than impedances and reactances.

MISCELLANEOUS METHODS

Decoupling is necessary where several stages are to be cascaded, as oscillation can result. It is conventional, therefore, to isolate several or all the stages, not only in the interest of hum reduction, but to eliminate the unwanted regeneration introduced by common coupling in the power supply.

Hum which cannot be eliminated in any other manner can be reduced by the application of degeneration which will reduce the hum, within the loop, proportional to the amount of feedback. In several cases, this feedback loop could be resonant at the hum frequency only, so that a maximum of degeneration is introduced at the hum frequency.

In cases where the low-frequency response is not important, it is feasible to reduce the coupling time constants by reducing the coupling condensers and grid resistors, reducing the gain at the hum frequencies. When all other means fail or when economy dictates, hum may be balanced out by applying to the circuit in question a hum voltage of proper amplitude and 180° out of phase. This voltage may be applied to any of the tube elements in a number of ways.

Remember that the field of a dynamic speaker, when used as choke in the power supply, has a very strong hum field surrounding it and an input transformer should not be located close thereto. A velocity microphone will pick up a strong hum voltage when located as far as 8 or 9 feet from such a speaker field. Microphone orientation will reduce this pickup to a minimum.

When connecting a self-powered tuner to an amplifier, remember to reverse the line connections if undue hum results. If both units have by-pass condensers from one side of the line to ground, it is possible to plug the units into the supply mains in such a way as to place some, or all, of the 110 V A.C. 60 cycle power source in series with the common ground between the units.

Consider, when using a cathode follower, that the cathode is swinging with the signal, and, at some parts of the cycle, it may well be a hundred volts above the filament, which may give rise to cathode-filament emission, or capacitive hum coupling.

Electrolytic condensers are a potential hum source. Their capacity reduces with age and their impedance increases, which can also give rise to oscillation. They should not be depended upon for R.F. by-passing and, in such instances, should be paralleled with a good paper or mica condenser.

Don't forget to by-pass to ground all the cathodes in which degeneration is not desired. The value of the condenser should be large so that its impedance at 60 cycles will be much lower than that of the cathode resistor, so that any hum developed between the heater and the cathode will be by-passed to ground. It is important that this condenser be grounded to the same place as the grid and cathode resistors, so that an AC circulating current in the chassis is not connected in series with the cathode by-pass condenser. (See Fig. 2.) Electrolytics used for by-passing sometimes give rise to tunable hums in radio tuners. Tunable hums have also been known to be caused by unwanted 60 cycles introduced into the oscillator of a superheterodyne receiver, due either to faulty by-passing or a faulty tube.

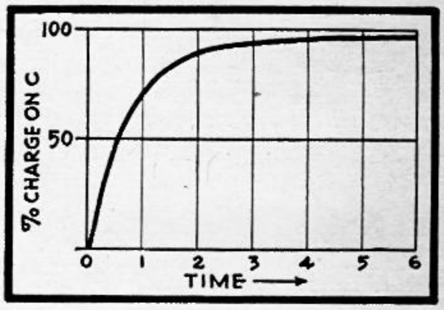

Fig. 4—Graph of condenser charging time.

Hum can be caused by induction from a phonograph motor to a magnetic pickup. This can be reduced by magnetically shielding the pick-up and using an iron turntable. Of course, the leads from the pick-up should be run through shielded wire and, in low-level pickups or microphones, the shield braid should not be relied upon for the ground return. Rather, use double wire shielded cable, connecting shield braid to the amplifier chassis and the ground wire to the amplifier ground. In this instance, do NOT connect the braid to the ground at the microphone or pickup but only to its frame. In connection with phonographs, it may be noted that what appears to be a hum only when records are played, may be turntable rumble. This may be deduced by replacing the rubber drive wheel on the rim drive models or by reducing the low frequency response of the amplifier.

Last, but not least, mechanical vibration can be responsible for hum. In such cases mechanical isolation is indicated. Mounting on rubber or removal of the source is the answer.

There are very few cases where the annoying hums cannot be eliminated or reduced to the point where they are no longer objectionable and the full capabilities of the unit under consideration can be realized.