Handbook of Sound Reproduction

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Chapter 15, Part 1. Power Supplies, Hum and Noise

An audio amplifier must control an independent source of energy in order to amplify, and for its operative needs must also use up power that does not get passed on. The a.c. power receptacle is the most common source of this energy, but the electric power supplied commercially must be changed in form before it can be used. The circuit that performs the necessary conversions is called the power supply.

The alternations of the a.c. line make power transmission and distribution more convenient, and make it possible to employ step-up and step-down transformers in the amplifier. The common value of 117 volts (in the U.S.) is, similarly, a convenient one. However the alternations have no direct use in the vacuum-tube circuit itself, and the voltages required by the amplifier stages differ in value from 117 volts. The power supply must therefore step the voltage down for tube heaters, and perform the operations of voltage step-up, rectification, and filtering for the plates and screen grids.

Unfortunately the alternations always get into the signal channel to a greater or lesser degree, creating hum output at the fundamental and harmonic line frequencies. In addition the power supply intrudes its own characteristics into the picture, limiting the amount of power that can be drawn by the load, disturbing the essentially constant-voltage nature of the line source, or serving as an inadvertent path for low-frequency positive feedback between stages. A properly designed power supply reduces all of these effects to such proportions that there is no significant effect on amplifier operation.

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Power Supply Design

A typical audio amplifier power supply is illustrated in *Fig.* 15—1, labelled with voltages common to such application. The dual diode tube acts as a full-wave rectifier, conducting during both halves of the power cycle. Since each plate is alternately positive for each half-cycle, electrons can flow from the cathode to one or the other of the plates during both cycle halves, as illustrated in *Fig.* 15—2.

The resultant rectified voltage has a fundamental frequency double that of the input—a 60-cps a.c. line produces a rectified output of 120-cps pulsating d.c.—and this fact works to our advantage by making the task of smoothing out the pulsations easier. The shunt capacitive reactances of the filter capacitors are halved, and the series inductive reactance of the choke is doubled for the same values of capacitance and inductance, which gives us a more effective filter or, for the same effectiveness, a smaller one. Where the size and weight of the power supply components are critical, as in aircraft equipment, a primary supply frequency of 400 cps or higher is used in order to reduce the requirements imposed on the filter.

The power amplifier stage uses the major part of the total B current, and is relatively insensitive to ripple. It is fed from the supply point indicated in *Fig.* 15—1, because the low d.c. resistance of the choke enables this component to carry a large amount of current without introducing too great a voltage drop, and because the power amplifier does not need the added filtering of the R-C sections. (In some cases the screen grids may require added filtering.) A comparable number of milliamperes flowing in the filter series resistors, besides requiring resistors of high wattage, would introduce a totally unreasonable voltage drop. It is thus desirable to use a choke with the lowest possible d.c. resistance; any changes in load current associated with signal variations will not then involve a significant change of d.c. voltage drop across the choke, and hence will have little effect on the B+ voltage.

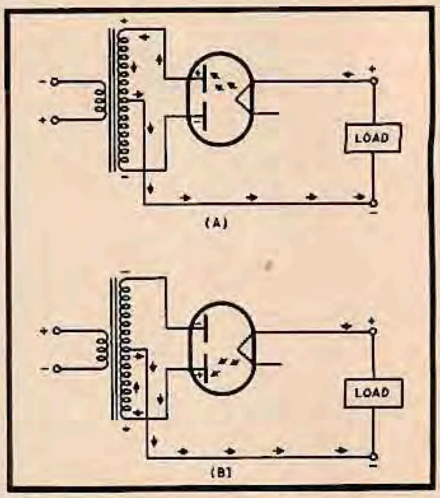

Fig. 15—2. Operation of a full-wave rectifier. Each half of the tube conducts alternately.

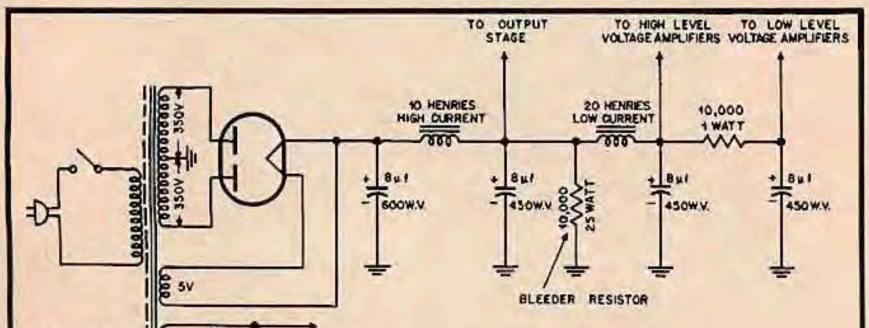

Fig. 15—1. Typical power supply for an audio amplifier. The high voltage winding of the transformer is rated as 700 v c.t., or as 350-0-350. The bleeder resistor is not required if the output stage is in Class A.

Voltage Regulation

The voltage regulation of the B power supply refers to its constancy of voltage under changing load. A straight Class A amplifier draws the same amount of current at all times, but class AB amplifiers draw more current at large signal amplitudes. If the B supply voltage goes down significantly on signal peaks the amplifying characteristics of the tubes will be instantaneously changed and distortion introduced. This is particularly true of Class B amplifiers, and in some cases gas-filled voltage regulator tubes have been employed to keep the voltage constant despite changes of either load current or line voltage. It is possible to

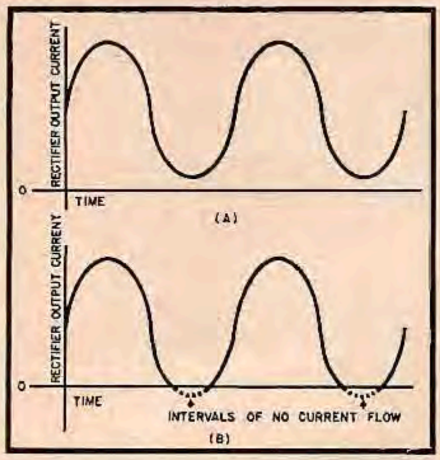

Fig. 15—3. (A) Full-wave rectifier output current. (B) Rectifier current with insufficient load. The discontinuities create an increase in output voltage. This can be avoided by the use of a bleeder resistor, which increases the minimum value of the current.

secure sufficiently good regulation without going to such lengths, however, and voltage regulators are in general reserved for other, more critical applications. The use of a well-regulated power transformer conservatively rated as to current capability, of a rectifier tube with good regulation, and of a low-resistance choke is normally sufficient.

Rectifier tubes present a resistance in series with the line which causes the output voltage to vary inversely with the amount of current drawn. Where regulation is important because of anticipated changes of current flow, the regulation characteristics of the rectifier tube, as described by tube manuals, should be taken into consideration. The voltage *vs.* load characteristics of several rectifier tubes are listed in Table 15—1.

The filter shown in *Fig.* 15—1 is of the capacitor-input type. When the first capacitor is eliminated the circuit becomes a choke-input filter. The latter has lower output voltage (the voltage of the capacitor input filter is usually at some value between the r.m.s. and peak values of the input a.c. voltage to the rectifier) and greatly reduced effectiveness as a filter, but better voltage regulation. It is not usually considered necessary to accept the first two results as payment for the last.

The "bleeder" resistor across the B supply line is for the purpose of improving regulation when there is a danger of load current dropping to low values. It has only a minor effect on the total percentage of current change, but it prevents the current from dropping below a certain minimum point. This minimum is that value of d.c. load current which falls below the negative peak of the variable component. If the d.c. flow did fall below this point discontinuities would be introduced into the wave form, as illustrated in *Fig.* 15—3. Such a discontinuity represents a sudden break in the rate of change of the current, and is like introducing an additional voltage in series with the choke,[1] causing the total voltage output of the filter to increase. A power supply serving a variable load usually has a bleeder resistor connected as shown, of a value equal to about 1100 ohms per henry of choke inductance.

Ratings of Power Supply Components

Components of power supplies are rated for given voltages and specified maximum load currents. If these ratings do not meet the requirements of the amplifier the results may be improper operation, failure in service, or both.

Filter capacitors must have a working voltage rating with a comfortable margin of safety over the voltage at the rectifier cathode. Current is not drawn from the rectifier until the cathodes of the working tubes have warmed up. Since the latter are usually indirectly heated they are only beginning to draw current when the directly-heated rectifier has already become operative. The voltage across the filter capacitors (and especially across the first one) is thus reduced very little by voltage drops in the power transformer or the rectifier tube, and may be significantly higher than normal during the warm-up period.

Transformers and chokes that are made to carry more current than they are designed for exhibit several effects: they overheat and in time may fail, and they cause the available voltage to vary unduly with change of load. Furthermore the inductance rating of a choke is in terms of a maximum current flow, and if this maximum current is exceeded the electrical inductance is correspondingly reduced due to core saturation.

Power Supply Filtering and De-coupling

As the amount of amplification ahead of a stage is increased the percentage of ripple that can be tolerated in the B supply is reduced. It is a lot simpler and cheaper to improve the filtering for such low-level stages separately, rather than to filter the entire B supply so well that the point from which the output stage derives its power is also suitable for the rest of the amplifier. But there is another factor, over and above considerations of hum, that makes separate filter sections necessary in any case. This is the danger of regenerative interstage coupling through the power supply.

[1] L. B. Arguimbau, "*Vacuum-Tube Circuits.*" New York: John Wiley and Sons, Inc., 1948, p. 40.

TABLE 15—1

VOLTAGE REGULATION CHARACTERISTICS OF COMMON RECTIFIER TUBES

Tube Type	Approximate change in output voltage associated with change from half-load to full-load current*	
	Capacitor-input filter	Choke-input filter
5T4	50 v	15 v
5U4	80 v	20 v
5V4	40 v	10 v
5Y3	40 v	25 v

* At specified input voltage

Consider the three cascaded amplifier stages in (A) of *Fig.* 15—4. The output signal voltage coupled from one stage to the next is that between plate and ground. While this voltage is almost equal to the voltage across the plate resistor at signal frequencies (B+ being considered as signal ground due to the effective short of the high capacitance filters), the reactance of the filter capacitors becomes large enough to be significant at very low frequencies, and the above is no longer true. The impedance between B+ and B– then forms part of the load impedance of each of the stages, and this added element of load impedance is common to all three. Part of the output voltage of the second and third stages is thus coupled back to previous points in the signal channel.

For any two adjacent stages the feedback is negative—a fraction of the output signal of the higher level stage is effectively fed back to its own input, where the signal, ignoring phase shift, is exactly opposite in phase. But the feedback between the first and third stages is positive. The input signal to the first stage has suffered two phase reversals, and the output of the third stage has the same phase as the output of the first stage. When the amount of feedback is great enough, which is to say when the frequency is low enough for the filter reactance to have become sufficiently high, regeneration and self-sustaining oscillation occur. The subsonic frequency of this type of oscillation has given it the name of motorboating, and

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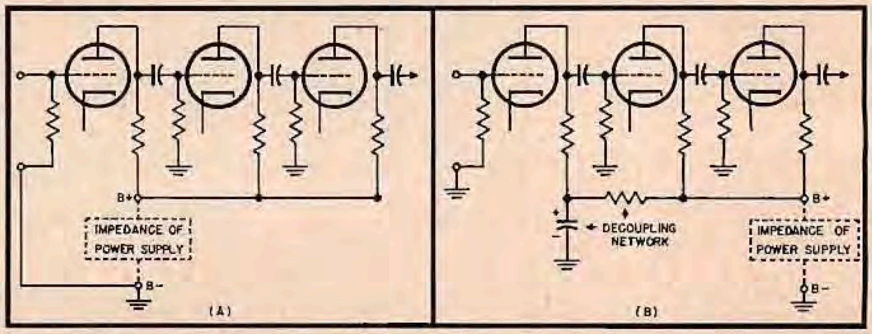

Fig. 15—4. (A) Feedback between stages due to common power supply impedance. (B) Avoidance of regenerative feedback through the power supply, by the insertion of a de-coupling network.

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occasionally the oscillation is at so low a frequency that it can be observed as a very slow oscillatory motion of the speaker cone, sometimes referred to as "breathing."

The standard cure for such regeneration is the use of added R-C sections of filtering, called de-coupling networks, as illustrated in (B) of *Fig.* 15—4. Decoupling networks improve the anti-hum effectiveness of the filter, but their primary purpose is to prevent alternate stages from having a common load impedance. No more than two successive stages of amplification can be fed from the same B supply point without danger of regeneration. Phase-splitters that use two tubes must be considered as two stages, and the preceding amplifier should be fed from a de-coupled point.

Hum and Noise

We may now turn to a more detailed consideration of the way in which noise is introduced into the signal channel, and of ways to combat it. Although the additional components may be periodic rather than composed of random frequencies, they are classified as noise because of their irritating nature, in accordance with the definition of noise of the American Standards Association.

Noise can be readily generated by defective tubes, resistors, capacitors, lead connections, and so on. We will confine ourselves here to discussing noise inherent in original design rather than that resulting from defective parts. Three types of noise will be considered: hum, "microphonic" disturbances, and thermal noise. Two other types of noise which the signal may pick up are record surface scratch and turntable rumble. These are associated with mechanical activities of the pickup and of the phonograph motor rather than with electronic flow in the amplifier, and are referred to in appropriate chapters.

Probably the most common "bug" in individually built or design model audio amplifiers of high gain is hum. Modern low-output pickups and tape reproducing heads require amplifiers of such gain that several potential sources of hum, which might not have had any significant effect in an amplifier of lower gain, must be carefully eliminated.

Hum Level

The amount of hum at the output of an audio amplifier, or at some point within the amplifier, is most often described in terms of the decibel relationship between the hum voltage or power and the maximum signal at that point. This procedure is followed in recognition of the fact that the tolerable amount of hum depends upon its relative level in the total range of amplitudes being reproduced. The absolute amount of hum produced by a public address system in a large hall, for example, may be considerably greater than the hum produced by a low-power living room amplifier, but the amount of noticeable hum of the two may be the same.

A relative rating of this type, however, must be used with care. There is a certain amount of amplifier hum output which is introduced above the volume control and which therefore remains constant regardless of the volume control setting and the level of reproduction. This hum will have a higher ratio to the signal when soft passages are being reproduced. It may leap into prominence if the loudspeaker system is especially efficient and if the maximum power capacity of the amplifier, upon which the hum rating is based, is far in excess of the power used. In the latter case it is important to know the relationship of the hum level to the maximum electrical output actually in use rather than to the output capabilities of the amplifier. The absolute minimum value of the output hum of an amplifier, in microwatts, may therefore be a useful rating to have in addition to the relative rating in db below maximum output.

The Federal Communications Commission regulations permit a total hum and noise level for AM broadcast stations, exclusive of microphone and studio noises, of 50 db below 100 per cent modulation (representing maximum audio level) at frequencies between 150 and 5,000 cps, and 40 db down from the maximum signal outside of this frequency range. FM stations are required to keep their hum noise level 60 db below the maximum amplitude of passages being broadcast. Modern amplifiers should, and commercial amplifiers usually do meet or exceed the FM requirements.

If a 10-watt amplifier has 10 microwatts of hum output the signal-to-hum ratio is 10/.00001, or a million to one. Converting to db by the power formula:

$$db = 10 \log \frac{P_1}{P_2} = 10 \log \frac{1{,}000{,}000}{1} = 60$$

we find the hum level to be 60 db below 10 watts.

It would be extremely difficult to measure 10 microwatts in the low-impedance secondary of an output transformer, as the voltage involved is minute. The voltage across the relatively high-impedance primary winding of the output transformer is much greater, and may be measured with a low-scale a.c. voltmeter or calibrated oscilloscope of known volts/inch sensitivity. (If the latter is used, peak-to-peak indications are employed directly; sensitivity is normally rated in sine-wave r.m.s volts.)

The secondary is connected to the proper value of resistive load rather than to the loudspeaker, in order that the impedance rating of the primary, which is a reflected value, be accurate. The square of the voltage across the primary, divided by the primary impedance, will then give the power of the hum output. For example, 0.2 volts across a 4,000-ohm secondary indicates a power of 10 microwatts.

The hum level of voltage amplifiers is calculated in the same way, except that the db/voltage formula [$db = 20 \log (E_1/E_2)$] is used.

Examination of the Fletcher-Munson curve will reveal the fact that 60-cps hum, at the usual order of intensity that might be expected of such a disturbance, requires an intensity level at least 10 db higher than that of 120-cps hum to be heard with the same loudness. Suppression of hum at harmonic frequencies of the line is therefore especially important. One of the best methods (and certainly the simplest) for checking final noise level in a complete home reproducing system is a listening test, which automatically takes into consideration speaker efficiency, hum frequency, and acoustical conditions under which the reproducing system will perform. With the volume control set for high but usable volume and no program material present, an exceedingly low hum level would be represented by little or no audible sound in a quiet room at a distance of two or three feet from the loudspeaker.

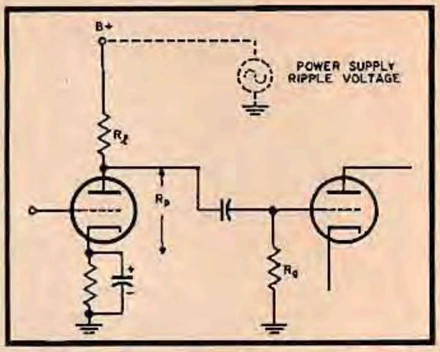

Fig. 15—5. Application of power supply ripple voltage to the voltage divider consisting of plate resistor as an upper arm, and the parallel combination of tube and grid resistor as lower arm.

Sources of Hum

The sources of hum in an audio amplifier may be divided into four main categories:

1. Insufficiently filtered B supply, the common garden variety of hum.
2. Inductive or capacitive pick-up, by some point along the signal channel, from components or leads carrying a.c. or pulsating d.c.
3. Coupling from a.c. heaters.
4. Differences of a.c. potential along the chassis or between different chassis.

Hum is also introduced into the signal in r.f. circuits, in which case it is called "modulation" or "tunable" hum.

B+ Filtering

Alternating ripple in the plate supply of a resistance-coupled stage is applied to the voltage divider formed by the load resistor and tube impedance and is coupled to the grid of the following stage, as illustrated in *Fig.* 15—5. It is sometimes thought that B+ hum is introduced by plate modulation of the electron stream in the tube being supplied, but vacuum tubes are relatively insensitive to plate voltage changes, and the fractional ripple voltages involved cannot have an appreciable effect on current flow. Thus the tube does not have to be in its socket for ripple in its plate supply to be introduced into the signal. As a matter of fact less plate supply hum will be introduced with the tube in place than without it.

The voltage division of plate-supply ripple will be most favorable to a low hum level when the tube has low plate resistance, when the circuit uses a high value of plate resistor, and when the grid resistor following, which is effectively in parallel with the plate resistance of the tube, is low in value. Pentodes are more susceptible to B+ ripple than triodes because of the fact that their plate resistance is higher, and because electron flow in the tube may be screen modulated by the ripple voltage. The screen requires a more highly filtered supply than the plate.

When there is doubt as to whether hum is due to inadequate filtering an extra resistance-capacitance section may be temporarily connected in series between the suspected stage and the B+ line. For the output stage the test circuit would have to be an inductance-capacitance section.