Valve Amplification Company

VAC Technical Monograph 90-10 - Power Supply Regulation

[illustrations and graphs to come; printed copies available from VAC]

Introduction

VAC Technical Monographs are provided to help anyone interested in vacuum tube electronics to better understand the issues involved in the design of truly "high end" amplifiers. They are a direct response to the (unintentionally) inaccurate impressions created by the marketing arms of manufacturers, as well as other writings fraught with misunderstanding and outright inaccuracies regarding basic concepts of tube electronics, laws of physics, operation of circuits, measurement standards, and historical attribution. It is our intention to create an unambiguous and accurate reference for many of these issues. As such, these Monographs should prove valuable not only to individuals who are just becoming aware of these issues, but also to many experienced audiophiles who are awash in the competing claims.

To ensure accuracy and provide the reader with a source for even more information on these topics, extensive reference will be made of authoritative works in the electronics field. Thus, the thoughts presented herein are not merely the random musings and recollections of one individual, but a condensation of the accumulated wisdom of a great many authorities.

Naturally, no one work is ever exhaustive, so the reader may encounter an omission, or even spot an error (hopefully only typographical in nature). We are anxious to clarify any fuzzy points and correct any inaccuracies. As such, we encourage all interested readers to correspond with us on such points. After all, the goal here is to enlighten, not to confuse!

Readers with little electronics background will probably wish to check into some of the introductory sources contained in the "Recommended Readings" at the end of this Monograph.

Finally, remember that in audio electronics there is never one uniquely and absolutely correct way to design an amplifier. Design always entails compromise. The real question is which parameters are compromised and to what degree. The best way to judge audio equipment remains familiarity with live acoustic music. Listen, and let the sound be your guide.

STARTING AT THE BEGINNING

In a sense the power supply is the heart of an audio amplifier. It supplies the raw material that the tubes, capacitors, resistors, and other components will use to amplify the input signal. The quality of amplification is directly dependent upon the quality of the power source.

The British and Australians refer to the vacuum tube as a valve, which is a descriptively satisfactory word. In essence, a high voltage is applied across the tube (between the plate, also called the anode, and cathode). A small voltage applied to the grid of the tube then can control the passage of electrons between the cathode and the plate. To use a fluid analogy, the plate voltage is like water under pressure at a faucet, and the action of the grid signal controls the passage of electrons just as a faucet controls the passage of water. An input signal applied to the grid can thus impress its character on the large current flowing through the tube, creating an amplified replica of itself.

In most cases, the purpose of the power supply is to provide a ready reservoir of DC energy at a voltage that remains essentially constant at all times. However, the demand for energy placed upon the power supply by an amplifier is not constant, but changes with input signal. In our fluid analogy, this is similar to needing the water pressure to remain constant even when the faucet is opened widely.

A power supply that has poor regulation will not deliver a steady voltage to the amplifier as the load varies, and thus will superimpose its variation on the amplifier and the musical signal. It is important that the DC energy provided to the amplifier circuit be steady, since the tube will essentially modulate that steady DC with the varying AC musical signal. Any variation in the DC energy will combine with the musical signal, resulting in some forms of distortion.

A simple unregulated power supply consists of a transformer, rectifier, and filter (Figure 1). The transformer converts the 120 (or 220) volt AC line voltage to a higher or lower voltage, as appropriate for the associated amplifier circuit. The rectifier converts the AC to DC, but a great deal of ripple (fluctuation) present in this DC. The ripple is smoothed out by a filter system consisting of capacitors along with resistors and/or inductors.

A regulated power supply incorporates additional tube and/or semiconductor devices. They are arranged such that they sense the difference between a desired voltage and the voltage actually being delivered to the amplifier. The regulator then increases or decreases its conductance so that the delivered voltage is close to the desired voltage. When implemented correctly, the action of the regulator causes the amplifier circuit to see an essentially steady and clean source of DC power.

POWER SUPPLY PERFORMANCE

There are two major measures of power supply performance.

1) Regulation refers to how much the supply output voltage drops as the amplifier presents a more difficult load to the supply, such as when the amplifier is called upon to produce high output power and/or reproduce very low frequencies.

2) Voltage stabilization refers to changes in the power supply output as the AC line voltage varies.

While it may at first seem a contradiction in terms, but even an unregulated supply possesses a degree of regulation. This is primarily a function of the size and quality of capacitance in the power supply filter. Regulation is also affected by the resistances of its components and the leakage inductance of the transformer. In essence, a power supply that has low impedance at all audio frequencies will have good regulation.

(Note for those reading the older references: the capacitance in the power supply filter was often referred to as by-pass capacitance. The modern use of this term refers to the use of high quality film capacitors across electrolytic capacitors in the power supply filter. This is done to help prevent audio frequencies from flowing through the electrolytic capacitors, which generally resonate within the audio frequency range.)

Voltage stabilization becomes an issue because the power available in your home is far from constant. In the United States the goal of power companies is to hold the voltage delivered at 120 volts AC (VAC) +/- 6%, which is a range from 113 VAC to 127 VAC. Some authors have reported measuring brief variations to as low as 90 VAC and as high as 135 VAC.

To illustrate how serious the problem of voltage stabilization can be, consider an unregulated high voltage supply for the output stage of a tube power amplifier. Suppose that the designer targets 480 volts DC (VDC) as the appropriate voltage for the output plates. Given the power companies' goal, the actual voltage delivered to the tubes can range all the way from 451 VDC to 509 VDC (Figure 2). This will be true even if the power supply has perfect regulation. Such wide swings of supply voltage with affect by the performance and reliability of the tubes, altering the amplifier's power output, distortion, and frequency of catastrophic tube failure.

Recognizing the risk of tube failure implied by an unregulated power supply, some designers will ensure that the highest voltages likely to be encountered are well within the maximum limits for the tube and circuit type used. In many cases this means that the tubes can not be used to their full potential in terms of distortion or power. This is usually preferable to frequent tube failures.

Unlike regulation, voltage stabilization can not be improved by additional filter capacitance. In addition, one or two of the current crop of devices sold as power line conditioners can help with voltage stabilization, but can not cure poor regulation.

THE NEED FOR REGULATION

The more an amplifier circuit's demands for power vary, the greater the impact of poor power supply regulation. Accordingly, different types of amplifier circuits display different tolerances for unregulated power supplies. Class B power amplifiers are perhaps the least tolerant of all, since the tubes are constantly being switched off and on (cut-off), constantly varying the load on the power supply, even at low power levels. (See VAC Technical Monograph 90-8.) Class AB power amplifiers are somewhat less sensitive, as cut-off is not always being hit. A push-pull Class A amplifier is least sensitive to poor regulation, as the lack of cut-off here results in a more consistent load on the power supply.

Surprisingly, single-ended (not push-pull) Class A operation, as found in virtually all unbalanced home preamplifiers, is also sensitive to power supply regulation. The low frequency limit of this configuration is a function of the capacitance in the filter of an unregulated power supply. Filter capacitance in most modern designs is sufficient for robust low frequency performance.

Pentode amplifiers tend to be more sensitive to voltage variation than triode amplifiers. A change of only 1% in a pentode's plate and screen voltage will cause a reduction of approximately 2.5% in available power output. The screen circuit is the more sensitive of the two. When the same supply is used for both plate and screen, regulation can again have a profound impact on low frequency performance. Beam power tubes may be slightly less sensitive than pentodes in this regard.

Poor supply regulation can also allow for an increase in unwanted coupling between the various stages of a complete amplifier. This is an often undiagnosed problem in many contemporary amplifiers that use only one large capacitor reservoir common to all stages, and can lead to an increase in dynamic distortions or, in extreme cases, cause parasitic oscillations. In a stereo amplifier, this coupling will affect the channel separation and imaging. Power supply interaction is probably the single most important reason why audiophiles tend to prefer two separate monophonic ("mono-block") amplifiers over stereophonic amplifiers.

FORMS OF REGULATION

As previously noted, a regulated power supply utilizes an electronic feedback or control circuit to ensure both good regulation and good voltage stabilization. This can be accomplished with either vacuum tubes or solid state devices. The following discussion will refer to tubes.

The most primitive form of voltage regulation uses a gaseous voltage regulator (VR) tube in shunt with the power supply (across the output of the supply and in parallel to the amplifier circuit) as shown in Figure 3. As the output voltage ER increases, the regulator tube takes more current, and thus increases the voltage drop across resistor R1. As a result, the voltage across the load (shown here as resistor RL) is held near the desired value. Of course, there are limits beyond which this circuit can not maintain the desired voltage, and beyond which damage to the regulator tube will occur.

Better regulation may be obtained through series regulation, such as the cathode follower series regulator. This circuit converts the high impedance of the basic power supply to a low impedance, with a corresponding improvement in regulation. Figure 4 shows a basic cathode follower regulator, in which the regulator tube is referred to as the series pass tube.

In Figure 5 we see amplified series regulation. Here the sensitivity of the regulator is improved by an additional tube (T1) which amplifies the difference between the reference voltage and the actual output voltage. The reference voltage is usually provided by a VR tube, as in the complete circuit shown in Figure 6.

The solid state equivalent of a VR tube is the zener diode, and transistors may be used as series pass and amplifier elements.

CAVEATS IN THE USE OF REGULATION

It is easy to create problems with regulators, to the point that they degrade sound rather than improving it. One important factor is the location of the regulator. If the regulator is placed directly after the rectifier, it will be subjected to the switching transients created by the rectifier. These can be significant, particularly in the case of solid state rectifiers, and can momentarily overload the regulator, causing an erroneous output both during and after the transient.

Similarly, if adequate bypass capacitance is not placed between the amplifier circuit and the regulator, a significant portion of the audio signal will flow through the regulator itself. This is undesirable as the regulator may not be a particularly linear device. If the regulator is a semiconductor, the inherent charge storage and poor dielectric characteristics of the device can color the sound.

The problem of adequately isolating the regulator from the audio signal can be particularly severe when regulation is used to provide an "automatic bias" circuit for the output stage. In many such circuits a regulator device, often a semiconductor such as the type 7805, is placed in the cathode circuit of the output stage in such a way as to allow the audio signal to flow through it. This can cause degradation of the audio signal.

In spite of the above problems, it is important that the regulator or final capacitive reservoir be physically close to the circuit which will use the power. This is important both to keep the overall power supply resistance low and its impedance relatively low at high frequencies. In additional, the self inductance of the wire connecting the supply to the amplifier circuit can significantly lower the self resonant frequency of the power supply capacitance, thus effectively lowering the frequency at which the capacitor stops behaving like a capacitor, often well into the audio frequency range.

It is also important to note that active regulation dissipates power during normal use. As such, a highly regulated power supply may run quite warm as compared with an unregulated supply. Also, power transformers with good inherent regulation tend to be quite a bit larger and heavier than their lesser counterparts.

SUMMARY

The load presented by an amplifier to its power supply changes rapidly as the musical signal varies. This is particularly severe when a tube is driven to cutoff or draws grid current, as in the case of Class AB1, AB2, and B power amplifiers. (See VAC Technical Monograph 90-8.)

A power supply that has poor regulation will not deliver a steady voltage to the amplifier as the load varies, and thus will superimpose its variation on the amplifier and the musical signal. This will result in increased harmonic and intermodulation distortion, lower power output, and distorted dynamics.

An unregulated power supply also can not deliver a consistent (stabilized) voltage to the amplifier circuit as power line conditions vary. In the case of a typical tube output stage, the plate voltage may change by upwards of 60 volts even when the house current stays "within spec". This means that the circuit is often functioning at a point other than that intended by the designer, with significant possible degradation to the sound.

Thus, while less costly to construct, lighter weight, and cooler in operation, the unregulated supply may be inadequate for two reasons. The first by definition is poor regulation; even with the best precautions the output voltage is far from constant as the load varies. The second is no voltage stabilization. A power supply with active regulation can address both of these problems.

To prevent active regulation from damaging the sound in its own ways, it is important to locate the regulator correctly and provide adequate filtration.

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Recommended Background Reading

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Graph Credits

Figure 3 after Langford-Smith, page 1215.
Figure 4 after Millman, page 521.
Figure 5 after Millman, page 522.
Figure 6 after Millman, page 524.
