Audibility of Power Supplies

Over the years it has become general knowledge that, over and above "traditional" measurements of THD and IMD, there are other factors responsible for the sonic character of audio components. The final sonic signature is the summation, and more importantly, the interaction of many ingredients including the choice of tubes (leading to the very popular practice of "tube rolling"), passive selection (resistors and capacitors), component placement, interconnect type and routing, grounding methodology, and power supply design – the subject I would like to explore further in this paper.

The designer is presented with an infinite array of combinations and permutations of components and topologies that all factor into the final result. This is the reason for the never-ending debate over types of power supply – tube rectifiers or fast recovery diodes, regulated vs. non-regulated, choke input vs. capacitor input. Regardless of the topology chosen, all of these configurations will contribute to the voicing of the combination. It is common to see an improvement with simple component changes - as for example if the soft character of a tube rectified supply is combined with an audio amplifier circuit having "hard" character aberrations. To some this "less irritating" result may be acceptable but it is not accurate and it certainly can be improved. More often however the "one best solution" philosophy causes the changes to accumulate in the same direction causing the aberrations to add in like fashion and become intolerable. For example, the typical "cookbook" high voltage regulator exhibits a characteristic sound that is hard, grainy, and thin. Applying this power supply regulator to the above example will result in an accumulation of errors that is horrible. As a result, some knowledgeable audiophiles have categorically rejected "regulated power supplies". Similar comments have been associated with solid state rectification. The truth is that the designer must carefully understand the contributory factors and must either eliminate those that are relevant or minimize those that cannot be eliminated. All these factors must be considered in the final design.

What's Goin On

If one were to carefully examine virtually any vacuum tube audio circuit, it becomes clear that the tube amplifies by controlling the current thru an impedance – most times a resistor. Voltage appearing at the input (between the control grid and cathode) causes the current flowing from the plate to the cathode to change in response. The current is provided from the power supply and flows from the power supply, through the impedance (again usually a resistor), through the tube and finally back into the power supply. The output is usually derived by sampling the voltage across the plate impedance via ohms law (Output Voltage = Tube Current X Plate Resistance - and notice this is theoretically a direct linear relationship). If everybody is following their theoretical and simplified model, we will be provided with a perfect sounding distortionless output – a perfect replica of the input only higher in amplitude – the perfect amplifier.

Unfortunately, in the real world, all three depart from perfection and as a result both individually and in total, contribute to the overall "sound" of the total amplifier. The tube isn't perfect by definition – it's output only approaches linear when operated under certain strict conditions all hopefully understood by the designer. Resistors deviate from linearity - mostly from the effects of voltage drop across its internal structure, but nowhere near as significant as the tube. Finally, poorly designed power supplies, in addition to injecting noise (hum or hiss), can deviate from perfect (no change in voltage level nor current availability regardless of the demand requested). Worse, the power supply can deviate in a manner that, of the three, has the greatest effect on the amplifier sound. And note that these artifacts do not show up on any traditional steady state measurements (THD, IMD, or frequency response). **Our listening tests have shown that the power supply performance contributes more to the overall sound of the amplifier than any other single factor - more than the tube choice, circuit topology (cascade, cascode, SRPP, Hybrid, MU whatever) and more than the choice of passives**. It is clear that although these other factors do have a contribution, many end users become engaged <u>the art of part rolling (tubes, capacitors, and resistors) are simply "tuning" their circuits to counterbalance and compensate for poor power supply design</u>.

The quest for an audibly inert power supply

When called upon by the tube, the power supply must <u>instantaneously</u> deliver the exact (not more, not less) current requested through the resistor. It must not differentiate if the demand is at 10 Hz or 1 MHz. It must do so without any delay and it must do so without being sent into a reactive short oscillatory condition (called ringing). Any failure to meet these requirements alter the current expected into the resistor and will be heard creating a characteristic "sound" to the circuit. That sound may be hard, sterile, thin, or on the other extreme, soft, fat, recessed depending upon how the power supply performs.

Each of the power supply components including the line filter, transformer, rectifiers, choke (if utilized), and certainly the smoothing capacitors and regulators (if utilized) all have a role in the sound of the power supply. As the amplifier (tube and plate resistor) "looks back into" the power supply it would like to see a pure DC voltage source of zero ohms at any frequency. In reality it sees an impedance curve that varies from milli-ohms to tens of ohms across the audible frequency range. The degree that it deviates from flat in many "high end" audio circuits is frightening – you would never purchase an amplifier that specified an equivalent frequency response. We have found that the impedance frequency response of a power supply is very close to the mirror image "sound" of the total amplifier using that power supply. And as the power supply's components change in value and material of construction, the impedance is modified causing a direct effect on the sound.

Now comes the regulator to the rescue. A regulator is an electrical circuit designed to provide all the current needed as demanded by the amplifier without any fluctuation in the DC voltage output – essentially a zero impedance voltage source.

To do this regulators combine a DC amplifier with lots of feedback – the feedback "watches" the output voltage and compares it to a "reference" voltage (the regulator's "input"). Should the DC amplifier detect any change at the output via its feedback path, it is designed to (as quickly as possible) restore the desired voltage. Notice that it can only correct the voltage after it sees the change. What do you think happens if the regulator responds slower than the audio signal causing the current demand? Dull and sloppy sound. However this is rarely the problem since high frequency solid state devices are readily available. Most times a far more serious problem is triggered – ringing.

To visualize ringing you need to imagine that most music is not simple sine waves but more often a complex collection of quickly rising pulse like waveforms. These steeply rising pulses of current demand, appearing at the tube's plate, expect the power supply to respond in kind with exactly the current needed. Regulators operating with high speed high feedback DC amplifiers when placed in this quick demand position tend to overshoot their intended target – they quickly respond and actually deliver much more current that is called for. The equivalent of an "off sides" penalty from an aggressive defensive lineman. Afterward, and trying to recover, the regulator goes into a short burst of oscillation from supplying too much to too little and then again too much current. This goes on for a few cycles until it finally stabilizes. To you and me the "outburst" sounds like hardness and edginess.

CAE Approach

CAE has elected to utilize high-speed wide bandwidth regulators in all of our designs. Our "reference" product line employs our patented high-speed wide bandwidth servo design. We are flattered to observe that it has been "cloned" by others and humored by the fact that their "subtle" changes (such as the substitution of a power MOS-FET in the pass element) has compromised its damping resulting in ringing thereby giving it a "sterile" signature.

Our design incorporates a floating 317 pre-regulator that provides an ultra stable voltage reference and bias supply to a bank of high speed proprietary operational amplifier slaves. (Many of our customers have used these same op-amps in their crossovers and CD players telling us they are "the most musical" they have auditioned.) Each high speed operational amplifier is coupled to a bipolar transistor (not MOS-FET) to form an unconditionally stable voltage source that exhibits near zero impedance over an ultra wide bandwidth (from DC to well beyond 1MHz). More importantly the circuit is critically damped to deliver instantaneous response to a step current demand without any ringing whatsoever. We place a slave regulator at every stage and every channel of the associated amplifier. In this way each regulator is responsible only for the current demands of the stage supported. For example, our Sarah reference phono preamplifier is comprised of three stages of amplification for both channels (right and left). In this case six independent op-amp "slaves" are incorporated into the design.

The result is that each stage of amplification is provided a foundation and environment of complete isolation form adjacent stages (except where the signal is supposed to couple – at the input and output) and supported by a power source that provides the exact current requested, on time and without overhang.

To us listeners, it sounds accurate, musical, three dimensional, and dynamic.