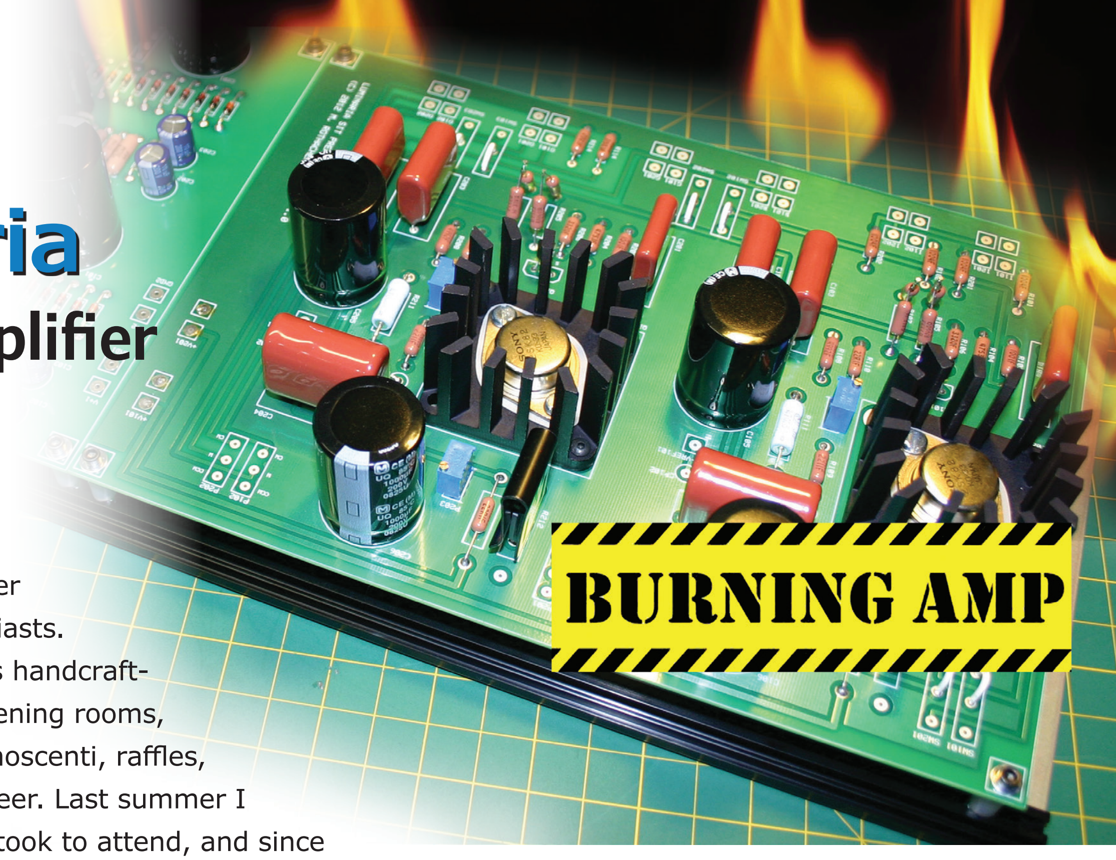

LuminAria

A SIT Preamplifier

By
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(United States)

The annual Burning Amp Festival (BAF) in San Francisco, CA, is the premier event for DIY audio enthusiasts. Each year the BAF provides handcrafted equipment displays, listening rooms, brilliant talks by audio cognoscenti, raffles, giveaways, sausage, and beer. Last summer I resolved to do whatever it took to attend, and since many of my audio friends and heroes would be there, I didn't want to go without a DIY project to display. So, I had to come up with something small enough to fit in my suitcase and light enough to schlep from my hotel to the festival, which was held at Fort Mason on the bay.

Paradoxically, in audio invention is oftentimes the mother of necessity, so I decided I needed a preamplifier. All I had to do was design and build a BAF-worthy, good-sounding, unusual preamplifier with a spiffy set of performance specifications and have it show-ready in about two months. Nothing inspires me quite like an unreasonable objective and self-imposed pressure. This is the story of that project, which I named the LuminAria, warts and all.

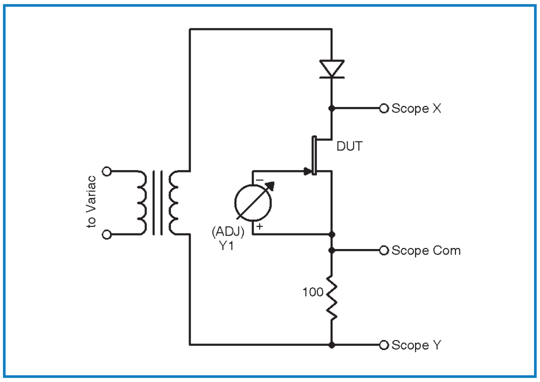

Figure 1: The makeshift curve tracer enables us to get a closer look at the 2SK82.

Design Goals

Starting a design project is easy, but finishing one generally requires some specific goals so we'll begin there. DIY preamplifier projects are a bit scarcer than amplifier projects; perhaps this is because preamplifiers can be a little more difficult to build, demanding more in terms of switches, volume controls, wiring, metalwork, and so forth. So, when I decided to do a preamplifier project, I knew I wanted something simple, not only to satisfy my minimalist taste, but also to ensure that it may actually get built.

I also decided this would be an active preamplifier with voltage gain. Passive and buffered-passive preamplifiers are popular among audiophiles because they handle input switching and volume control without adding much coloration to the music signal. As long as your amplifiers have enough gain and cooperative input circuits, they do a really great job.

However, I like to experiment with simple little one-stage amplifiers that often require some special attention at the input in terms of voltage and source impedance (see my article, "L'Amp: A Simple

SIT Amp," *diyAudio*, 2011). I wanted a versatile preamplifier that would address these issues and work well in a variety of situations.

How much voltage gain and output do we want? I thought 12 dB or more would be nice, and it would be good to provide more than just a couple of volts in case we want to drive a power follower such as a Firstwatt F4 or some other design; let's say 20 Vpk or more.

High input impedance would work well with a variety of music sources, and low output impedance would be good in case the amplifier has low input impedance and/or high input capacitance, which is sometimes the case with minimalist amplifiers. And, naturally, there should be really low distortion with little or no feedback.

To summarize: a simple, unusual preamplifier with ample gain, a lot of voltage swing, high input impedance, low output impedance, low distortion and no feedback, which fits conveniently in a suitcase would be preferable.

There's Plenty of Room at the Bottom

I also decided it might be fun to explore uncharted waters and experiment with some exotic devices. Thanks to Nelson Pass, I'm hooked on static induction transistors (SITs). Their characteristics are great for building simple, low-distortion gain blocks with little or no feedback. Having built a number of single-stage power amplifiers with SITs, I wanted to see if these devices could work their magic in a preamplifier.

SIT characteristic curves are very triode-like and linear so they seemed like a good fit for a best-of-both-worlds preamplifier design. Of course, a SIT whose characteristics are optimized for the voltages and currents found in a preamplifier circuit would be optimal, but when I searched for a suitable small part I quickly discovered the choices are really limited. A few small SITs have been made (e.g., the 2SK63 or the 2SK79) but I wasn't confident that enough of them would be available to support this DIY project, so I chose the more readily obtainable Sony 2SK82.

Now, you may be thinking that's a power part. It doesn't have enough gain. What about capacitance? Insert your favorite protest here. But, sometimes we have to work with what we've got. Working through the various problems and opportunities can be part of the fun.

First, observe that the current-voltage characteristics (i.e., I-V curves) in datasheets don't always tell the whole story, and the ranges of current and voltage shown are chosen for specific applications. Sometimes though, it is useful to "zoom out" or "zoom in" on a particular part of the graph and see how things look on a different scale. This is easily accomplished with a curve tracer if you

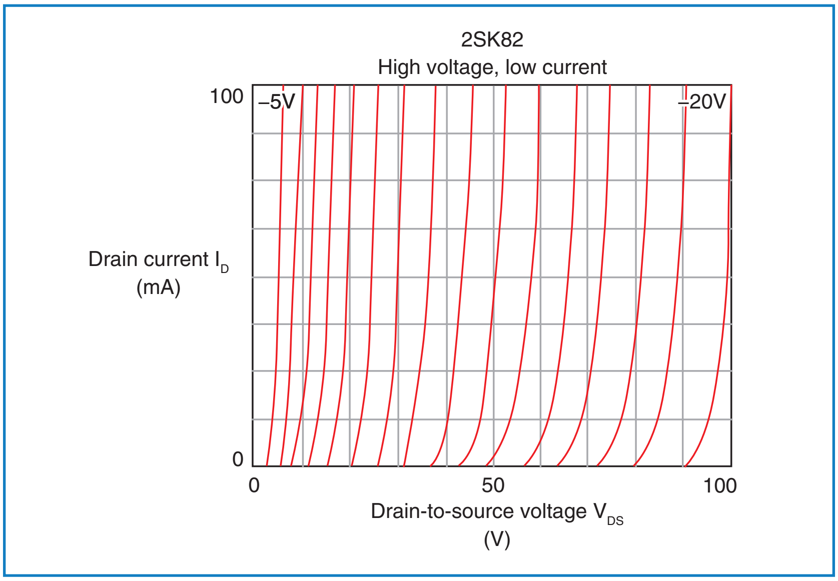

Figure 2: The 2SK82's I-V curves are shown at high voltage and low current.

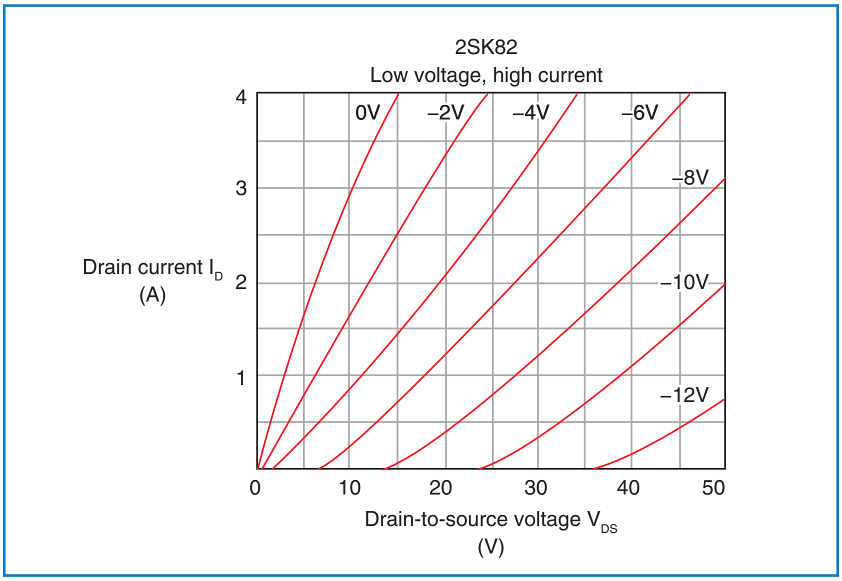

Figure 3: The 2SK82's I-V curves are shown at low voltage and high current.

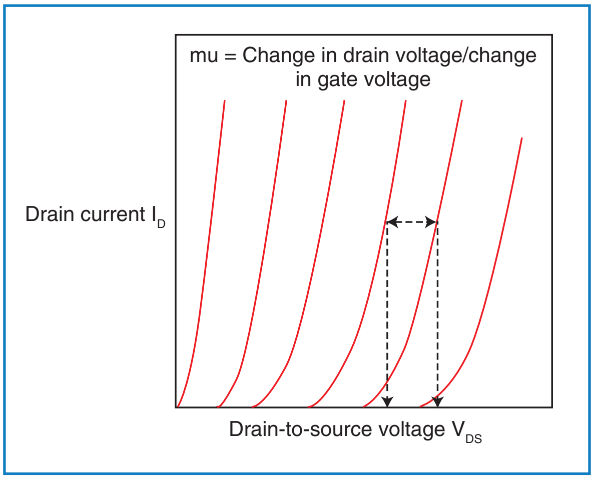

Figure 4: The amplification factor (mu) is determined by examining the change in drain voltage divided by the change in gate voltage when the drain current is held constant.

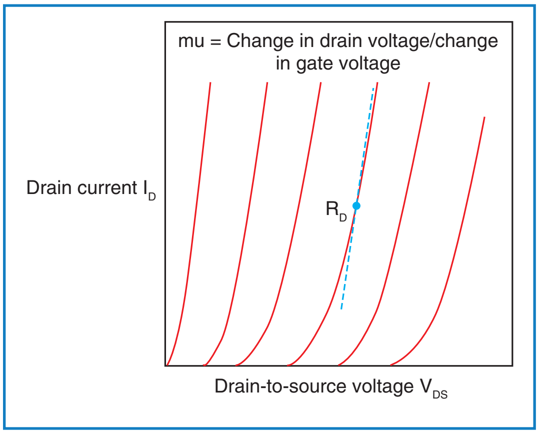

Figure 5: The drain resistance shows the change in drain voltage divided by the change in drain current with the gate-to-source voltage held constant.

have one. Of course, curve tracers can be expensive, especially the ones that measure high voltage and current.

To get a closer look at the 2SK82, I used the circuit in **Figure 1** to generate the set of curves in **Figure 2**. This is an economical and lab-expedient way to make I-V curves. However, it is more labor-intensive than using a curve tracer and you have to be very careful not to exceed the device's limits. I detailed the specifics of creating a plot similar to this in my L'Amp design. Because the voltage and current scale is different, these curves look more like a triode's familiar curves compared to those in **Figure 3**, which shows the same device at power amp voltage and current levels.

SIT Characteristics

The rescaled I-V curves show how the device behaves within the desired operating window. To determine the device's amplification factor (mu), examine the change in drain voltage divided by the change in gate voltage when the drain current is held constant (see **Figure 4**). It can be easily found from the 2SK82's characteristic curves. **Figure 2** shows that mu increases as the drain voltage increases.

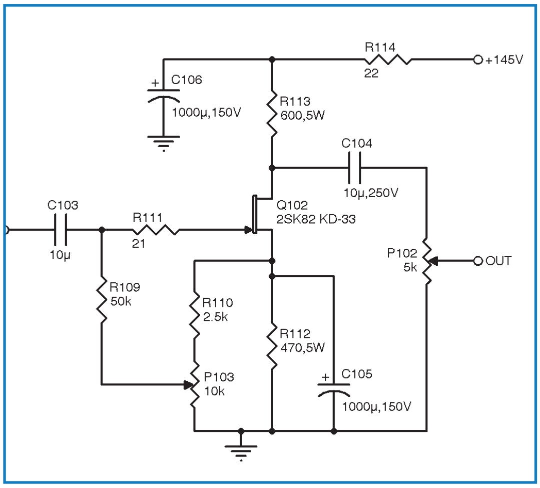

Figure 6: The circuit is a simple common source amplifier.

At around 80 to 90 V and 50 to 60 mA, the mu is approximately 8. This would be difficult to surmise from the curves shown in **Figure 3**, which suggest a mu of 4 or 5, since the horizontal axis only goes to 50 V. A higher amplification factor is necessary for this project, and this opportunity may have escaped my attention if I hadn't rescaled the curves and taken another look.

Another important characteristic is drain resistance, which is the change in drain voltage divided by the change in drain current with the gate-to-source voltage held constant (see **Figure 5**). It is the slope of the line tangent to the curve at the point of interest (e.g., the operating point). The SIT's drain resistance makes it possible to design low-output impedance gain stages without global negative feedback.

Figure 2 also shows that the drain resistance at around 80 to 90 V and 50 to 60 mA is approximately 75 Ω. This is much lower than the plate resistance encountered in a small triode vacuum tube.

SITs, like other transistors and vacuum tubes, exhibit capacitance between their terminals, which if sufficiently high, will negatively impact high-frequency performance.

In my L'Amp design, a SIT power amplifier utilizes the 2SK82, and the effective input capacitance is approximately 2,500 pF. High capacitance isn't uncommon with big-die power devices, and using one in a preamplifier is a worthwhile challenge. The good news is that the 2SK82's input capacitance decreases as the voltage increases across it. Still, at 80 to 90 V and 50 to 60 mA, the capacitance will be about 1,500 pF. This will need to be addressed if the music source's output impedance is too high.

The Basic Circuit

Figure 6 shows a simple common source amplifier. The source pin is tied to ground and the output is taken from the SIT's drain. The common source configuration provides both voltage and current gain. If a music signal is introduced between the SIT's gate and source, the AC voltage varies the AC current from drain to source. It is then converted to voltage across the drain resistor, R113, which provides an amplified copy of the music signal at the output node, high-pass filtered by C104 to remove DC.

To bias this circuit properly, a negative DC voltage must be supplied between the SIT's gate and source to set the flow of current from drain to source. As this bias voltage is made more negative, and the SIT will conduct less until finally current no longer flows, pinching off the SIT.

This circuit uses adjustable self-bias. Self-bias employs a resistor attached from source to ground, which raises the SIT's source by the voltage dropped across this resistor. If the gate is held at some lower voltage or ground, it will become more negative than the source. Here, the bias voltage is developed across R112, and P103's wiper provides an adjustable tap to control the gate-to-source voltage, which in turn controls the DC bias current through the SIT.

The R112's value is chosen by examining the SIT's IV curves and determining the gate-to-source voltage required to set the required idle current and drain voltage. **Figure 2** shows an operating point of 90 V at 50 mA will required around –19 V from gate to source. We'll want to drop a little more than this (e.g., 24 V) across the source resistor to enable some adjustment and variation among parts. Use Ohm's law to find the resistor value (470 Ω was the closest available value):

$$R = \frac{V}{I} = \frac{24\ \text{V}}{0.05\ \text{A}} = 480\ \Omega$$

There's also a large capacitor wired across the source resistor. To understand its purpose first look at the voltage gain without C105:

$$A = \frac{\mu R_D}{R_D + r_D + R_S\,(\mu + 1)} = \frac{8 \times 600}{600 + 75 + 470\,(8 + 1)} = 0.98$$

Where mu is the amplification factor in the operating region, r_D is the drain resistance, R_D is the drain resistor value, and R_S is the source resistor value. Clearly, −0.18 dB doesn't meet our design goal. The gain is drastically reduced because R_S is large compared to R_D, and provides a lot of degenerative feedback. And that's where C105 comes in. By placing an appropriately sized capacitor in parallel with the source resistor, R_S is bypassed at audio frequencies and the calculation is reduced to:

$$A = \frac{\mu R_D}{R_D + r_D} = \frac{8 \times 600}{600 + 75} = 7.11$$

So, now the input signal is amplified 7.11 times or 17 dB. Some or all of the source resistance can be bypassed depending on how much gain is traded for feedback. In this case, there isn't a lot of gain to start with, and the design goal calls for little or no feedback, so just bypass the whole resistance.

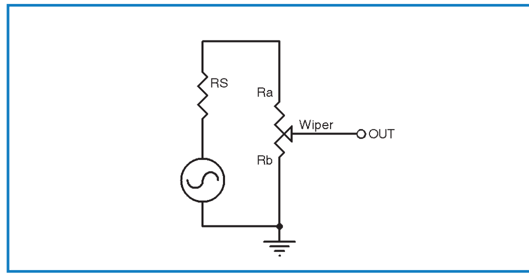

Figure 7: The output impedance is altered by the position of the volume control.

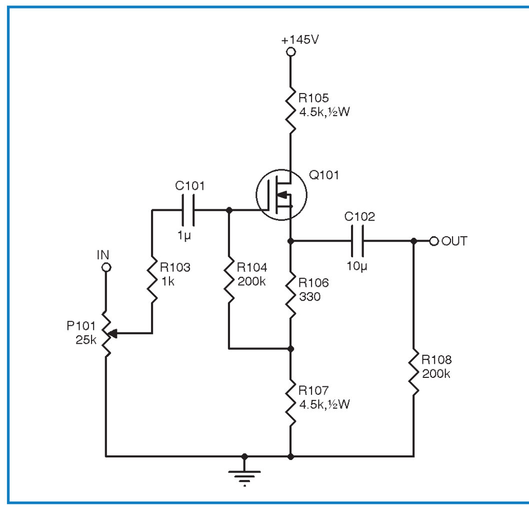

Figure 8: An optional buffer at the input drives the SIT, which provides the voltage gain and low output impedance.

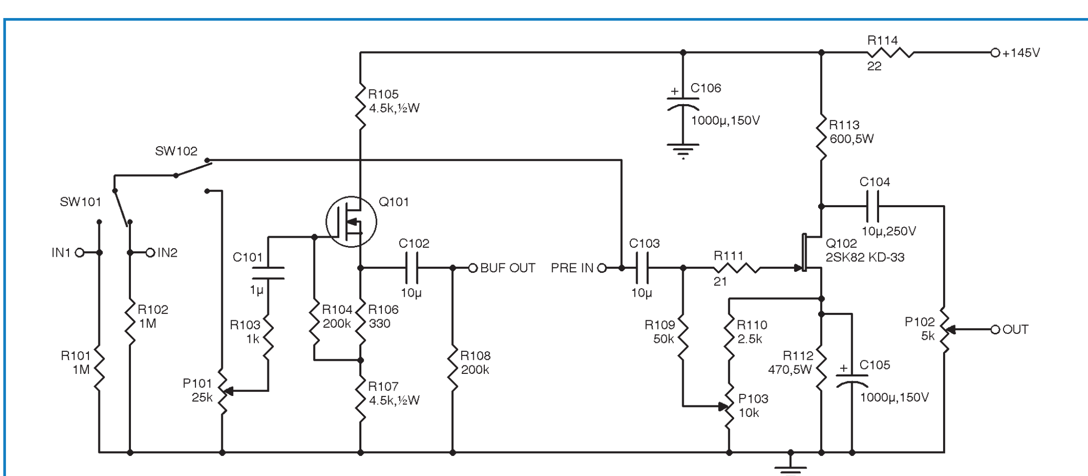

Figure 9: The complete schematic shows the buffer and gain sections with input selection and volume controls.

Photo 1: The LuminAria has a simple control interface.

To calculate the value for the bypass capacitor, use the following formula:

$$C = \frac{1}{2\pi FR}$$

I used 2 Hz for the cutoff frequency. F and R are computed as follows:

$$R = r_S \parallel R_S = (71 \parallel 470) = 62\ \Omega$$

where:

$$r_S = \frac{R_{LOAD} + r_D}{\mu + 1} = \frac{566 + 75}{8 + 1} = 71\ \Omega$$

$$R_{LOAD} = \text{Drain Load} \parallel \text{Driven Stage Load} = (600 \parallel 10{,}000) = 566\ \Omega$$

(I used 10,000 Ω for the driven stage load, assuming that to be the lower limit of what we're likely to encounter.) So:

Photo 2: External jumpers enable the preamplifier sections to be used alone or in cascade.

Parts List

(Resistors are 25 W unless marked otherwise)

Preamplifier (One channel)	
Parts	**Values**
R101, R102	1 MΩ
R103	1 kΩ
R104	200 kΩ
R105, R107	4.5 kΩ, 0.5 W
R106	330 Ω(for 7 to 8mA)
R108	200 kΩ
R109	50 kΩ
R110	2.5 kΩ
R111	21 Ω
R112	470 Ω, 5 W
R113	600 Ω, 5 W
R114	22 Ω
C101	1 µF, 100 V
C102	10 µF. 100 V
C103	10 µF, 100 V
C104	10 µF, 250 V
C105	1,000 µF, 35 V
C106	1,000 µF, 150 V
P101	25 kΩ, Log or Lin
P102	5 kΩ, Log or Lin
P103	10 kΩ, 0.5 W
Q101	DN2540
Q102	2SK82 KD-33

Power Supply (One channel)	
Parts	**Values**
R101	2.5 kΩ
R102	221 Ω
R103	82kΩ, 0.5 W
C101	1,000 µF, 200 V
C102, C103	10 µF, 200 V
D101-D110	12 V, 0.5-W Zener
D111, D112	15 V, 0.5-W Zener
D113	20 V, 0.5-W Zener
D114	Green LED
BR101	Diode bridge
Transformer	2 × 115-to-120-V Secondaries 80+ VA

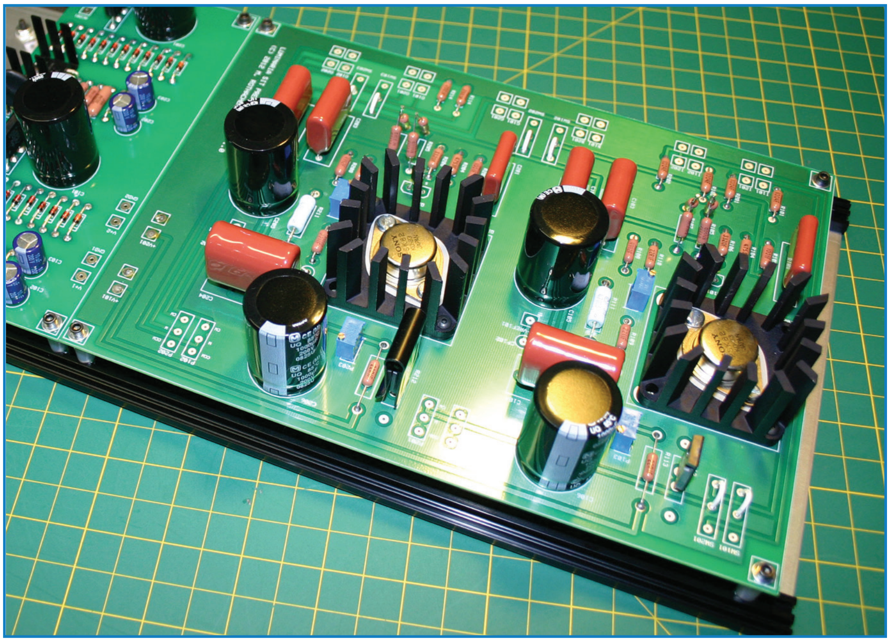

Photo 3: The prototype was built on a PCB.

$$C = \frac{1}{2\pi FR} = \frac{1}{6.28 \times 2 \times 62} = 0.00128\ \text{F}$$

That's 1,280 µF. I settled on 1,000 µF, which was a convenient on-hand value for a 2.6-Hz cutoff.

This circuit's output impedance is the drain load resistor in parallel with the resistance looking into the drain, which is why it is useful to have a low drain resistance.

$$R_D \parallel r_D = 600 \parallel 75 = 67\ \Omega$$

R113 is an important resistor, as it will affect the stage's gain, operating point, distortion, and output impedance. The load line chosen for this stage depends on the design goals. If maximum gain and voltage swing are desired, the load line is chosen to meet those criteria.

In this particular case, R113 was chosen for adequate gain with minimal distortion around 1 V. I arrived at the final value, 600 Ω, using a variable power resistor, which I tweaked while watching the distortion analyzer. The distortion is minimized or otherwise fine-tuned by load line cancellation, where gain variations due to drain current and

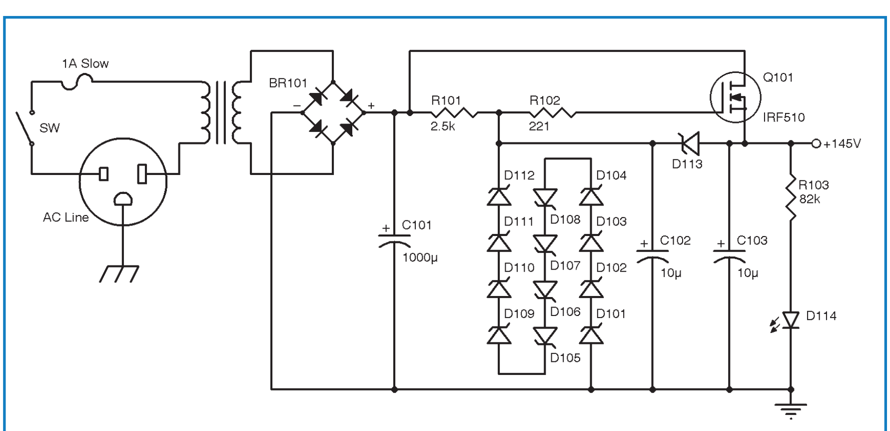

Figure 10: This schematic shows one channel of the power supply.

drain voltage partially cancel each other, often to very good effect.

Ins and Outs

Figure 6 shows the basic preamplifier, which has the volume control potentiometer at its output rather than its input. This enables the preamplifier to look directly into the music source's output impedance, which typically is low. If the volume control potentiometer is instead placed at the input of the circuit, an undesirable high-frequency rolloff may be introduced. This would occur due to the RC filter formed by the SIT's rather high input capacitance and the volume control's output impedance.

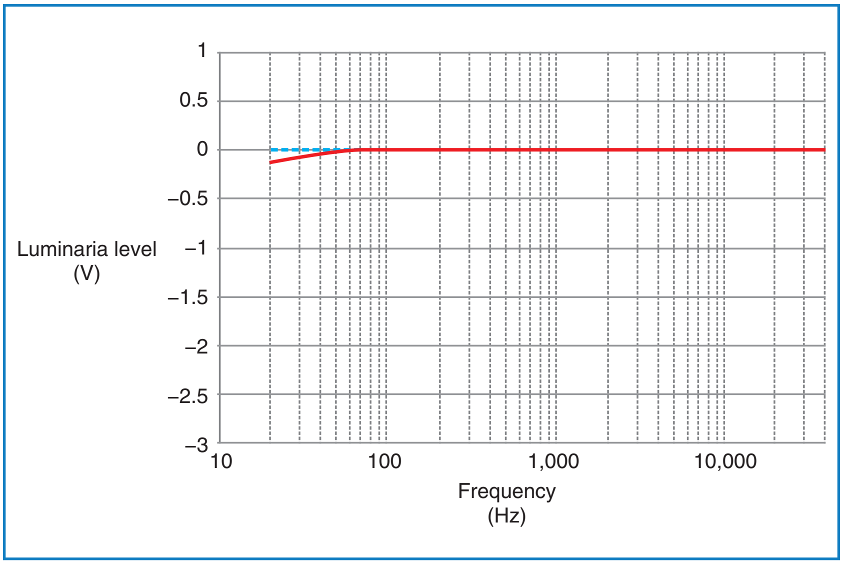

Figure 11: LuminAria's frequency response is shown.

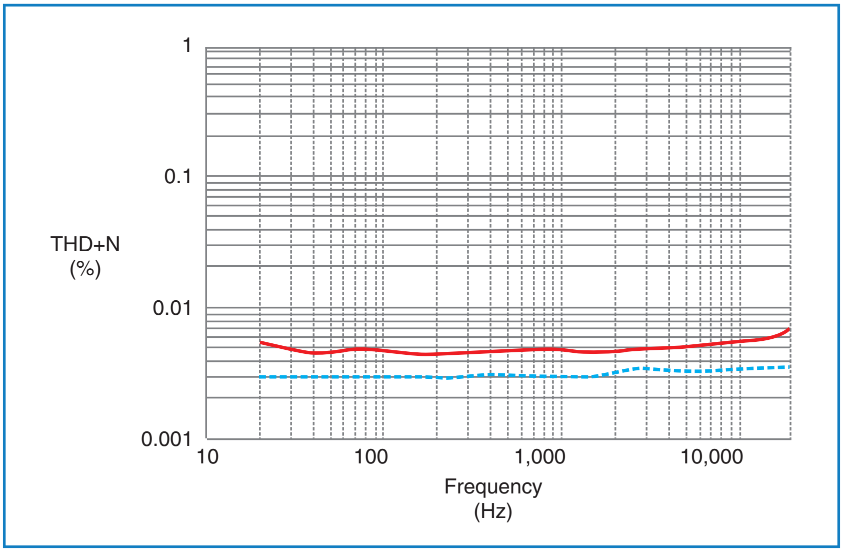

Figure 12: The distortion vs the frequency response is shown at 1 V.

A volume-control potentiometer's output impedance depends on the output impedance of the circuit driving it, the potentiometer's value, and the wiper's position (see **Figure 7**).

$$R_{OUT} = (R_{SOURCE} + R_A) \parallel R_B$$

For example, a 25-kΩ linear volume potentiometer with its wiper at the midpoint, driven by a 100-Ω source, will have a 6,275-Ω output impedance. Assuming R_{SOURCE} is low, the output impedance will always be highest around the resistance midpoint of the potentiometer. With the potentiometer rotated fully counter-clockwise, the output impedance will be equal to R_{SOURCE}, and, when fully clockwise the wiper is grounded and the output impedance is zero.

If this 25-kΩ potentiometer were connected to the basic preamplifier circuit's input, the high-frequency response will be −3 dB at less than 17 kHz when the volume knob is at 12:00, which doesn't meet the requirements. A lower value volume potentiometer could be used, but the source component may not drive the low impedance.

However, with a 5-kΩ volume potentiometer at the output, the output impedance will vary from 0 to 1,500 Ω. At the 9:00 position, a typical (loud) setting, the output impedance will be around 560 Ω if a logarithmic potentiometer is used. If the power amplifier doesn't object to this source impedance range, and the music source can handle the 1,500-pf input capacitance, this basic preamplifier will work. However, something a little more versatile may be preferable for use with a broader range of amplifiers.

Adding an Input Buffer

Most tube and transistor preamplifiers utilize a voltage gain stage coupled to an output buffer stage, which lowers the output impedance to effectively drive the power amplifier. LuminAria flips this around and offers an optional buffer at the input driving the exotic gain device, which provides both the voltage gain and low output impedance (see **Figure 8**).

A buffer stage offers high input impedance and low output impedance. This enables us to add a high-resistance volume control potentiometer at the preamplifier's input while driving the SIT without adversely affecting the high-frequency response. The circuit shown in **Figure 9** is a simple source follower using the Supertex DN2540 depletion MOSFET. The DN2540 doesn't make many appearances in linear amplifiers, but I wanted to give it a try in this 100% negative feedback buffer. This circuit's voltage gain is slightly less than unity (around 0.98):

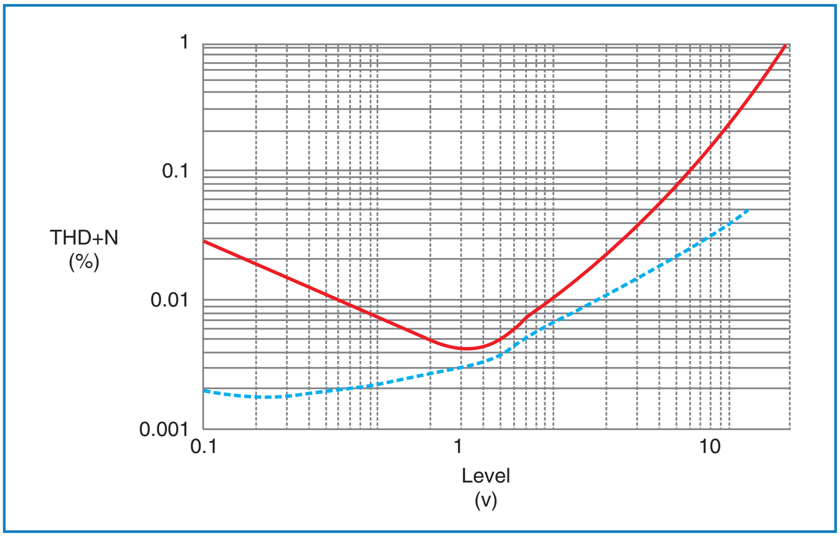

Figure 13: Harmonic distortion and noise are around 0.004% at 1 V.

$$A = \frac{\mu}{\mu + 1} \times \frac{R_S}{(R_S + r_D)} = \frac{4{,}500}{(4{,}500 + 75)} = 0.98$$

This circuit is self-biased by R106. The gate resistor R104 is bootstrapped, which causes the buffer's input impedance to be significantly raised as shown here:

$$r_{INPUT} = \frac{R_G}{1 - A \times \left(\frac{R_L}{R_L + R_K}\right)} = \frac{200{,}000}{1 - 0.98 \times 0.93} = 2.2\ M\Omega$$

The input capacitance is approximately:

$$C_{INPUT} = C_{DG} + (1 - A) \times C_{GS} =$$
$$100\ pF + (1 - 0.98) \times 100\ pF = 102\ pF$$

The output impedance is approximately equal to the MOSFET's inverse transconductance, or more specifically:

$$\frac{R_S}{G_M R_S + 1} = \frac{4{,}500}{0.03 \times 4{,}500 + 1} = 33\ \Omega$$

The high supply voltage enables us to use a higher value for R107, which reduces distortion in addition to raising the input impedance. The result is a pretty simple high-swing buffer with 0.003% THD+N at 1 V, and less than 0.03% THD+N at more than 10 V.

Build Notes

Figure 9 shows the complete schematic for one channel as built. There are just a couple of new parts here. The SW101 is for source selection and the R114 and the C106 provide some additional power supply filtration. The buffer and output sections are not internally wired together. This makes it possible to use the two stages separately, or in cascade by removing or inserting a jumper between the buffer's output RCA and the SIT stage's input RCA (see **Photo 2**). SW102 connects the appropriate stage to the input selection depending on whether or not the jumpers are present.

For the 2SK82, I used grade KD-33, which indicates a certain range of pinch-off voltage. Other grades will have different pinch off voltages and may or may not work properly in the circuit as shown. The SIT must be attached to a suitable heat sink as it will dissipate 5 W or so.

I built my prototype on a PCB (see **Photo 3**). This is not strictly necessary and you could certainly build this circuit point to point. I used linear-type volume controls from PEC, though log potentiometers would provide more fine control. You could use a higher value for P101 if you want to; 50 kΩ would not be unreasonable.

Figure 10 shows one channel of the regulated power supply I used. An isolation-type transformer with 115-to-120-V secondaries rated at 80 VA or more can be utilized to provide the unregulated voltage (around 160 V), which should simplify the parts search.

R101 feeds current through Zener diodes D101–112, which provide a 150-V reference to an N-channel MOSFET voltage follower. The reference voltage minus Q101's gate-to-source voltage appears at the regulator's output filtered by C101–103. D113 prevents Q101's gate-to-source voltage from exceeding the device rating. R102 prevents parasitic oscillation of the MOSFET. R103 and D114 provide the glowing green assurance that the preamplifier is powered on.

There are only a couple of adjustments. R106 is shown as 330 Ω, but it should be sized to give 7 to 8 mA through the MOSFET, or the MOSFET can be selected to provide 7 to 8 mA with a 330-Ω resistor. Once built, adjust the SIT's idle current for 50 to 60 mA with P103. Ideally, use a distortion analyzer or fast Fourier transform (FFT) analysis to reach the final operating point.

Usage and Performance

The LuminAria can be configured a few different ways. When you don't need gain, configure the preamplifier as a buffer with input selection and volume control. For use as a buffer, no jumpers

About the Author

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are installed, the output is taken from the "Buffer Out" RCAs, SW102 is switched to position B, and volume is controlled with P101.

If your music source has an output impedance of a few hundred ohms or less and can source a couple of milliamps, try listening to the SIT by itself. In this configuration, no jumpers are installed, SW102 is switched to the A position, output is taken from the preamplifier output RCAs, and volume is controlled with P102. As previously mentioned, the amplifier's frequency response may be negatively affected by the position of P102 if the input capacitance is very high.

The most versatile configuration cascades both amplifier sections, exploiting the benefits of each. In the cascade configuration, the jumpers are installed, output is taken from the preamplifier outputs, and SW102 is set to position B. Volume is controlled with P101. Set P102 to the fully clockwise position where the output impedance will be 67 Ω, though you can experiment with its setting.

Figure 11 shows the LuminAria's frequency response. The dashed line is the buffer section, while the solid line represents both stages in cascade. We're down 0.15 dB at 20 Hz and flat beyond 40 kHz with a 600-Ω source.

Figure 12 shows THD+N vs frequency response at 1 V. Again, the dashed line is the buffer section, while the solid line represents both stages in cascade. Both sections exhibit distortion performance that's fairly flat across the audio spectrum.

Figure 13 shows THD+N vs output level. Harmonic distortion and noise are around 0.004% at 1 V and remain below 0.01% between 0.4 and 2 V where most of the action will take place.

Performance

The LuminAria was a really fun project, and ultimately, it did make the journey to San Francisco where it was displayed with equipment from audio greats such as Nelson Pass, Wayne Colburn, and many of my DIY friends.

Perhaps you're wondering how it sounds? Well, I will tell you that it has stayed in my equipment rack for six or seven months as of this writing, and I've never been tempted to put my commercial preamplifier back into service.

The LuminAria is a very simple design, but I wouldn't call it a beginner project. The SITs are expensive and ought to be gain matched for best results. It utilizes a high-voltage power supply and the final adjustment requires a distortion or spectrum analyzer.

If you need an unusual preamplifier with a lot of output, low distortion, and low output impedance, perhaps you'll build this one. If you do, I hope you'll agree that it's a neat gadget. There are many ways to make a preamplifier that sounds good and measures well, but this one's unique. Now go build something.

Resources

M. Rothacher, "L'Amp: A Simple SIT Amp," *diyAudio*, 2011, www.diyaudio.com.

N. Pass, "SIT Introduction," *First Watt*, 2011, www.firstwatt.com.

Sources

2SK82 KD-33 Static induction transistors
Acronman | www.circuitdiy.com

DN2540 Depletion MOSFET
Supertex | www.supertex.com