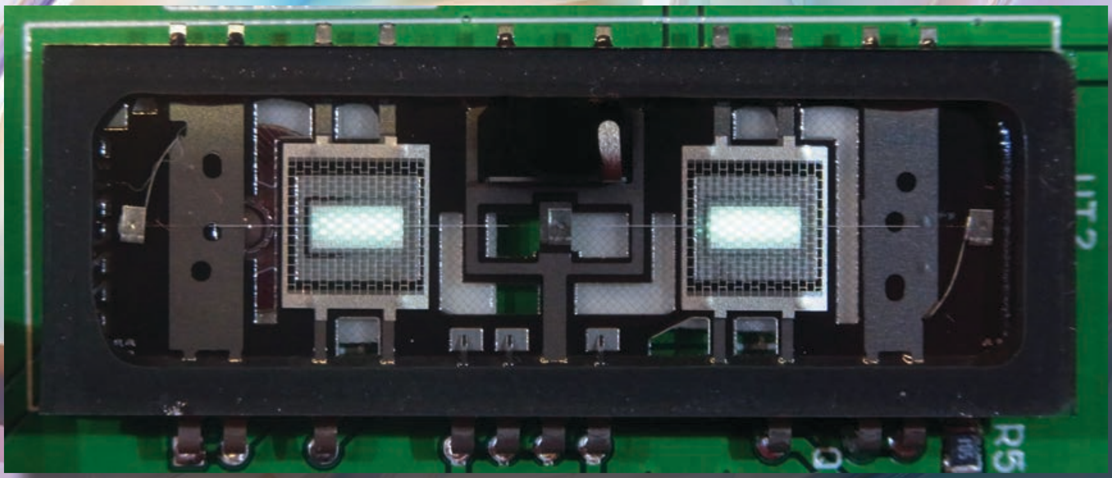
The Korg Nutube



Learn more about the Korg Nutube 6P1—a new miniature, low-power dual directly heated triode device developed by Korg (of musical instrument fame) and Noritake Itron, a Japanese manufacturer of vacuum fluorescent displays. Although it is a true directly heated triode, it is manufactured differently than traditional vacuum tubes, which gives it some unique attributes.

By
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(United States)

Electrically, the Nutube 6P1 is somewhat comparable to the battery-powered "hearing aid" tubes. It operates on very low voltages—the filament is rated at 700 mV, and plate supply voltages can be as low as 5 V.

Nutube 6P1 Typical Characteristics (each triode)		
Filament voltage	Vf	0.7V
Filament current	If	17 mA
Plate voltage	Va	12 V
Grid voltage	Vg	+2 V
Plate current	Ia	32 µA
Amplification factor	µ (mu)	14.5
Transconductance	gm	54 µS (54 µA/V)
Plate resistance	Rp	330 kΩ
Grid current	Ig	6 µA
Maximum Ratings:		
Filament voltage	Vf	0.8 V
Plate voltage	Va	80 V
Plate dissipation	Pa	1.7 mW

Table 1: These are the Nutube 6P1's electrical characteristics.

Electrical Characteristics

The Nutube is a low power device—the filament consumes only 12 mW of power per triode, and the plate dissipation is rated at only 1.7 mW. The consequence of such low-power operation is that, compared to most traditional vacuum tubes, it also has low transconductance (gm). Refer to **Table 1** for a summary of the 6P1's electrical specifications.

Even though the numbers are a bit different than a common tube (e.g. the 12AX7), a first look at the plate characteristic curves will seem familiar (see **Figure 1**). The curves are typical for a triode and are quite linear. However, when selecting an operating point and load line, you must observe the maximum plate dissipation and maximum permitted plate voltage, which significantly constrains operation. Also notable is the fact that to get much of an output signal with a low plate voltage, you must operate the grid in the positive region—Class A2.

Since much of the Nutube's advantage is its ability to operate on low-voltage power supplies, most applications will utilize a positive grid bias. This means that some grid current will flow, and a somewhat low impedance source (e.g., a source follower) must be used to drive the grid.

Figure 2 shows the grid current. You can see that the grid current, although only tens of microamps, is significant when compared with the low plate current.

Mechanical and Physical Attributes

The Nutube is manufactured by Noritake Itron in Japan, using a process similar to the one used to make vacuum fluorescent displays. It is, in fact, a one-pixel vacuum fluorescent display (VFD) device. The plate is coated with a phosphor just like a VFD, and it glows a blueish-white color when plate current is flowing.

A close look at a 6P1 triode shows a fine coated wire running across the device (see **Photo 1**). This is the filament. Even though it is heated enough to emit electrons, it does not get hot enough to show a visible glow. Below the filament is a fine, open mesh—this is the grid. Below that is a metal plate with the phosphor (glowing) applied—this is the plate. Two triodes are packaged together into one glass package, which is again borrowed from VFD manufacturing. It looks a bit like an old 40-pin DIP IC package, but only has pins along one edge (see **Photo 2**).

The two filaments share a common center terminal. In most applications, this terminal is at ground potential. Because of this, certain circuits—such as cathode followers or differential amplifiers—can be more difficult to implement, since they would require a floating filament supply.

One notable side effect of the construction is that the filament wire, under tension, is a lot like a piano string—when subjected to a shock or mechanical impact, it vibrates at an audible frequency (5 kHz or so). This microphonic behavior seems identical to that of the sub-miniature battery tubes and could cause problems when the Nutube is used in low signal applications. In some cases, it might be desirable to mechanically isolate or shock mount the tube.

The package is a glass sandwich, 45 mm × 16 mm, and is designed to mount to a PCB with pins spaced on 2 mm centers (see **Figure 3**). A small metal disc on the back of the package is used to seal the port where the air is exhausted.

Reference and Example Circuits

The basic application circuit provided by Korg uses simple JFET source followers to buffer the signal in and out of the Nutube (see **Figure 4**). An input buffer is used to support the relatively low impedance looking into the grid and bias source. The output buffer is needed to drive anything but high impedance loads due to the low transconductance and high plate resistance of the tube.

This circuit is intended to operate from a single power supply between about 5 V to 30 V, plus it

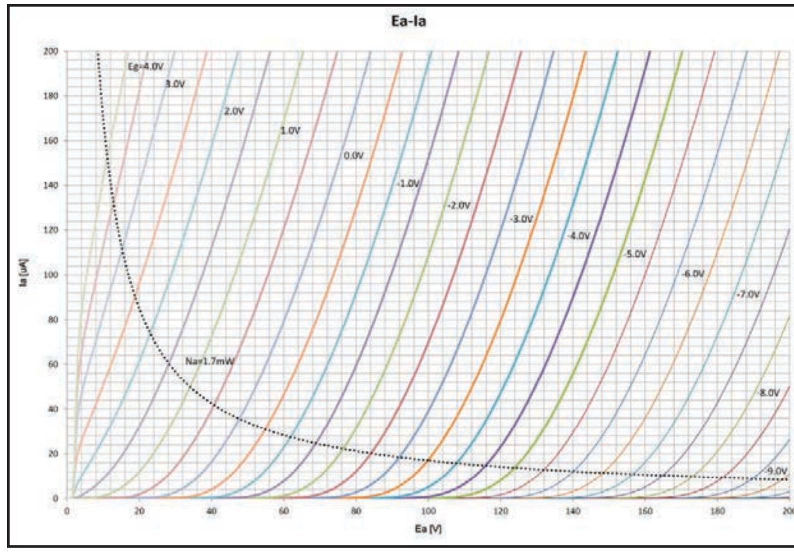

Figure 1: The curves are typical for a triode and quite linear.

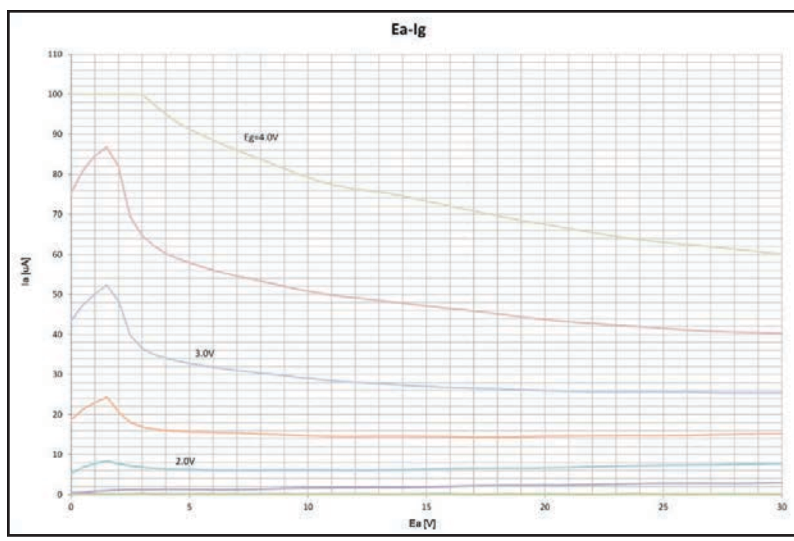

Figure 2: The grid current is significant when compared with the low plate current.

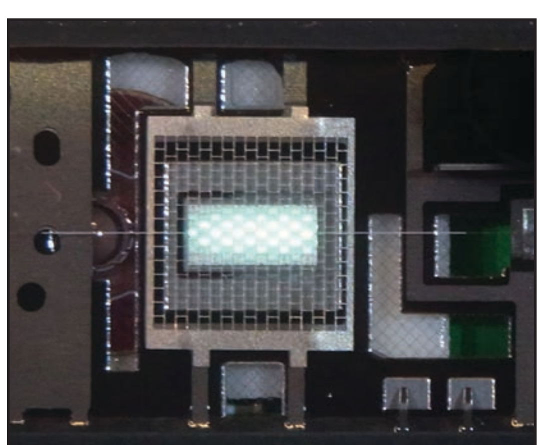

Photo 1: The 6P1 triode has a fine coated wire running across the device.

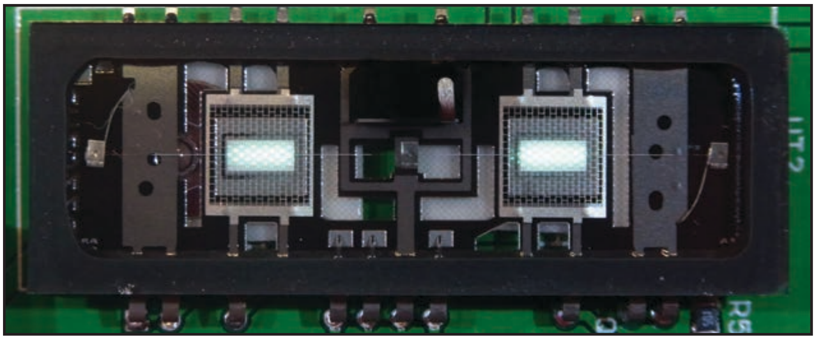

Photo 2: The Nutube resembles an old 40-pin DIP IC package, but only has pins along one edge.

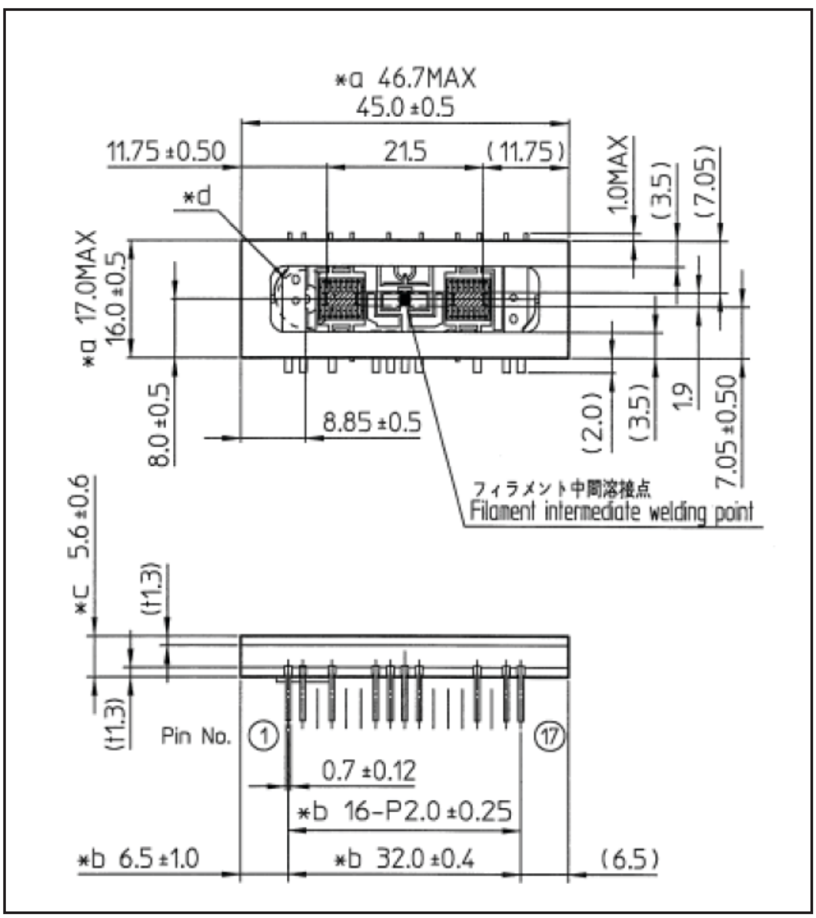

Figure 3: The package measures 45 mm × 16 mm and is designed to mount to a PCB, with pins spaced on 2 mm centers.

About the Author

Pete Millett is an electrical engineer, currently employed as a Technical Marketing Engineer at a semiconductor company, where he defines and supports mixed-signal power ICs. Previously, he worked as a board-level hardware design engineer in the computer and consumer electronics industries for more than 30 years. The design and construction of vacuum tube audio equipment has been a hobby of his for many years.

needs a regulated 3.3 V supply, typically from an low dropout (LDO) regulator. Bias is adjustable from 0 to +3.3 V. To support the grid current, a relatively low value resistor (33 kΩ) is used to provide DC bias to the grid. This mandates that a large (10 µF) coupling capacitor be used to couple the audio signal. There is no doubt there could be some bias shift with signal level in this arrangement but with the values shown, it doesn't appear to be significant. Filament power is obtained from the 3.3 V supply with a dropping resistor.

Figure 5 shows another example. In this circuit, ±18 V supplies are used, as well as a higher voltage B+ voltage for the plate (in this case, about 75 V). Both triode sections are connected in parallel, to increase gm and lower the noise level. A DC-coupled JFET follower is used to directly drive the grid at zero bias, and an op-amp is used to buffer the output.

I also used this as a gain stage in the Apex Sangaku headphone amplifier. Note that an op-amp with low input current offset and noise is needed, as a large resistor (1 MΩ in this case) is necessary at the op-amp input due to the 6P1's high Rp.

Audio Performance

As with any vacuum tube, the audio performance—gain and distortion in particular—are dependent on the circuit implementation. Bias point and plate loading make enormous differences in the performance of an amplifier stage.

I ran some tests using the Korg application circuit, at the recommended bias and plate load, to determine the audio performance. All the tests were run with a grid bias voltage of +2.5 V, and a plate load resistance of 330 kΩ. With a single +12 V supply, the circuit provided a gain of about 2.6 times. With 0.5 V RMS in, and 1.35 V RMS out, total harmonic distortion (THD) was around 1%. The THD increases with the level as one would expect.

In **Figure 6**, the horizontal axis is the input voltage. The green line shows the THD, read on the left scale. The yellow line shows the output voltage, read on the right scale. You can see the compression of the waveform at higher levels, causing the yellow trace to bend downward. The THD reaches 5% at about 3.1 V out. At this operating point, with 0.5 V RMS input, a Fast Fourier Transform (FFT) graph shows that the second and third harmonic distortion products were nearly equal in level at -40 dB, with dropping levels for higher order products (**see Figure 7**).

Using the same operating point and load, things greatly improve at a higher supply voltage. **Figure 8** shows the same circuit running from 24 V. You can see that the gain has increased to about 3.5 times. THD is lower, with 0.7% at 0.5 V in and 1.8 V out.

A 5% THD isn't reached until the output reaches 6.5 V RMS. The FFT at 24 V shows that the second harmonic product has dropped, and now the third is the highest, at about -43 dB (see **Figure 9**).

By changing the bias and/or plate load, you can tune the harmonics however you want. A small change in bias will change the relative levels of the second- and third-order products. Negative feedback can also be employed to trade lower gain for lower distortion.

Applications

The Nutube 6P1 is intended to be used in various audio circuits, mostly in musical instrument applications. Its low power requirements enable its

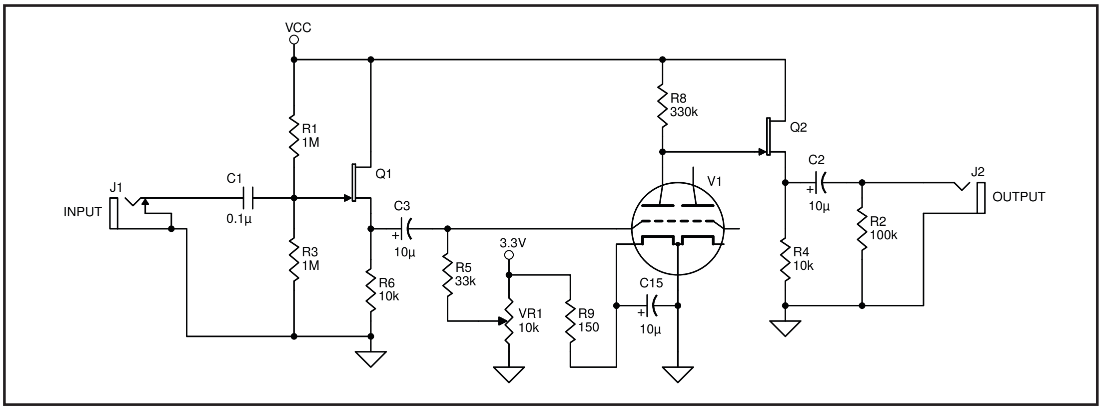

Figure 4: The Korg application circuit uses simple JFET source followers to buffer the signal in and out of the Nutube.

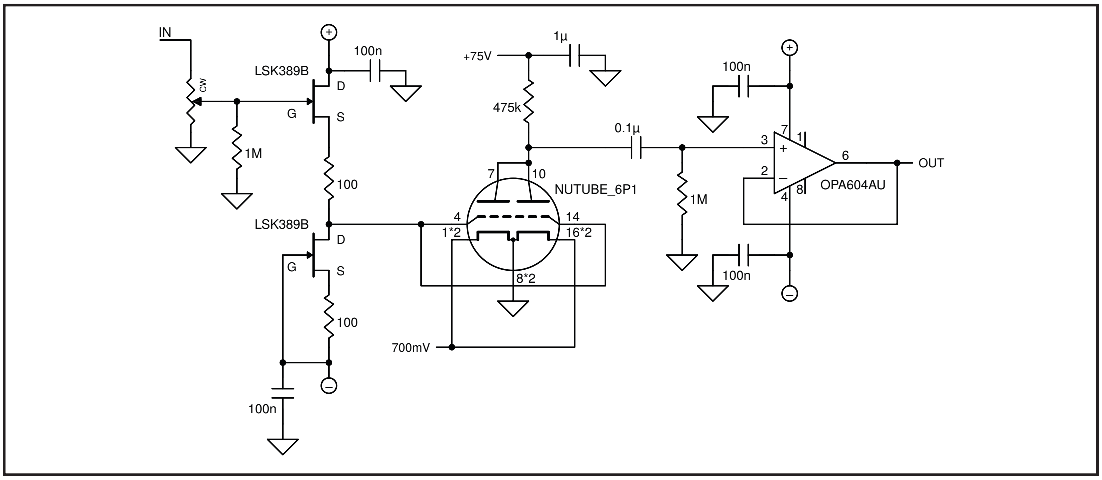

Figure 5: This is an example of a split-supply application.

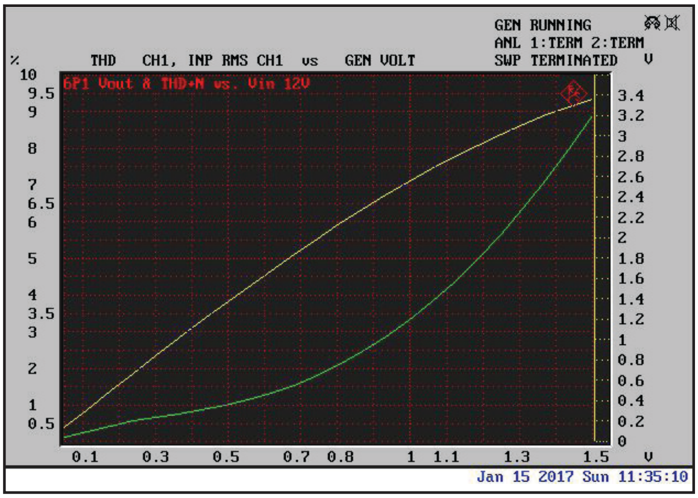

Figure 6: With 12 V gain and distortion, the THD increases with the level.

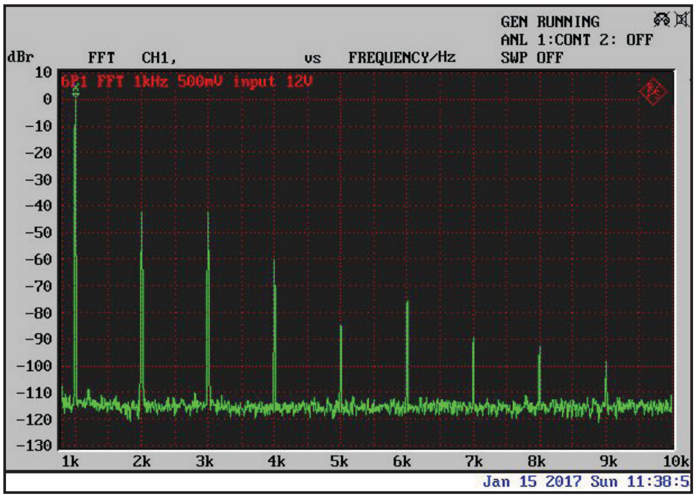

Figure 7: At this operating point, a Fast Fourier Transform (FFT) shows that the second and third harmonic distortion products were nearly equal in level at -40 dB, with dropping levels for higher order products.

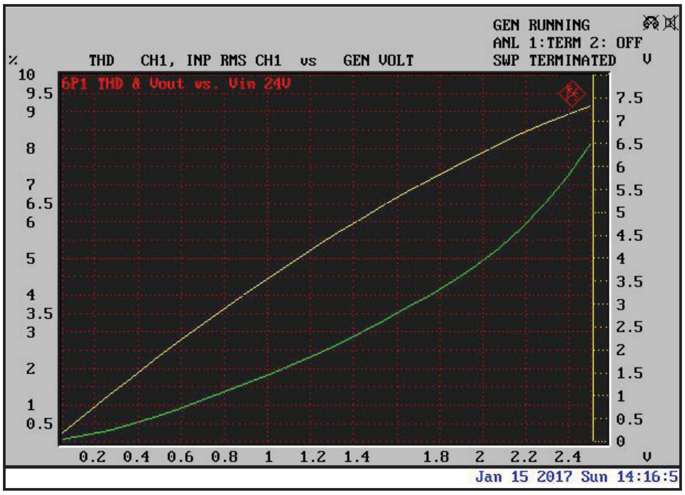

Figure 8: Using the same operating point and load, things improve considerably at a higher supply voltage. Here is the same circuit running from 24 V.

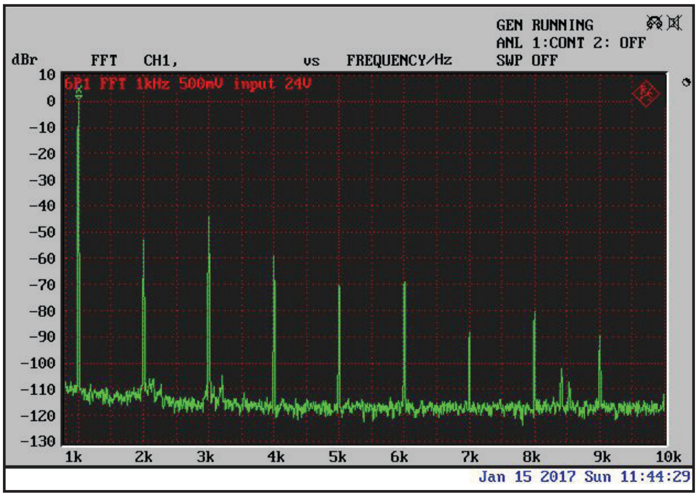

Figure 9: The FFT at 24 V shows that the second harmonic product has dropped, and now the third is the highest, at about -43 dB.

use in battery-powered systems, ideal for a product such as a guitar effects pedal. However, due to its low gm and correspondingly high noise, it is difficult to use in low-level applications (e.g., the input stages of microphone or phono preamps). In some cases, the Nutube can also find use in hi-fi audio equipment.

As you might conclude, based on the audio performance measurements, I view the Nutube not so much as an active amplifying device as a signal processing element. Yes, it does provide voltage gain—but if accurate voltage gain is your goal, you are much better served by using other devices, both tube and solid state.

In a guitar amplifier, it can be used to provide distortion similar to that of a conventional tube, with much lower voltage and power requirements. In hi-fi, it can be used to emulate the harmonic characteristics of single-ended triode power amplifiers. Not everybody's "cup of tea" to be sure, but it opens up some interesting possibilities.

As an experiment, I designed and built a hybrid amplifier using the Nutube 6P1 in conjunction with a self-oscillating Class-D amplifier IC, the MP7770 from Monolithic Power Systems (see **Photo 3**). This combination yields about 50 W output power, and harmonically, it is much like a large single-ended triode amplifier. It runs on a single 28 V power supply and each channel occupies only a few square inches of PCB space, certainly smaller and much less expensive than a big tube amplifier.

In this amplifier, I set the MP7770 Class-D circuit up for slightly lower gain than it would normally have and used the Nutube 6P1 as an input stage, feeding a JFET phase splitter. Since it is powered from a single 28 V supply, I used a circuit similar to the Korg reference circuit, with a couple of differences. I connected both triodes in parallel, and also added some plate-to-grid feedback. With a positive grid bias, it's easy to add feedback by simply adding a resistor (see **Figure 10**).

This type of feedback stabilizes both the DC operating point and reduces distortion. With this arrangement, it is easy to tune the stage to have whatever gain and harmonic profile you want, as you can vary the plate load resistor, bias voltage, and negative feedback.

The MP7770 amplifier has quite low distortion by itself (I measured about 0.02% at 1 W), but as with most Class-D amplifiers, it does have low-level harmonics that extend to many times the fundamental. A theory of harmonic masking says that

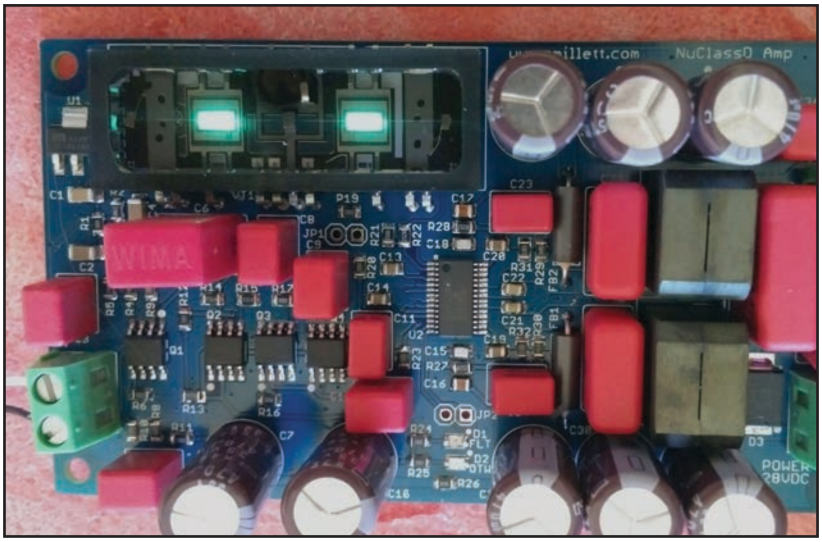

Photo 3: As an experiment, I designed and built a hybrid amplifier using the Nutube 6P1 in conjunction with a self-oscillating Class-D amplifier IC, the MP7770 from Monolithic Power Systems.

higher amplitude, lower-order harmonics mask the audibility of higher-order harmonics. So the hope here was that the sound of the resulting hybrid amplifier will be dominated by the Nutube input stage, with its relatively large amounts of low-order (mostly second harmonic) distortion. It does, in fact, measure similarly to a large single-ended tube amplifier. People who have heard it agree that it does indeed sound like a single-ended triode amplifier but has improved damping due to the low output impedance of the Class-D circuit.

Conclusions

Though it won't make conventional small tubes (e.g., the 12AX7) obsolete, the Korg Nutube can be a useful device for audio DIYers. I expect it will find many uses in musical instrument amps, guitar effects, and hi-fi equipment. Its low power and low operating voltage makes it a natural for experimentation by those who are not familiar or comfortable working with the high voltages typically used with tube circuits.

For more information, visit www.korgNutube.com. The Nutube 6P1 and supporting evaluation hardware is available from www.Nutube.us.

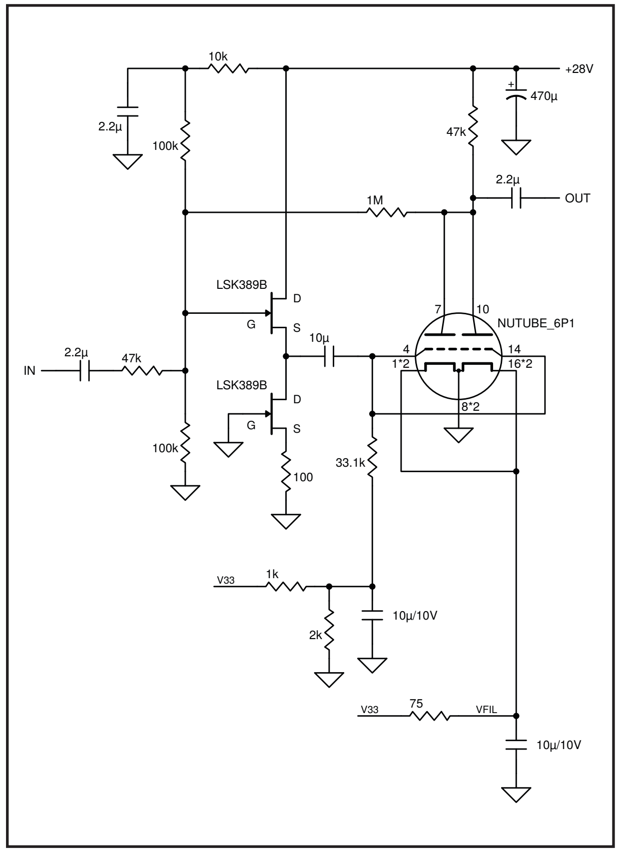

Figure 10: I set the MP7770 Class-D circuit up for slightly lower gain than it would normally have and used the Nutube 6P1 as an input stage, feeding a JFET phase splitter.