

Burning Amp 2022 – Simple DIY SIT Power Amplifiers

By Nelson Pass

It is perhaps surprising to note that the Static Induction transistor (SIT) was invented in Japan in 1950 and is one of the oldest semiconductors, preceding even the Jfet and Mosfet. In the 1970's it was popularized by Yamaha and Sony under the name VFETs and was found in amplifier circuits by these companies into the 1980's. After that time, VFETs faded from the mass market but still enjoyed a high reputation among sophisticated audiophiles.

SIT transistors continued to be manufactured for industrial use due to their unique characteristics, primarily by the Japanese company Tokin. Unfortunately Tokin ceased production of these parts some years ago. Meanwhile eleven years ago, in a conversation with the R&D head at SemiSouth, I was offered the opportunity to have a custom batch of SIT transistors made of Silicon Carbide, and in spite of the enormous cost I jumped at the opportunity.

Some months later found myself in possession of nearly 2000 transistors which were employed in a series of three amplifiers, creatively named SIT-1, SIT-2 and SIT-3. At this time I have used up my supply, and unfortunately SemiSouth ceased operations after my initial purchase.

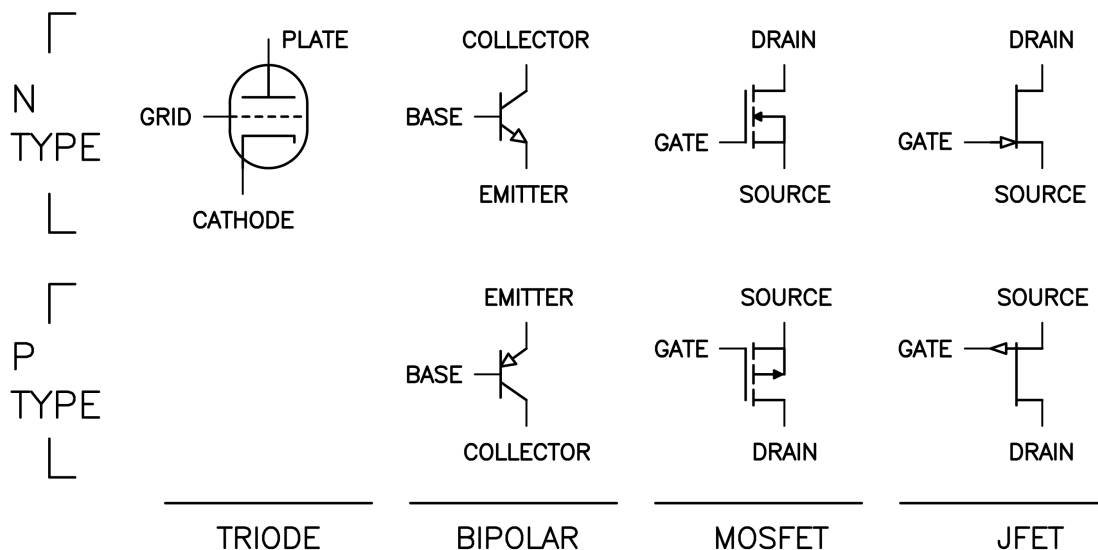
Later I discovered sources of the Sony Vfet transistors and also SIT devices made by Tokin in the form of “New Old Stock” (NOS) and began playing with those parts as well. I employed the Sony parts in the “Sony 40th Anniversary Commemorative Amplifier” and also in the DIY Sony VFET project, a single-ended Class A design kit offered by DiyAudio.com.

I also began acquiring inventory of the Tokin 2SK180, 2SK182es and THF-51s and began exploring designs based on these large industrial grade SITs. A little over a year ago I opened a thread on diyAudio.com titled “While They Last...”, advising DIYers to obtain what remains of these transistors for use in DIY audio power amplifiers, promising to develop some designs for them. Eleven hundred posts and 160,000 views later, this is the follow up. As of this writing you can still get these Tokin parts on Ebay from reliable seller Watanabetomoaki, although the price continues to climb.

I am here to explain why you might want these parts and the basics of how you can employ them to build high quality audio power amplifiers.

The Basics of Gain Devices

I would like to start with a review of the basic gain devices we use so as to highlight their similarities and differences. Here is a chart showing a Triode tube and six different transistor types. They all have three pins that perform similar functions. In the case of the Triode we have the Plate, the Cathode and the Grid:



For Bipolar transistor the Collector, Emitter and Base pins are the corresponding pins. For Field Effect Transistors (FETs) we have the Drain, Source and Gate.

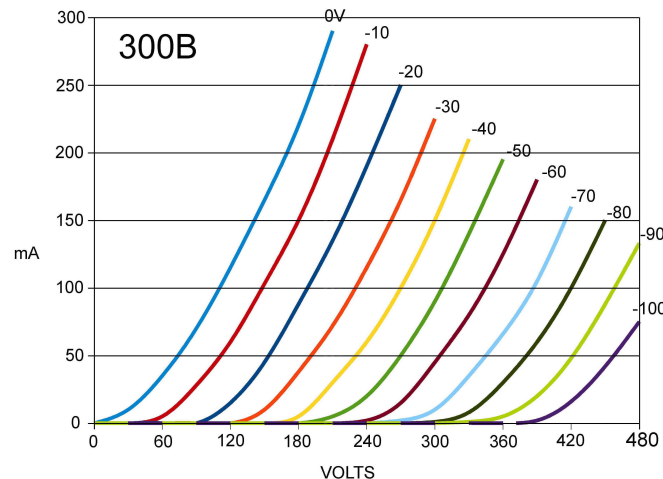
For tubes the current flowing from the Plate to the Cathode is controlled by the voltage between the Grid and Cathode. As the Grid voltage goes positive more current is allowed to flow Plate to Cathode. Similarly for the FETs, the current is controlled by the Gate to Source voltage. The Bipolar transistor the Collector to Emitter current is controlled by a smaller current flowing Base to Emitter.

You will notice that the P type devices are inverted from the N types. The same ideas apply except that the voltage and current polarities of the P are inverted. Tubes of the P type are likely found in an antimatter universe.

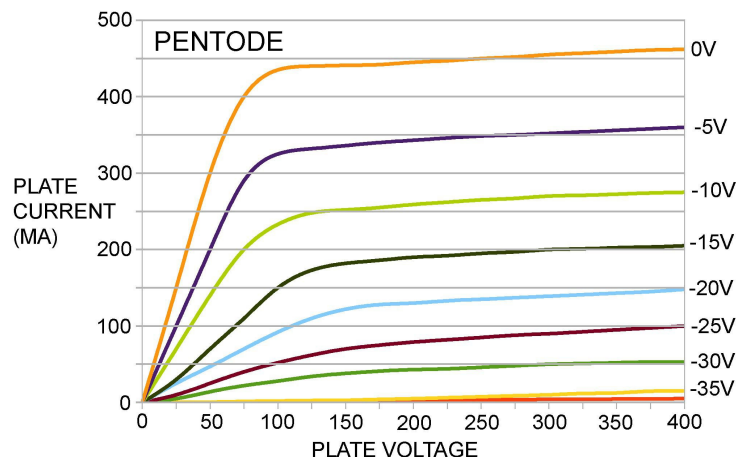
To appreciate the particular charm of SIT transistors we want to know that the current through these devices is not only a function of the control voltages but also the voltage across the whole device. For example the Triode tube's current is also dependent on the Plate to Cathode voltage - as this voltage increases the current increases. This is true of all these devices to some extent.

Following are a bunch of curves illustrating important point.

Here we have a graphic of the curves of a Triode, this case the venerable 300B. The horizontal axis is the Plate to Cathode voltage, and the vertical axis is the current flowing from Plate to Cathode. You can see a family of curves representing the behavior of the tube for eleven different Grid to Cathode voltages. Of importance here is types of curves (concave vs convex) and the degree to which the current varies with Plate to Cathode voltage.



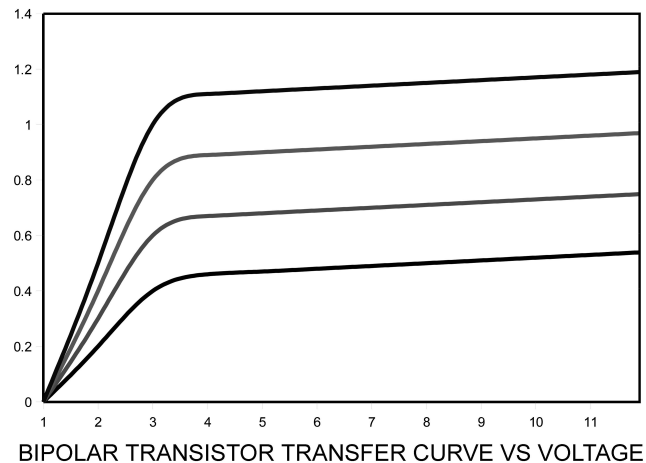
In tubes this variation is due to what is known as Plate resistance. This character is particularly important to the performance of Triodes and SITs. Here you see the same sort of curve for a different type of tube, a Pentode.



It has a much higher Plate resistance than the Triode due to a different arrangement with additional grid elements. You can see the difference in the flattening of the curves, where there is less change with the Plate voltage.

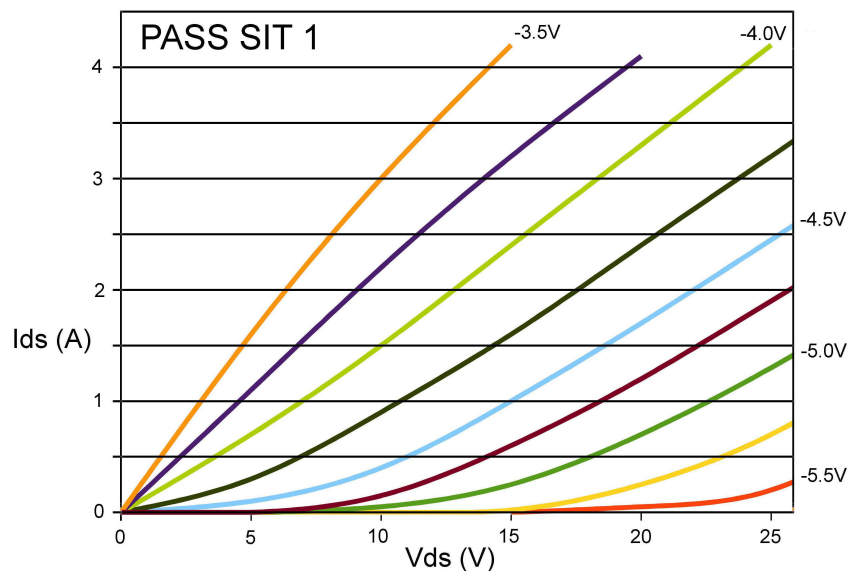
Also the curves have a convex shape instead of concave. This has advantages in many applications, although some audiophiles prefer the sound of Triodes.

Here is the plot for a Bipolar transistor. It is similar to the Pentode, with convex flattened curves and a high impedance characteristic.



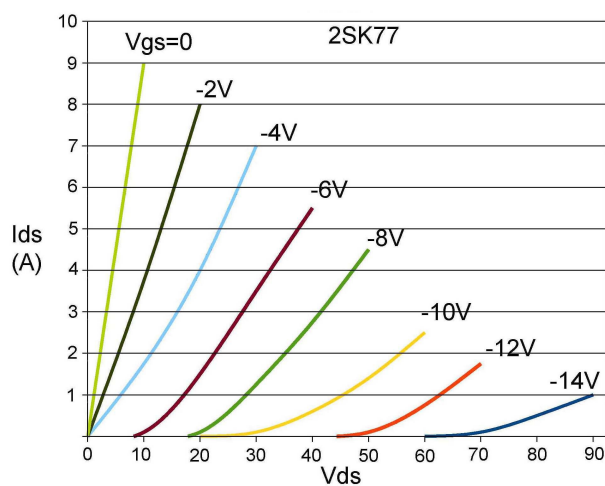
Below the curves for a Mosfet, similar to the Pentode and Bipolar. These gain devices all tend to ignore the effects voltage variations across the power pins. This is often a big advantage over Triodes and SITs, but it limits the kind of easy manipulation of the character that comes with those parts.

At last we come to the curves for a SIT-1 transistor. The Drain impedance is much lower than other transistors, seen by the higher slopes of the curves and we also note that the curves have a concave shape like the Triode.



Both the Triode and SIT have a somewhat “square law” character in both the Transconductance and the Drain impedance. If you run square law curves in opposition to each other, it is possible to have these two nonlinear behaviors cancel into a more linear result. This requires only the proper choice of a load line, which involves specific bias current, voltage and load. As the audio signal moves through the load line, the distortion can be inherently canceled.

We also have the curves for the 2SK77B, an updated version of the original Yamaha 2SK77 VFET. It has higher current, high voltage gain and power.



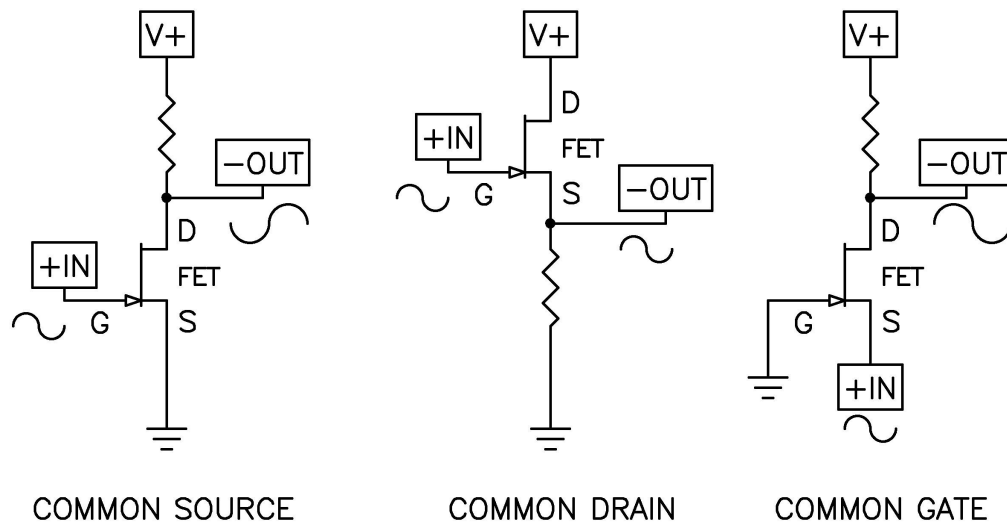
Here is a chart of other Tokin SITs and their ratings:

Term Model	Storage Temp. range	Gate-to-Source Voltage	Gate-to-Drain Voltage	Drain Current	Total Power-Diss. capability	Trans- ist. Gain	Cut-Off Frequency	Drain-to-Source ON Resistance	Turn-On Time	Turn-Off Time						
2SK180	- 50 ~ + 150°C	70 V	600 V	20 A	300 W	15*	10 MHz	1.5Ω max.	200 ns*	250 ns*						
2SK181			800 V					2Ω max.								
2SK182E			600 V	60 A	500 W	20*	10 MHz*	1.0Ω max.	250 ns*	300 ns*						
2SK183E			800 V					1.5Ω max.								
2SK183HE			1200 V													
2SK183VE			1500 V	60 A	1000 W	15*	10 MHz*	1.0Ω max.	250 ns*	300 ns*						
2SK182			600 V					1.5Ω max.								
2SK183			800 V													
2SK183H			1200 V					1.5Ω max.								
2SK183V			1500 V			20*										
TS300				50 V	600 V	200 A	3000 W	15*	7 MHz*	0.3Ω max.	350 ns*	350 ns*				
TS300H					1200 V	180 A				0.5Ω max.						
TS300V					1500 V								20*			
THF-50	450 V	30 A			400 W	15*	50 MHz*	0.6Ω max.	50 ns* max.	50 ns* max.						
THF-51								600 V			0.7Ω max.					
THF-52								800 V			1.0Ω max.					
THF-53								1000 V			1.2 Ω max.					
TM II-M	- 50 ~ + 125°C	70 V			600 V	60 A	500 W × 2	15*	10 MHz*	1.0Ω max.	250 ns*	300 ns*				
TM II-N					800 V					1.5Ω max.						
TM II-H					1200 V											
TM II-V					1500 V			20*								

The 2SK180 is rated at 600 volts, 20 amps and 300 watts, which is pretty hefty, but the THF-51s is 600 volts, 30 amps and 400 watts. The 2SK182es is more at 600 volts, 60 amps and 500 watts and the TS300 tops out at 1200 volts, 200 amps and 3000 watts.

OPERATING MODES

Here we are with some remarkable parts, and we want to play with them. Shown here are three basic operating arrangements:



Common Source is where the signal goes in the Gate and develops voltage and current at the Drain. It inverts the phase of the signal in the process.

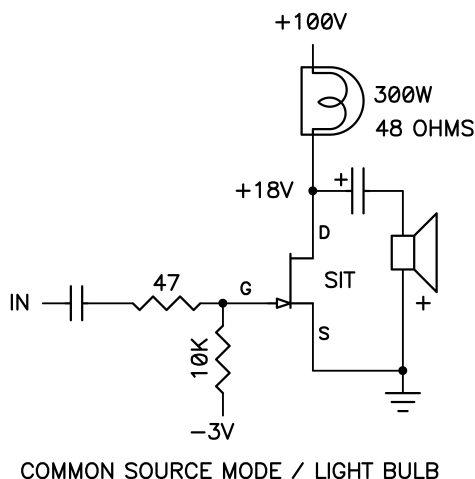
Common Drain mode, also known as a follower, does not amplify voltage, it just delivers current without phase inversion

Common Gate has no current gain, but it can deliver voltage amplification, again with no phase inversion.

All three modes are routinely seen in audio circuits, but we are going to consider just two of them here, Common Source and Common Drain.

The characteristics of SITs make them uncommonly useful in simple audio amplifiers, and we will look at their performance as power amplifiers operating in single-ended Class A without negative feedback. First we will look at Common Source operation.

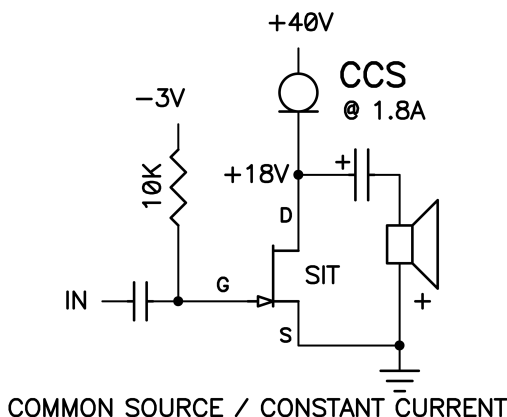
Because the SIT can deliver some gain with a high input impedance and a fairly low output impedance with reasonably low distortion it can be used in some very simple amplifiers. Here is an amplifier consisting of an SIT, two power supplies, two resistors and two capacitors.



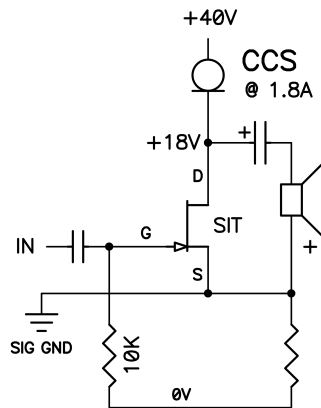
The signal goes into the Gate and comes out the Drain. The capacitors are there to block DC to the signal source and the loudspeaker, the 47 ohm resistor stabilizes the circuit at very high frequencies and the 10K resistor delivers approximately -3V bias to the Gate which sets the operating point. Because the circuit inverts signal phase, the speaker + is connected to circuit ground.

The result is an amplifier that performs nicely into an efficient loudspeaker. On the downside, it puts out slightly more than 5 watts at a cost of 170 watts of consumption, with 30 watts dissipation in the SIT and the rest in the bulb. On the upside, it has a pleasing sound and makes a great conversation piece.

Here the light bulb is replaced by an active constant current source at 1.8 amps. It delivers pretty much the same performance, but dissipates only 72 watts.

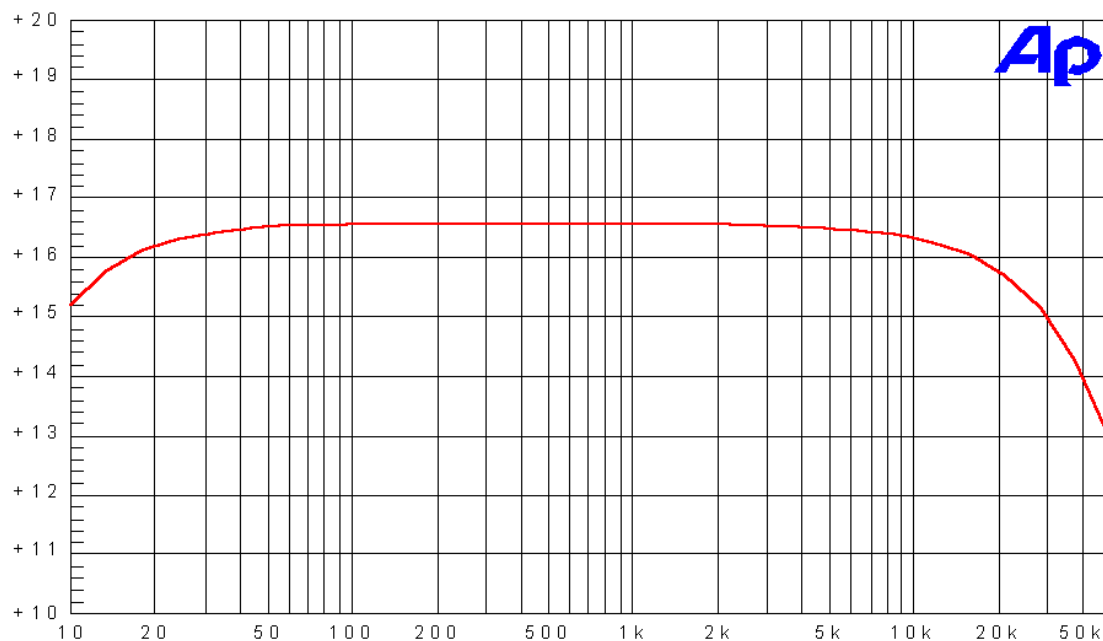


Another variation which eliminates the need for a separate supply for the bias voltage uses a resistor which attaches between the Source pin and what used to be Ground to generate the bias voltage. At 1.8 amps, something less than 2 ohms will likely do the job. A new input signal ground is formed, and is separate from output ground, which you may recall is attached to the positive terminal of the speaker.



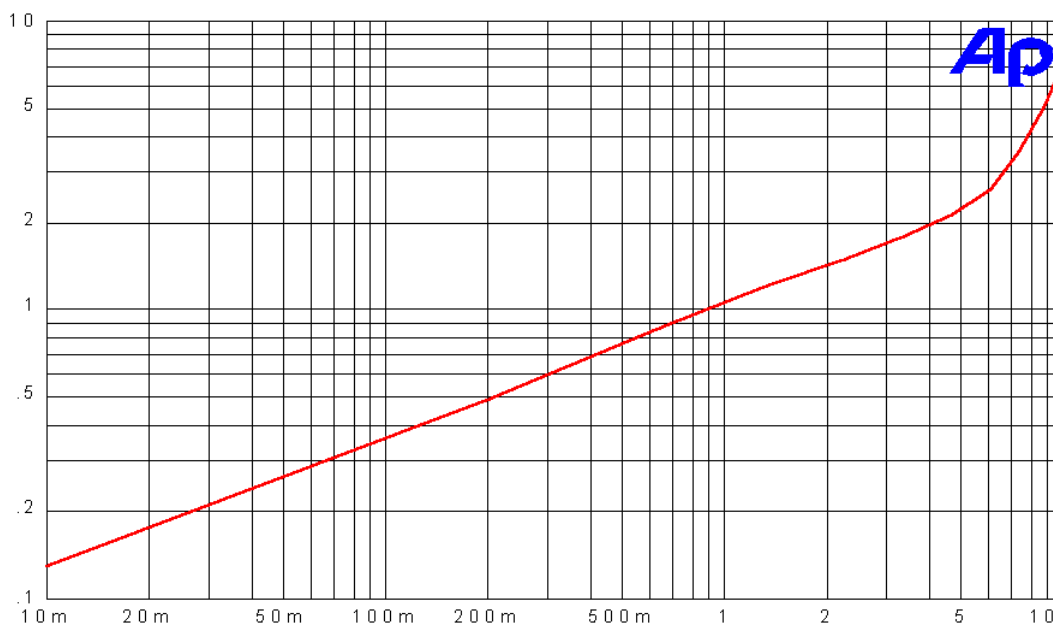
COMMON SOURCE / CONSTANT CURRENT
WITH PASSIVE BIAS CIRCUIT

All three of these circuits give approximately the same performance. Here the operating point is selected not for lowest possible distortion but for distortion where a negative phase 2nd harmonic component is dominant, as this appears to be the most subjectively popular setting. However you can set it as you please. Here you see the gain response of the circuit driven by a 50 ohm source and an 8 ohm load.



THF51S COMMON SOURCE FREQUENCY RESPONSE

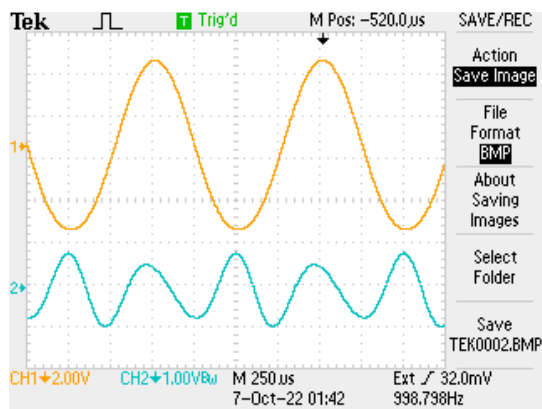
Remarkably, the performance is also very similar across the range of the SIT-1, 2SK180, 2SK182es and THF-51s, so I am only going to show one set of curves which are typical. The 2SK180es has a bit more gain but the THF-51 is a bit faster, and so on. Here is the distortion vs power into 8 ohms. The damping factor for 8 ohms comes in at about 3 or 4.



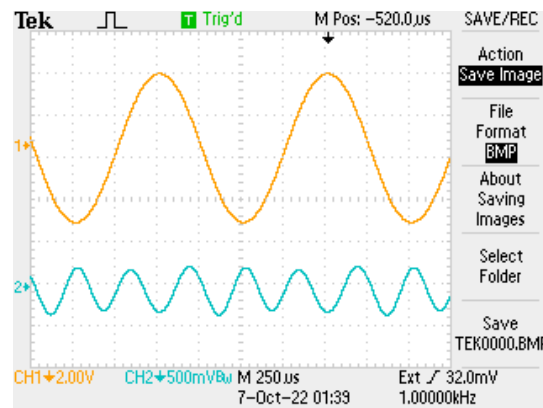
2SK182ES COMMON SOURCE DISTORTION VS OUTPUT

One of the pleasures of working with SITs is the adjustability of the distortion character. By adjusting the voltage and/or current bias points, balancing the opposing Transconductance and Drain impedance you can alter the load line of the transistor and change the amplitude and nature of the 2nd harmonic content.

Here you can see the fundamental and the distortion in scope traces where the fundamental is in orange and the magnified distortion wave is in blue. First, a “positive phase” 2nd where the distortion is positive on all fundamental peaks.

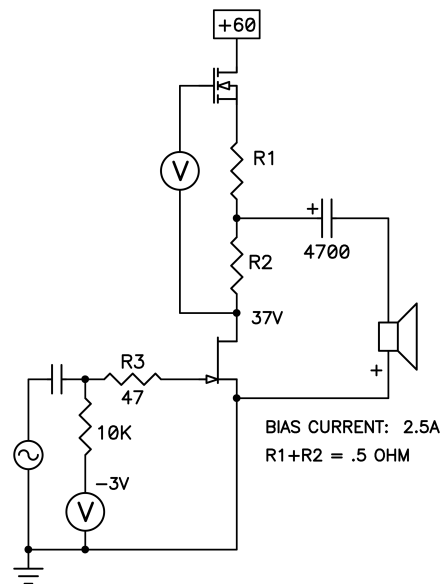


Lowering the Drain to Source voltage takes us to the middle ground, showing cancellation of the 2nd, leaving only 3rd harmonic.



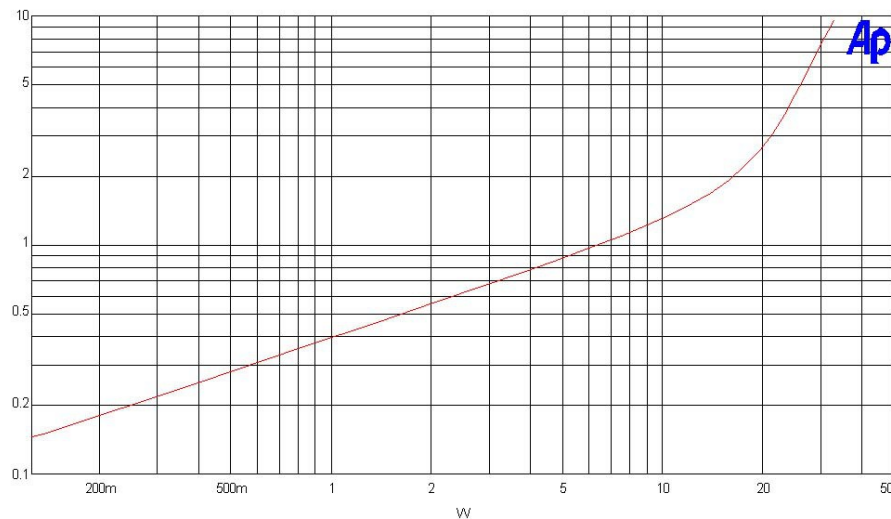
Lowering the V_{ds} further, we get the 2nd harmonic back, but with “negative phase” alignment. If you like you can put a potentiometer in the bias circuit and adjust this with a knob on the front panel, as I did with the SIT-1 amplifier.

Here's cute technique you can use – loading the SIT with what is known as a “mu follower”.



Here a power Mosfet is biased by a voltage so as to act as a variable current source which senses the output current and increases it by some multiple, usually around 50% but adjustable by the ratios of R_1 and R_2 . For $R_2 = 0$ it acts as a constant current source. For $R_1 = R_2$ it contributes about $\frac{1}{2}$ the output current, and for R_1 less than R_2 it starts to supply most of the output current. This improves the efficiency of the circuit and also allows easy adjustment of the load line that the SIT experiences and thus the quantity and type of distortion

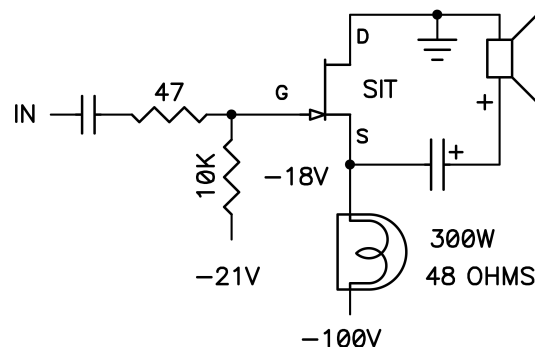
As seen here, this can dramatically lower the distortion and increase the maximum power by a factor of about 4 in this case of $R1=R2$.



THF51S CS DISTORTION 8 OHMS

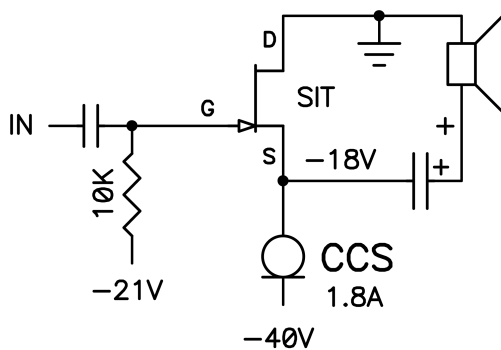
Now we look at another mode - Common Drain. Common Source Mode is quite pleasant and makes for a nice emulation of single-ended tube amplifiers, but if you already can provide the needed voltage gain at the input and would like to have a lot lower distortion, wider bandwidth and higher damping factor you would certainly pick Common Drain Mode, where the SIT acts as a follower, generating only current gain.

As before, we begin with a light bulb. We use the same parts, differently arranged with an inverted power supply and an altered bias voltage of -21 volts to get a Source pin voltage of -18. Because the Common Drain circuit does not invert the signal this time we attach the speaker positive to the active output terminal. The bandwidth is significantly improved, the damping factor jumps from about 3 to about 30, and the distortion is down by about a factor of 10.



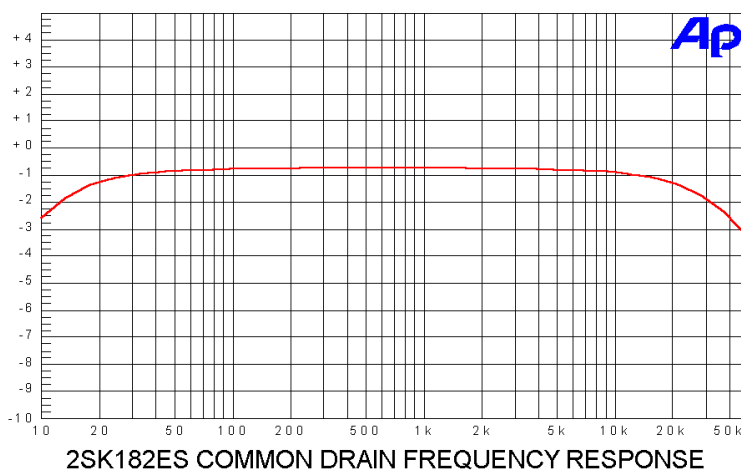
COMMON DRAIN MODE / LIGHT BULB

Here is the equivalent circuit with a constant current source. Again, the performance is about the same as the light bulb version, but more efficient.

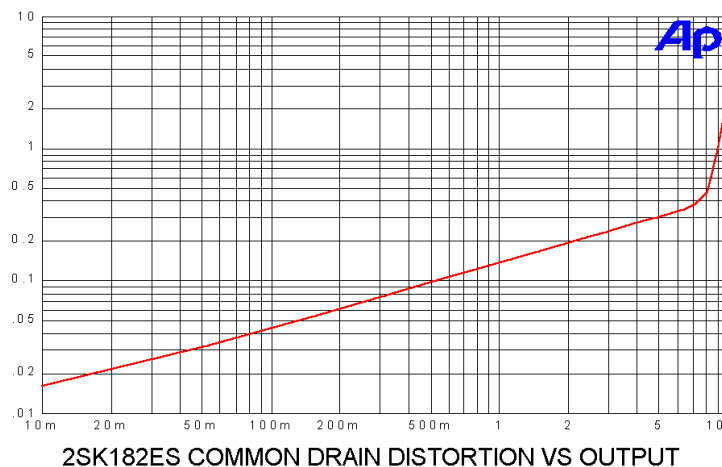


COMMON DRAIN / CONSTANT CURRENT SOURCE

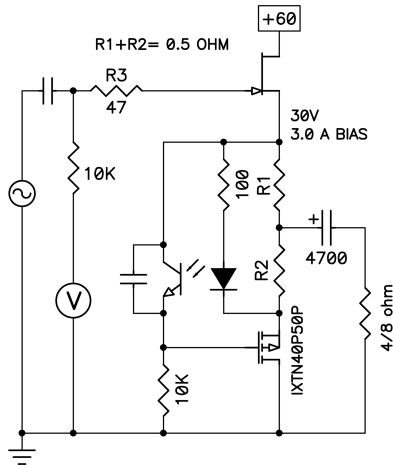
Here is the response curve. I has slightly better bandwidth but no voltage gain. It's a follower and the voltage gain generally has to come from a previous circuit.



And here is the distortion curve vs power, where we see the big improvement.

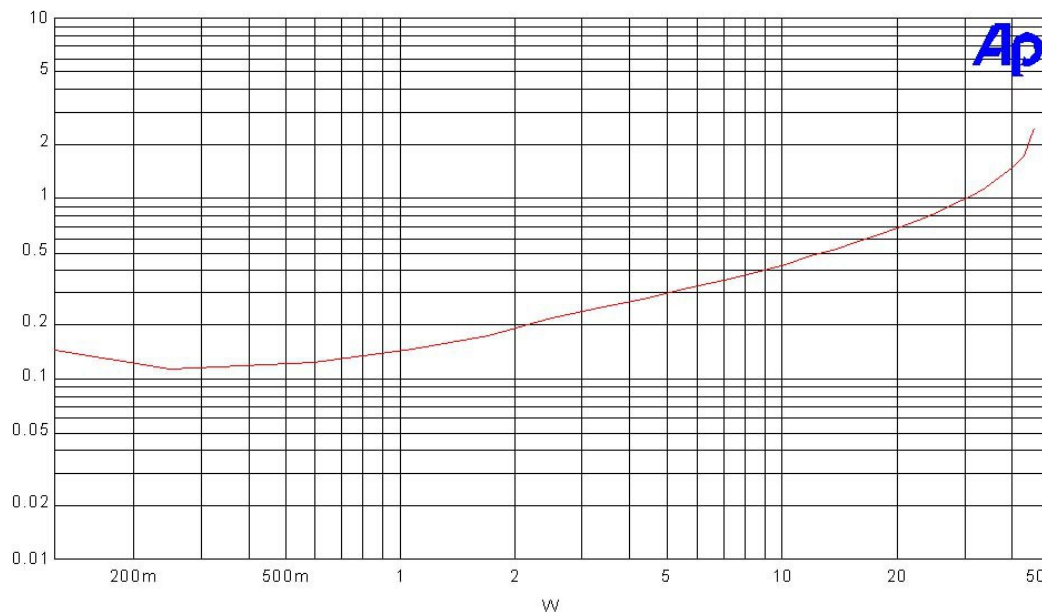


Want more power? Using a P channel Mosfet we will make another version of the mu follower circuit which I call MUFF, for MU Follower Follower. It performs the same task as seen in the previous example, but takes its drive from the Source of the output device instead of the Drain. Works like glue.



R1 and R2 perform the same function as before and the voltage source is provided by an opto-isolator which senses the voltage across R1 + R2 so as to provide constant regulated DC current but variable AC.

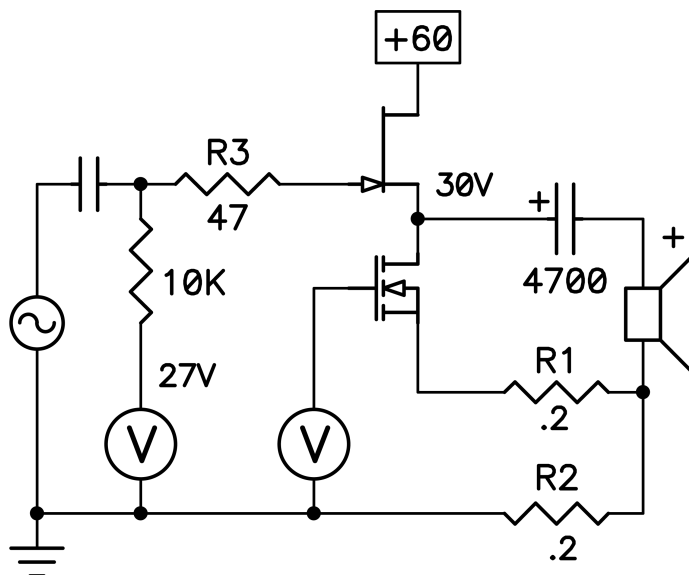
The result is fairly spectacular. Now we are getting into the 30-40 watt power range for output power and even higher damping factor. You will find it amenable to tweaks as with Common Source circuits, although more subtle.



TH51S CD DISTORTION 8 OHMS

Note that you can invert the power supply polarities on this particular circuit so that the Drain of the SIT is at ground and the Drain of the Mosfet is at V^- , and in this way can avoid having power supply noise injected into the output, otherwise you need to have a quiet positive supply. The result would be like the first two examples of Common Source shown earlier, but biased by the Mu follower/

Lastly, here is an alternate to the last schematic which gives about the same performance, a variation of the MUFF which uses an N channel Mosfet.



This is attractive because it is easier/cheaper to buy good high power N channel Mosfets than P channels. The bias circuit for the Mosfet can use the opto-isolator circuit shown previously.

In conclusion, you can re-use the SIT transistors to build all of these examples if you want, and the sonic experiences are worth the effort. The Tokin SITs are tough and reliable – I have yet to encounter a bad one and haven't blown any up either, not for lack of trying.

If you like the sound of single-ended Triodes, you know what to try first. If you want the power and the glory, you skip right to Common Drain mode, but you will need a front end that gives adequate voltage gain. I have one coming up shortly, but you can use a preamp with lots of gain and a low output impedance.

Well that's it. I hope you will build something that you have seen here. They're simple enough, and cheap in the context of high end audio.