



Two SE Power Amps: Triode or Ultralinear

Now you can enjoy the low distortion performance you achieve from push-pull amplifiers with this single-ended amplifier.

By Joseph Norwood Still

This Class A1 single-ended, triode/ultralinear power amplifier (**Photo 1**) is an excellent performer designed to leave the high distortion associated with single-ended amplifiers relegated to the history books. The 1kHz, 0.6% distortion at 20W triode mode and 25W, 0.64% distortion ultralinear (UL) mode is not an aberration but the actual distortion of this amplifier, which is achieved through careful design to obtain the lowest distortion of each stage throughout the amplifier. The design requires selecting the proper operating point for the tubes and increasing the operating plate current of the paralleled 6550s power tubes from a typical 60mA to a more aggressive 95mA.

By increasing the plate current, the distortion of the 20W triode amplifier is reduced from 9% to 4% (with 6550s cathode bypassed). The next step is to leave the cathode resistors of the power tubes unbypassed. This produces degeneration within the triode output stage and reduces the distortion of the power amplifier to 2.5% at 20W. The final step

in the distortion reduction process is obtained by applying 7dB of loop feedback to reduce the distortion of the power amplifier to 0.6%.

These three events describe the primary reason for the dramatic reduction of the distortion from 9% to 0.6% for the 20W amp. The amplifier sensitivity is 0.46V RMS for 20W triode mode and 25W UL mode.

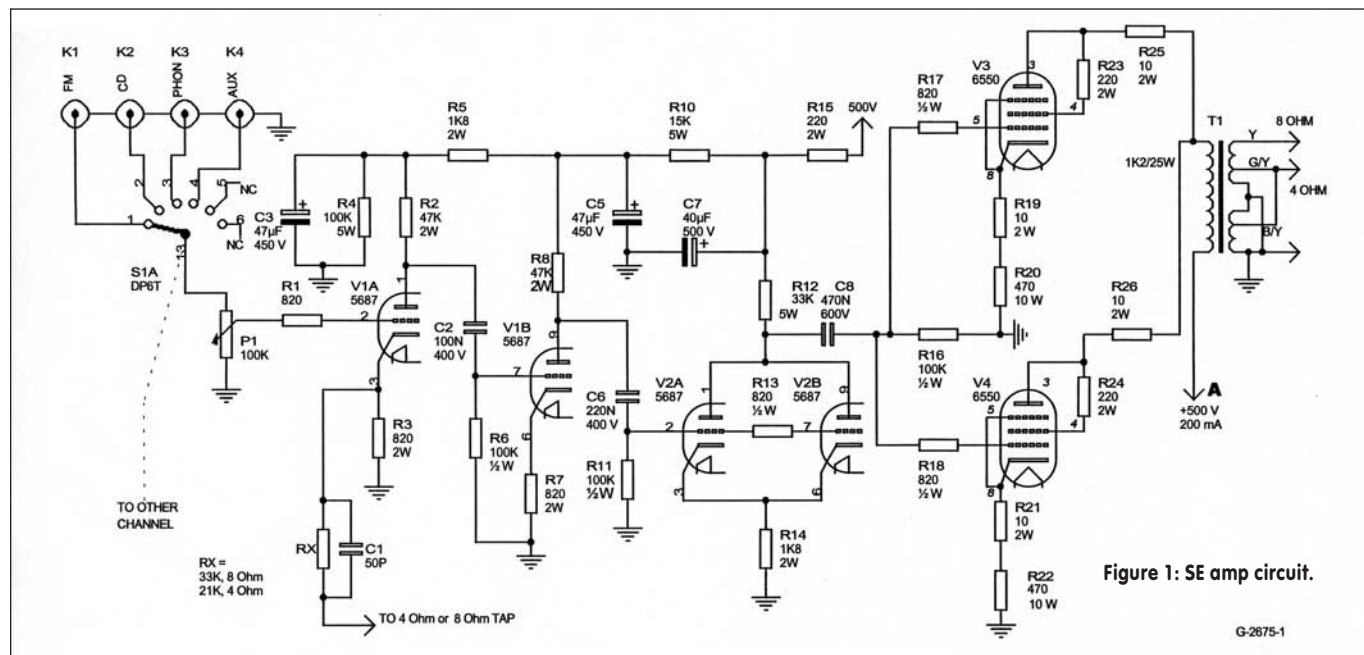
When operated in the UL mode at 25W/1kHz, the amplifier has a distortion of 0.64% or 0.8%/1kHz distortion

at 30W. The 25W level is the rating limit of the Hammond output transformer. For operation in the UL mode, disconnect the 220Ω resistors from the plates of the 6550s and connect them to the screen tap of the output transformer. The sensitivity of the amp is 0.46V RMS for an output of 25W. This is the only circuit change required to modify the amplifier from triode to UL operation.

Of Interest: If you look at the sine wave of a single-ended amplifier (with



Photo 1. Finished unit.



cathode bypassed or fixed bias) on an oscilloscope, you can see the unsymmetrical nature of the sine wave. This is greatly improved by providing degeneration in the cathode of the output stage. The distortion obtained by employing cathode degeneration and increased plate current of the 6550s greatly reduces the distortion in this SE amplifier. The final distortion mimics or improves the distortion levels typically found in push-pull amplifiers.

The 6550 power output tubes are operated at the design center limit to obtain the lowest distortion, and no color of the plate is evident. Also, at this level of operation the sonics of the sound, which is commonly referred to as a "sweet spot," is greatly improved. With an un-bypassed cathode resistor in the cathode, the plate resistance of the triode output tubes is increased, which reduces the damping on the voice coil of the speakers. This is not a major problem, because triodes naturally have an inherently low plate resistance. Thus, the inherent low impedance of the triode is still present, although diminished.

The damping of the triode and ultralinear amplifiers is satisfactory. When the 8Ω secondary winding is adjusted for a 2.8V RMS output and connected to an 8Ω load, the voltage increases to only 4.0V RMS (triode) and 6.2V RMS (ultralinear) when the load is removed. This damping is sufficient, and the bass frequencies of the woofer are effectively controlled.

At 10W (normal listening level), the triode amplifier has less than 0.5% distortion from 30Hz to 15kHz, and the ultralinear amplifier has less than 0.56% distortion from 30Hz to 15kHz.

FEATURES

The amplifier is a complete unit, and two amplifiers are required for stereo operation. A line amplifier/preamplifier is not required to drive the amplifier, which has a right- and left-channel volume control. A double section, six-position rotary switch is required to select FM, CD, SACD, Phono, and so on.

Important: I recommend that you construct the amplifier on a single aluminum $17 \times 10 \times 3$ " chassis and not as shown in **Photo 1**. Also, do not use a steel chassis box, because grounds re-

quire stripping the painted steel chassis to bare metal. Furthermore, drilling and punching holes is much more difficult with a steel chassis. The front of the power amplifier chassis has a heater and high voltage on-off switch and two volume controls. The rear of the amplifier chassis has a power cord and fuse, four speaker terminals, and eight phono jacks.

I further recommend that you use an 80-cfm fan, located directly behind the plate transformer, and with the air circulating around the transformer directed at the 6550 power output tubes. I also suggest that you "notch-out" the chassis at the lower end of the fan to provide under-chassis cooling from the fan. These recommendations will ensure proper cooling of the tubes, transformers, and electrical components.

CASCADE PREAMPLIFIER

The first stage of the cascade amplifier (**Fig. 1**) has a flat frequency response of 20Hz to 30kHz, distortion of .08% at 1V RMS, and voltage gain of 10. The DC supply is +305V, the plate voltage is +85V, and cathode voltage is +3.7V.

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The second stage of the cascade amplifier has a flat frequency response of 20Hz to 30kHz, distortion of 0.54% at 10V RMS, and voltage gain of 10. The DC supply is +320V, the plate voltage is +88V, and cathode voltage is +4V. Do not attempt to bypass the cathode resistor with a capacitor, as instability of the amplifier will occur. Note: disconnect the feedback loop when making these tests.

DRIVER STAGE AMPLIFIER

The driver stage amplifier (Fig. 1) is a paralleled 5687 with a flat frequency response of 20Hz to 20kHz. It uses a plate resistor of 33k Ω and a cathode resistor of 1800 Ω . The DC supply is +500V DC and the plate voltage via 33k Ω plate load resistor is +250V DC. The cathode voltage is +14V DC, and the distortion is 1.2% at 1kHz with 70V RMS output (6550 tubes plugged-in, F.B. loop not connected).

Do not attempt to bypass the 5687 cathode resistor, as instability of the amplifier will occur. Furthermore, distortion reduction is obtained by the unbypassed cathode resistor of the 6550s and the higher plate current of the 6550s. This is verified by referring to the distortion data in **Tables 1** and **2**. Note: disconnect the feedback loop when making these tests.

POWER OUTPUT STAGE

The power amplifier stage (Fig. 1) consists of two 6550s connected in a Class A1 single-ended configuration. The 6550 degenerative output stage (unbypassed cathode) requires 70V RMS signal drive for the grids of 6550s to obtain a 20W output in the triode mode and 25W output in the UL mode. The reason for classifying the 6550s as operating in a

Class A1 mode is: The amplifier's plate current is virtually constant and the grid current at maximum signal is only 1mA. This amount of grid current is a typical drive requirement to overcome the capacitance encountered in paralleled high transconductance 6550 power tubes.

Of the 70V RMS drive signal, 35V RMS is required to develop the degeneration (6dB of negative feedback) in the cathode circuit of the 6550s. The other 35V RMS of the 70V RMS signal is required to drive the 6550s to obtain a 20W output. The grid bias of the 6550 is -50V DC and the signal is 35V RMS. This signal is required to drive the 6550s to a 20W triode output and a 25W UL output.

The 6550 output tubes employ isolat-

TABLE 1: TRIODE POWER AMPLIFIER DISTORTION %.

	5W	10W	15W	20W
32Hz	0.48	0.46	0.62	1.0
100Hz	0.46	0.44	0.54	0.64
1kHz	0.46	0.44	0.5	0.6
10kHz	0.44	0.42	0.5	0.62
15kHz	0.4	0.38	0.46	0.31

TABLE 2: ULTRALINEAR POWER AMPLIFIER DISTORTION %.

	5W	10W	15W	20W	25W	30W
32Hz	0.46	0.46	0.64	0.8	1.5	2.3
100Hz	0.45	0.4	0.5	0.52	0.7	0.94
1kHz	0.44	0.42	0.48	0.5	0.64	0.8
15kHz	0.42	0.38	0.4	0.46	0.6	0.9

TABLE 3: 6550 TUBE CHARACTERISTICS (SINGLE TUBE, UNLESS TWO TUBES SPECIFIED).

	Triode Mode	Ultralinear Mode
Ebb	500V DC	500V DC
Eb	485V DC	485V DC
Eg2 (220 Ω screen resistor)	483V DC	487V DC
Ek (485 Ω cathode resistor)	48-50V DC Ek	48-50V DC
Ib + Ig2 (zero signal)	93mA	93mA
Ib + Ig2 (maximum signal)	96mA	98mA
Grid Signal (maximum)	70V RMS	70V RMS
Plate dissipation (zero signal)	40W	40W
Plate dissipation (maximum signal)	32W	35W
Plate load (two tubes)	1250 Ω	1250 Ω
Power input (two tubes)	100W	100W
Power output (two tubes)	20W	25W

TABLE 4: 5687 VOLTAGE REQUIREMENTS.

	5687 Cascade Amplifier		5687 Paralleled Driver
	First Stage	Second Stage	Both Sections
Ebb	305V	320V	500V
Eb	85V	88V	250V
Ek	3.7V	4V	14V

PARTS LIST OF AMPLIFIER (DOUBLE FOR STEREO EXCEPT AS NOTED WITH #).

Part	Quantity	Source
10 Ω 2W 500V metal oxide 282-10	4	Mouser
220 Ω 2W 500V metal oxide 282-220	2	Mouser
470 Ω 10W wire-wound 280CR10-470	2	Mouser
820 Ω ½W carbon 30BJ500-820	3	Mouser
820 Ω 2W metal oxide 282-820	2	Mouser
1800 Ω 2W metal oxide 282-1800	2	Mouser
15k Ω 5W metal oxide 286-15K	1	Mouser
22k Ω 1W for 4 Ω speaker 281-22K	1	Mouser
33k Ω 1W for 8 Ω speaker 281-33K	1	Mouser
47k Ω 2W metal oxide 282-47K	2	Mouser
100k Ω 5W 500V metal oxide 30BJ500-100K	1	Mouser
100k Ω ½W carbon 30BJ500-100K	3	Mouser
33k Ω 5W 500V metal oxide 286-33K	1	Mouser
100k audio taper RV38-100KA	1	AE
#S1-Rotary switch, 2-pole, 6 position 275-1836	1	RS
50pF mica capacitor 500V C-SM 50	1	AE
0.1 μ F 400V polypropylene C-PD1-400 (orange cap)	1	AE
0.22 μ F 400V polypropylene C-PD22-400 (orange cap)	1	AE
0.47 μ F 400V polypropylene C-PD47-400 (orange cap)	1	AE
40 μ F 500V electrolytic CSA40-500	1	AE
47 μ F 450V, electrolytic, C-ET47-450	2	AE
5687, double triode (V1, V2)	2	AE
6550C-WC power pentode Winged C (matched-V3, V4)	2	AE
T1- Output Transformer, P-T1640SE Single-End, 25W, 200mA maximum, primary impedance 1250 Ω , secondary 4, 8, 16 Ω , 20Hz to 20kHz ($\pm$ 1dB maximum at 25W), weight 12 lbs.		AE
9-pin ceramic tube socket PST9-162	2	AE
Octal tube socket PST8-209MIP	2	AE

PARTS LIST OF POWER SUPPLY

Part	Quantity	Source
Fan 80 cfm, 4.7 in ² $\times$ 1" thick, "quiet"	1 (Specifications Typical) - -	
Diode Rectifier 1A, 1000V, P-Q1N4700	4	AE
Switch, Rocker, 6A at 250V SPST, Mtg. Hole-.71"	2	112-R13-130A Mouser
Resistor, Wire Wound, 20 Ω 25W	1	280-CR25-20 Mouser
75k Ω 500V 2W 282-75K	2	Mouser
0.2 μ F 600V, CSD2-600	1	AE
470 μ F 400V, CR-474	4	ALEL
Heater transformer, 120V to 12.6V, 10A, Hammond	1	P-T166S6 AE
Plate transformer, 120V to 200V, 870mA, Hammond	1	P-T167H200 AE
Chassis box, aluminum, 17 $\times$ 10 $\times$ 3", P-H1444-32	1	AE
Fuse holder, 3AG	1	--
Fuse, slow blow, 3AG, 5A 250V	1	--
Line cord (3 prong plug, 14 AWG)	1	--

tion resistors on all the tube elements to ensure the plate, grid, and cathode elements are free of unwanted signals. A plate "stopper" 10Ω metal oxide resistor, which measures static plate current, is used. The screen grid is connected to the plate via a 220Ω 2W metal oxide resistor for triode operation. A 470Ω 10W resistor is connected in series with a 10Ω 2W metal oxide resistor to provide a +48V DC bias voltage. With maximum signal drive the self-bias voltage is increased to 50V DC.

The two 6550s can be balanced for equal plate currents by interchanging the four 6550s until balance is achieved. If this exchange does not provide balance, replace the 10Ω resistor of the tube with high plate current with a 22 or 33Ω resistor.

I did not have this problem using matched output tubes. The current of each 6550 output tube is 95mA. The Ebb is + 500V DC, the Eb is +485V DC, and cathode-to-plate voltage is +435V DC. The 6550s are operated with 40W plate dissipation (no signal), and no color of the plates is evident. At 20W power output, the plate dissipation is 32W. At an output of 20W triode and

25W ultralinear, the 6550 control grid has a 70V RMS driving signal and a typical AC driving current of 1mA.

Note: 1.) The distortion of the power amplifier does not fall off rapidly as the power output is decreased but tends to remain relatively constant at approximately 0.5%. It is also evident that the distortion at 5W is slightly higher than at 10W (Tables 1 and 2). This is also due to the degenerative effects of the 6550 cathode circuit. Because the feedback effect is more pronounced as the frequency is increased, the distortion at 10kHz and 15kHz is decreased. This, of course, affects the shape of the 10kHz squarewave, which has slanted/rounded sides.

2.) The power amplifier shows no sign of ringing with a 10kHz square wave applied to the input when you place a 1000N capacitor across the 4 and 8Ω secondary windings of the output transformer.

3.) A single-ended amplifier connected to an oscilloscope reveals a non-symmetrical sine wave; as is typical for

single-ended amplifiers, the bottom end of the sine wave is broader than the top end. This condition does not occur in push-pull amplifiers. The unsymmetrical state of the sine wave is eliminated in self-biased, single-ended amplifiers when using an unbypassed cathode resistor.

4.) Before applying power to the amplifier, make certain a 100kΩ grid resistor is connected between the 6550 grid and ground. This precaution will prevent catastrophic failure of the 6550s.

5.) Hammond transformers fit well with my philosophy of designing affordable hi-fi equipment for the audiophile.

POWER SUPPLY

The power supply contains the power transformer, heater transformer, capacitors/resistors, switches (heater/plate), and a low noise blower fan (cools the power transformer). The front of the chassis has heater and high voltage switches for applying heater power prior to applying high voltage. The power supply provides power for two of the single-ended power

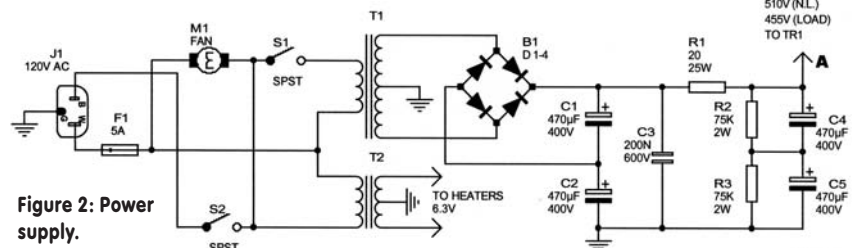


Figure 2: Power supply.

G-2675-2

WARNING: Lethal voltages are present. Exercise extreme caution when constructing and testing the amplifier and never leave the amplifier upside down when children are present.

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amplifiers described in this article.

The power supply (**Fig. 2**) has a 6.3V AC-C.T., 10A heater transformer, and a 200V AC 870mA plate transformer. The plate supply features a full-wave bridge, voltage doubler circuit, which uses two 470 μ F capacitors. The current rating of the transformer is reduced to 435mA. Filtering of the output voltage from the bridge rectifier is provided by series-connected 470 μ F electrolytic capacitors and a 20 Ω isolation resistor.

Two series-connected 75k Ω bleeder/voltage divider resistors are included in the output of the supply. The 200N capacitor (C3) eliminates AC hash. The AC ripple of the +500V DC output of the supply is 1.5V RMS. The plate and heater transformer furnishes power to two 20/25W power amplifiers. The 6.3V AC from the heater transformer is directed to the tubes of the right- and left-channel amplifiers via separate heater wires.

FREQUENCY RESPONSE TUBE CHARACTERISTICS

At 20W the triode amplifier is flat from 30Hz to 20kHz. At 25W the UL ampli-

fier is flat from 30Hz to 20kHz (**Tables 1 and 2**).

The stereo amplifier requires four 6550s and four 5687s. I recommend that you order six 5687s to ensure replacement of a failed tube or selection of low distortion tubes, if you have a distortion meter (**Tables 3 and 4**).

RECAP OF DESIGN

This low distortion design is the exclusive domain of a power output stage operating in the triode or ultralinear mode. Tubes that are especially suited for the degenerative cathode circuit are triodes having high cathode bias and low plate impedance.

The design is compromised with a pentode output stage and its inherent high plate impedance. The ultralinear mode also compromises the damping. If this amplifier used the conventional output stage with a bypassed cathode biased for 60mA, the distortion at 20W/1kHz would be 9%.

Currently, most single-ended amplifiers operate with between 5 and 10% distortion, which level is very noticeable and sonically produces a very unpleas-

ant sound and eliminates any positive features attributed to a single-ended amplifier. This design with the degenerative output stage and more aggressive operating plate current changes the whole design concept for single-ended amplifiers.

With its 0.6% distortion at 20W, this amp produces outstanding distortion numbers. As the frequencies are increased from 1kHz to 10kHz, the distortion is reduced at all power levels (**Tables 1 and 2**). This phenomenon is typical for a power output stage with self-bias having an unbypassed cathode resistor. The UL amplifier provided 25W with 0.64% distortion and 30W with 0.8% distortion.

I recommend the triode amplifier over the UL version, as the former has better damping. Try both modes and make your own selection based on listening observations. To confuse the issue, you might like to know I operate my amplifier in the UL mode.

The amplifier has excellent "sonics" as typified with SE amplifiers. The unpleasant sound of the high distortion SE amplifier is vanquished! The approximate cost to build the stereo amplifier and power supply is \$450.

Important: This amplifier design is presented to show that you can obtain low distortion in SE amplifiers with a very simple and logical design approach. It is intended for SE devotees and is not recommended as a DIY construction article for the typical audiophile. For the typical audiophile, I recommend and prefer my fixed bias push-pull AB1 35W triode/60W UL amplifier design in *audioXpress*, June 2004. **ax**

Joseph Norwood Still, retired from the Electronics Industry, is designing affordable high-quality amplifiers for the dedicated audiophile. He resides in Towson, Md.

SOURCES

Mouser Electronics 1-800-346-6873, mouser.com

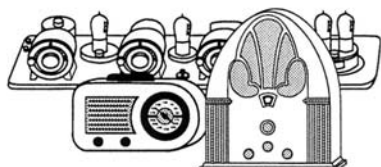
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