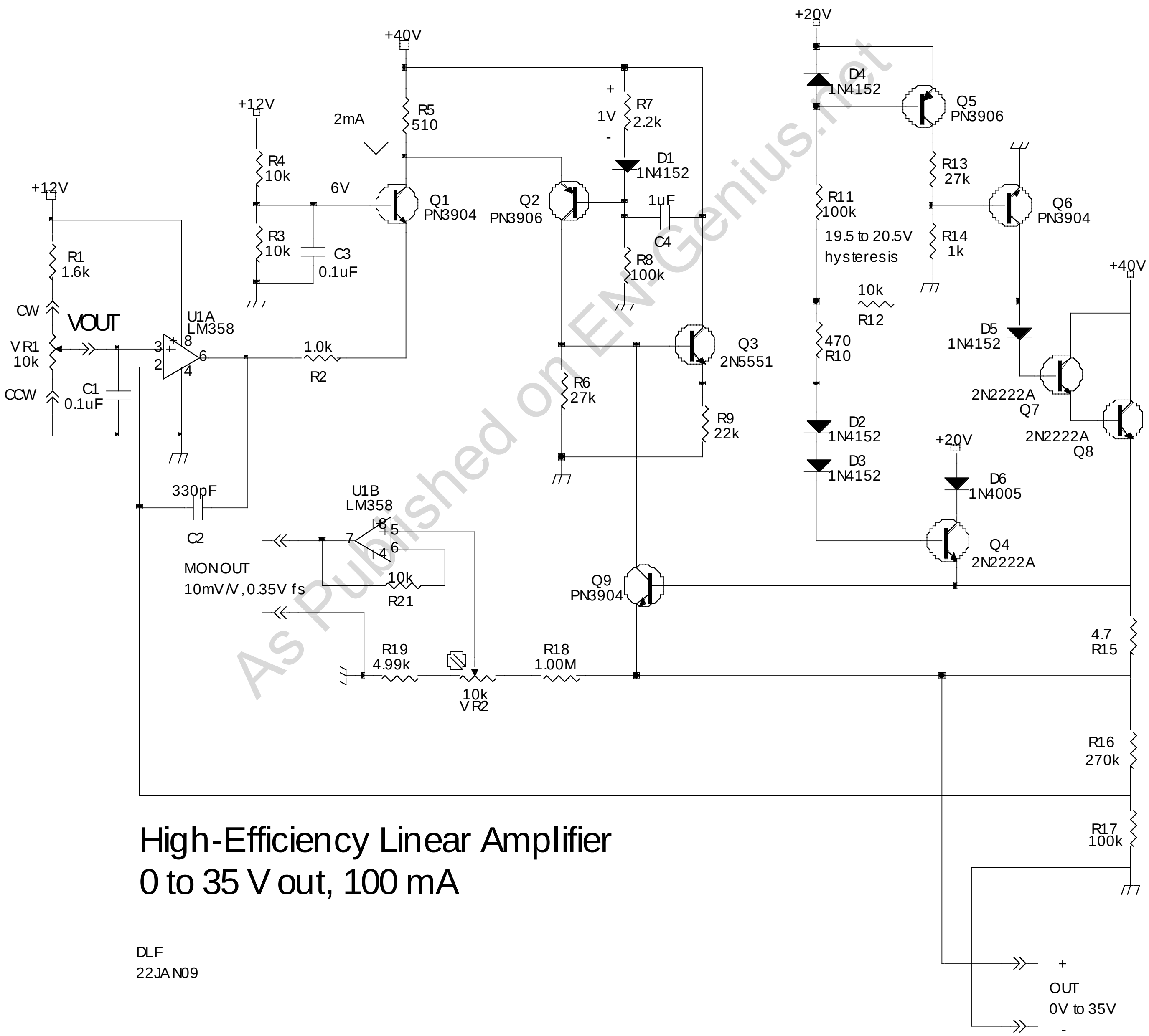
High-Efficiency Linear Amplifiers 2

by Dennis L Feucht

In the December 2006 dearDennis clinic, a brainstorm was unleashed precipitating ideas about how linear amplifiers might be made more efficient and perhaps preferred to switching amplifiers for applications requiring low noise as well. The basic idea was to segment the output into *N* parallel stages so that, like a bar-graph decoder, only one stage is on at a time over a limited output voltage range that is near the supply rail of that stage. With minimal voltage across the output transistor, power loss is minimized and efficiency increased. The scheme depends upon having a multi-voltage supply: this can be accomplished with different taps on the supply transformer secondary winding, whether it be switching or line-frequency. In either case, the efficiency remains largely unaffected by the multiple output voltages, one per output-stage segment.

To test the concept empirically, the following two-segment amplifier was designed and built.



This is a noninverting feedback amplifier with an op amp (U1A) first stage. The op amp drives complementary common-base (CB) stages (Q1, Q2). The CB interstage circuit is returned to +40 V to allow the Q2 collector to swing the full output range. The required voltage margin is less than 2 V (across R7, D1), to bias the cascade for a common static current (through R5) of about 2 mA. This bias current is split between Q1 and Q2, and R2 is sized for the required gain to achieve the 0 to 35 V output range. Because both BJTs are CB, their breakdown voltage is higher than for the other two configurations and PN3904, PN3906 parts can be used.

The common-collector (CC) buffer following these stages, Q3, is a 2N5551, rated for around 150 V. It drives the two output CC paths.

The paralleled output paths are through Q4 for 0 to 20 V and Q8 for 20 to 35 V out. D2 and D3 keep the Q4 *b-e* junction reverse biased and Q4 off when D5, Q7, Q8 are conducting. The circuit of Q5, Q6 decides whether the voltage input to the Q8 final Darlington stage will cause it to conduct or not. Q5, Q6 comprise a positive-feedback amplifier which functions as a hysteresis switch with about 1 V of hysteresis. The hysteresis range is set by R10, R12 so that at about 20.5 V, Q5 current is reduced sufficiently so that Q6 comes out of saturation and its collector voltage rises. A rising voltage feeds back through R12 and R11 to drive Q5 further toward cutoff, and the hysteretic behavior switches Q5 and Q6 off. Then the path through R12 to the Darlington output stage is free to pass the waveform from Q3, and this upper path takes over. The three conducting *p-n* junctions of the upper path allow the voltage at the emitter of Q4 to be raised and it cuts off. Its *b-c* voltage, however, continues to rise with rising output voltage. This would forward bias the *b-c* junction of Q4 were it not for D6, to keep it from conducting back into the +20 V supply.

As the output waveform voltage decreases, it must become less than about 19.5 V for the hysteretic behavior of the “segment switch” to turn Q5, Q6 back on, causing the anode of D5 to be at about 0 V. This switching does not appreciably perturb the output waveform as the junctions of the two paths turn on and off over a small but continuous range. When the upper-path BJTs are reversed biased, D5 keeps them from breaking down.

Q9 is a current limiter for over-current protection of the output BJTs. The limit is set at somewhat above 100 mA. This amount of current through Q4 or Q8, with about 20 V across either, results in a maximum power dissipation of 2 W, excessive for a plastic-packaged 2N2222A. Metal-can TO-18 packages were used in the prototype, though they can also become hot if the output voltage remains at or near the maximum value for any length of time. Yet the two-segment amplifier reduces power dissipation in these BJTs by 4 times in cutting the maximum voltage across them to half of 40 V.

The feedback divider, R16, R17, used ±5% tolerance resistors though for a calibrated design, a trim pot between them would be recommended. In the intended application, this is a variable power supply for providing a common-mode voltage for a differential-amplifier test fixture.

U1B is an amplifier output-voltage monitoring output that is input to an ADC, for digital readout of the output voltage. For this to be accurate, the trim pot is needed in its divider, scaled for ÷ 100 or 10 mV/V. The grounds of the two outputs should be well-connected to minimize error. Alternatively, U1B can be omitted, a single op-amp IC used instead, the output divider calibrated with a trim pot, and the ADC input voltage taken from the input 10-turn pot that commands output voltage.

The amplifier needs only a +12 V low-voltage supply. The 20 V and 40 V supplies can be provided from stacked and rectified windings of either a 50/60 Hz line-driven transformer or a switching converter transductor.

Although this amplifier has only two segments and reduces power dissipation by only 4 times, the concept can be extended to more segments, though intermediate segments must have somewhat different segment switches. Bar-graph display circuits perform a similar function though without regard for waveform fidelity. So does the X-AMP class of topologies developed by Barrie Gilbert of Analog Devices for precision, wide-range logarithmic amplification. X-AMP and bar-graph circuits offer stepping-stones to an optimal *N*-segment, high-efficiency linear amplifier.