Model(s): THAT4316 Very Low Voltage Low Power Analog Engine Dynamic Processor IC

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A Battery-Powered "One Knob Squeezer" using the THAT4316

By Wayne Kirkwood

Compression is a widely used effect in recording, sound reinforcement and on-stage performance. Most compressors designed for recording and reinforcement have a large number of knobs to allow subtle tweaking. Unfortunately, the large number of controls require interactive adjustment of threshold, ratio and "make-up" gain to achieve the desired effect.

The on-stage performer requires a simple, repeatable adjustment that can be made quickly. This Design Note describes a battery-powered compressor based on the classic dbx 163 "One Knob Squeezer" with a simple compression control labeled "More."

THAT Corporation's Design Note 125 describes a THAT4301-based One Knob Squeezer operated from split power supplies and provides an in-depth discussion on the theory behind a single knob compressor. This Design Note expands on previous work to show the THAT4316 applied to a low-voltage, low-current effects pedal powered by a single 9 volt battery.

The overall schematic is shown in Figure 9. The pedal contains six basic stages: Input, VCA, Output, RMS Detector with a Non-Linear Capacitor, Control Sidechain and Power Distribution.

Input Stage

As shown in Figure 2, an input preamplifier with 6 dB gain is composed of opamp A and associated components. C2 and R2, a bias resistor, provide an input -3dB point of 7 Hz. R3, R4 and C3 supply a filtered reference that is ½ the battery voltage to bias both opamp A and opamp B, the output stage, to mid supply. R5 and C4 emulate the input loading of classic triode-based guitar amps. R6 and diodes D1 and D2 protect the input from over-voltage conditions. The preamp gain is set by R7 and

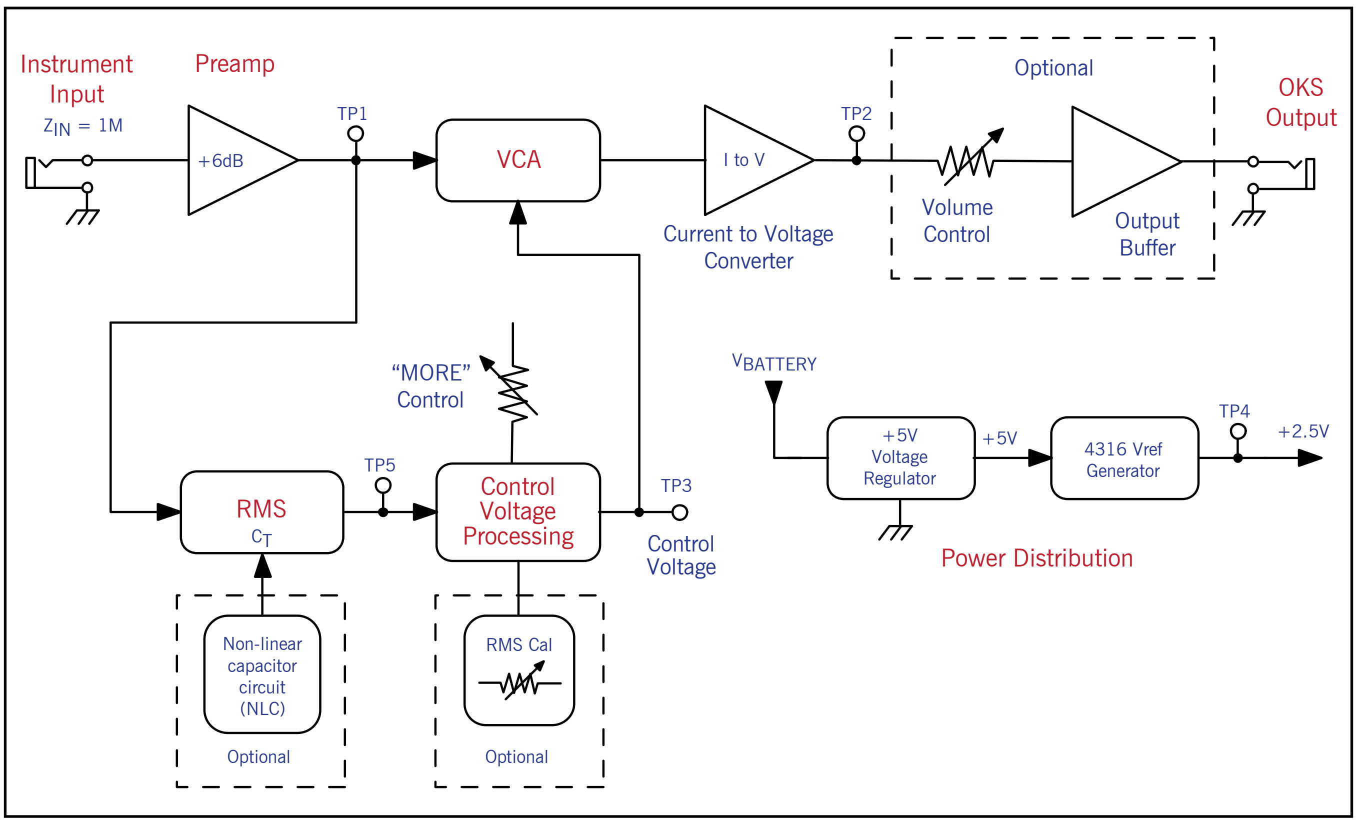

Figure 1. THAT4316 One Knob Squeezer Block Diagram

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R8. With typical instrument levels, the output at TP1 is -20 dBu or 77.5 mV RMS.

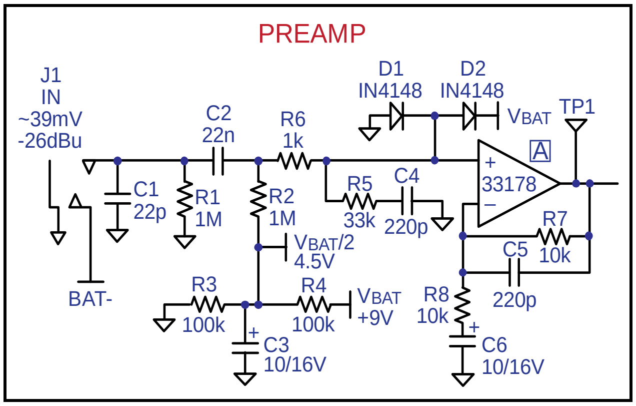

Figure 2. Input Stage Circuit

Voltage Controlled Amplifier

The VCA circuitry is shown in Figure 3. The THAT4316 used in the One Knob Squeezer operates from a regulated 5V supply. The input, output and control ports are biased to an internally generated reference voltage, V_{REF}, of +2.5V. C10 AC-couples the preamp to the VCA input. R10 converts the input voltage to current. R11 and C11 provide stability. The VCA output is also a current. Opamp D and R12 provide current to voltage, or "I-V," conversion. C12 aids stability.

The unused VCA Ec+ control port is tied to the +2.5V V_{REF} supply. The Ec- port is connected to the One Knob Squeezer's sidechain which is described in a later section.

Unlike other VCA offerings from THAT Corporation, the 4316 does not internally invert signal polarity. Overall polarity is inverted however due to current-to-voltage conversion by opamp D.

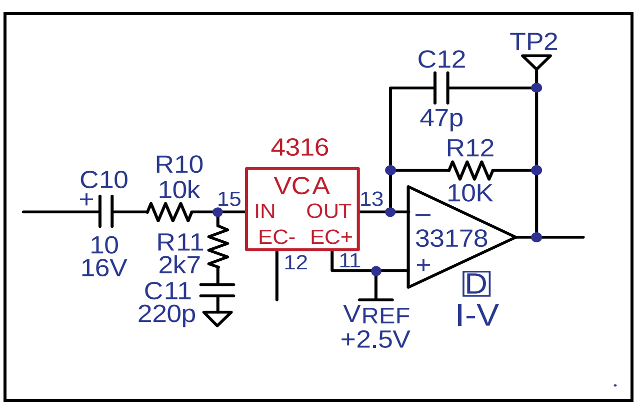

Figure 3. VCA Circuit

Output Amplifier

An optional output stage, opamp B, provides polarity inversion so that the overall input to output polarity is non-inverting. With an even number of opamps available and only seven required for the input, VCA output and sidechain, opamp B comes at virtually no cost. Adding a potentiometer to the output stage provides a volume control with a gain range of -infinity to +10 dB.

As shown in Figure 4, the non-inverting input of opamp B is biased to ½ the 9V battery voltage by sharing R3, R4 and C3 with the input preamp. C13 AC-couples the VCA output to the input network formed by R13, VR2 and C14. C14 prevents DC current in the wiper. R14 provides local DC feedback to opamp B.

VR2, a linear taper potentiometer, appears in parallel with R14. At full counter-clockwise rotation the AC feedback resistance is essentially 0 Ohms and the attenuation infinite. Full clock-wise rotation provides 10 dB gain calculated as Av = (VR2cw||R14)/R13. To increase the output gain range lower the value of R13. C15 provides stability. R15 isolates opamp B's output from capacitive loads. C16 provides AC-coupling to remove the output stage DC potential. C17 reduces radio frequency interference that might enter the output externally.

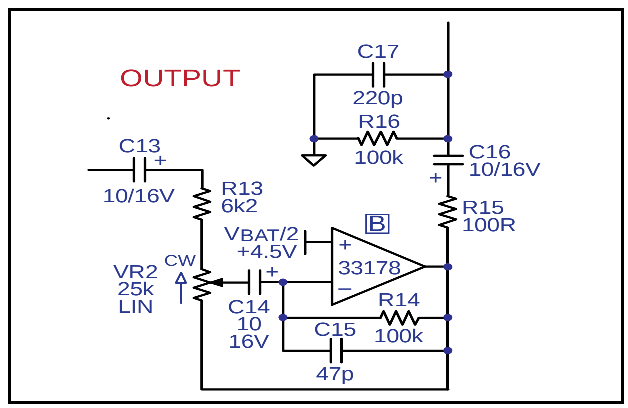

Figure 4. Output Amplifier Circuit

RMS Detector with Non-Linear Capacitor

The RMS Detector and Non-Linear Capacitor ("NLC") are detailed in Figure 5. The RMS detector is fed from the input preamp in a "feed-forward" compression topology. (See THAT Design Note 01A for the differences between feed-forward and feedback compressors.)

C20 AC-couples the preamp to the THAT4316's RMS detector input. R20 converts the input voltage to current. At the nominal operating level of 77.5 mV, the input current is 7.75 uA RMS.

The One Knob Squeezer uses a non-linear capacitor to provide both fast attack times and low detector ripple. At lower audio frequencies ripple in the detected RMS output increases distortion because it modulates the audio input. The NLC provides two effective capacitor values: A large value for slowly-changing or steady-state signal envelopes and a small capacitance value for transient ones. THAT application note DN114 provides an in-depth discussion of the NLC.

The NLC is comprised of opamp C and various external components. C21 and C22 are both connected to the 4316's timing capacitor pin C_T. For transient signals (using the values shown in Figures 5 and 9) the effective value of the timing capacitor seen by the C_T pin is:

For transients $C_T \sim= C21+C22 = 2.3$ uF

For steady-state or slowly varying signals
$C_T \sim= C21+[C22\{1+(C21/C23)\}] = 24.3$ uF

R21 isolates the output of opamp C from the capacitive load of C22. D3 and D4 clamp the opamp output. R22 provides DC feedback.

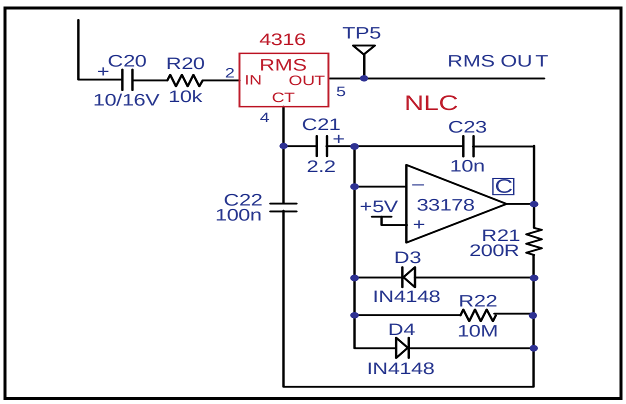

Figure 5. RMS and NLC Circuit

The NLC is AC-coupled to the timing pin. In order to provide maximum output swing from the NLC opamp due to output stage saturation and battery voltage decline, the non-inverting input of opamp C is referenced to the regulated +5V supply rather than the 2.5V or 4.5V references used elsewhere. The 2.5V reference does not permit sufficient voltage swing to allow for diode drops in the feedback loop and output stage saturation. The 4.5V reference can be as low as 3.5V with a discharged battery and is also insufficient. By referencing the NLC to the regulated 5V supply, the use of a rail-to-rail opamp is avoided. Note that the polarity of timing capacitor C21 is reversed from typical 4316 applications due to the fact that the inverting input of opamp C rests at +5V and the timing pin, C_T, is at +2.5V.

Output of the RMS detector is pin 5 of the 4316. At the nominal -20 dBu input level to the RMS detector (7.75 uA) the output at TP5 will be approximately 2.50V (V_{REF} +/-13mV) and will increase at +6.1 mV per dB.

The "One Knob" Sidechain

The Sidechain and More control, shown in Figure 6, are the heart of the One Knob Squeezer which uses soft knee compression to provide a pleasant-sounding, gently sloped, compression curve. The sidechain relies on three important concepts:

1) Soft knee compression exploits the exponential voltage-current characteristics of common silicon diodes (D6 in figures 6 and 9) to smooth the compression curve. THAT Design Note 00A provides an example of a soft-knee multi-control compressor and a detailed explanation of the "sloppy rectifier."

2) The amount of compression introduced by the More control relies on the dynamic impedance of diode D6 (approximated as Zd = 26mV/Id) to vary sidechain gain. The More knob shifts the operating point of D6 (and D7) to vary it's effective impedance.

3) The sidechain has two distinct signal paths. One path receives inputs from the RMS detector, More control and a diode pre-bias (V_{DIODE}). A second complimentary path receives inputs only from V_{DIODE} and More to provide automatic adjustment of "make-up" gain. The primary path is the dynamic sidechain path which passes through D6. The secondary path through D7 is corrective. The outputs of both sidechain paths are summed as currents and converted to a control voltage, Ec-.

THAT Design Note 125 provides a more detailed description of the "One Knob" concept where a single control simultaneously adjusts threshold, compression ratio and make-up gain. The 4316-based One Knob Squeezer described here uses the classic dbx 163 circuit modified for low-voltage, single-supply operation.

The entire sidechain is biased at the +2.5V V_{REF} supply. When analyzing or measuring DC voltages in the sidechain V_{REF} (TP4) should be used as a measurement common.

Opamps E, F, G and H, associated components and VR1 form the One Knob sidechain. Opamp E in the primary sidechain path computes an inverted sum of RMS+V_{DIODE}+More. Opamp F, the second sidechain path, sums V_{DIODE}+More. The RMS detector and More control shift the operating points of D6 through stage E and D7 (without RMS) through stage F.

Opamp G, D5 and R39 provide a "pre-bias" for diodes D6 and D7. With the values shown D5's forward current is 2.5V/R39 =

64 uA. Neglecting currents from the RMS and More inputs which can be zero (and assuming perfect diode matching) D6 and D7 are pre-biased at -64uA and +64 uA respectively. This is due to the gain for the V_{DIODE} terms being unity throughout opamp stages E, F and H. (R31=R33, R36, R38, R40 and R41.)

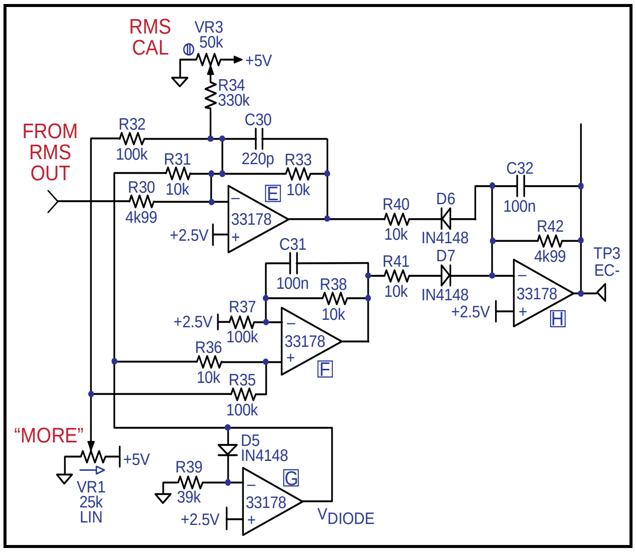

Figure 6. "One Knob" Sidechain Circuit

The RMS and More voltages, along with V_{DIODE}, appear inverted at the output of stage E to vary the dynamic impedance of D6. To increase the useful range of impedance variation versus the RMS detector output scale factor (approximately 300 mV total for a 1N4148 and 6.1 mV/dB for the 4316) the RMS input (R30) has a gain of 2 compared to V_{DIODE}. The RMS detector scale factor at the output of stage E becomes -12.2 mV per dB. The More control skews the output voltage by +/-250 mV (R32) to shift D6's operating point which controls compression. D6, in series with R40, controls sidechain gain using it's dynamic impedance while simultaneously providing a soft-knee compression characteristic from an exponential voltage-current relationship. The gain of stage H through the primary sidechain path is R42/(R40+Zd) where Zd is the dynamic impedance of D6.

The sum of V_{DIODE} and More voltages at the output of opamp F drive diode D7 to provide an inverted replica of output E without dynamic contribution from the RMS detector. R37 and R38 correct the gain error introduced by R35 and R36. The dynamic impedance of D7 plays an important role in providing corrective make-up gain which tracks the dynamic gain reduction in the primary sidechain. The gain of stage H through the secondary path is R42/(R41+Zd) where Zd is the dynamic impedance of D7.

Inverting opamp stage H converts the currents in D6 and D7 to a control voltage, Ec-. Current is subtracted by D6, raising the voltage at TP3 to decrease VCA signal gain, while current is added by D7 to increase VCA gain to provide compensating "make-up." The current through D6 is dynamic based on signal envelope. The current in D7 is static and varies with the More control. The gain of stage H (neglecting Zd) is 0.5 (R42) to re-establish a +6.1 mV per dB attenuation scale factor.

More control tracking is affected to a minor degree by thermal mis-match between D6 and D7. Since D6 and D7 tie to the same opamp input placing them side-by-side on a PC board layout is very easy. Thermal matching between D5 and the D6/D7 pair is not as critical since the change in D5's forward voltage affect D6 and D7's operating points equally.

Capacitors C30, C31 and C32 provide stability for sidechain opamps E, F and H.

The One Knob Squeezer's *internal* operating level is -20 dBu which defines the compression "pivot" or rotation point. The average level for correct tracking of the More control is at the rotation point. At average levels above or below the rotation point, the More control will introduce level shifts. Figure 7 shows the One Knob Squeezer's input-output level relationships with various degrees of compression rotated around this rotation point. The curves below were measured from the input jack and include the 6 dB of gain introduced by the preamp stage. Notice that the internal -20dBu rotation point is shifted down to -26dBu when viewed from the outside world.

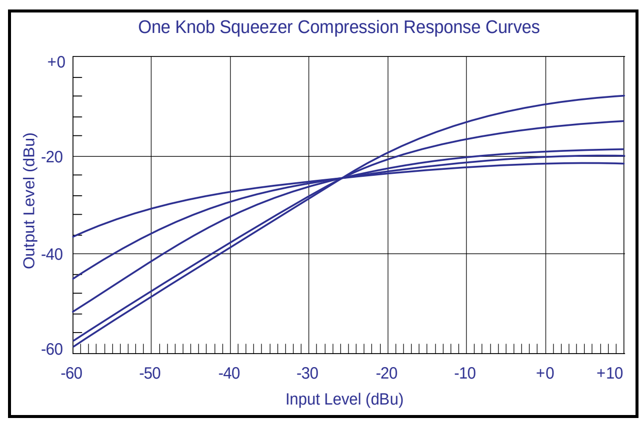

Figure 7. Input vs Output Levels

An optional, but recommended, trimmer (VR3) can be used to adjust the nominal operating level of the One Knob Squeezer to offset RMS detector level error (approximately +/-13mV at the output or +/-2dB input-referred). Without calibration, the rotation point can vary by as much as +/- 2dB. Adjustment of VR3 as a production trim is described in the Calibration and Test Procedures.

VR3 can also be a front panel control or user-adjustable screwdriver trim to permit operating levels other than -20 dBu. In pedal applications adjustment of instrument levels ahead of the One Knob Squeezer will usually suffice and no external adjustment of VR3 will be required.

Power Distribution

The 4316 One Knob Squeezer is operated from a single 9V battery. Operating current is typically 5 mA using four MC33178 dual low power opamps.

The input power connector is protected against reverse polarity by diode D8. C40 and C41 filter the battery supply. All opamps are powered from the 9V supply and include local bypass capacitors C45-C48. The +5V supply for the THAT4316 is provided by IC2, a LP2950 low dropout, low quiescent current, regulator. C42 and C43 bypass the LP2950 output and THAT4316 Vcc input. The +5V supply is also used by VR1, VR3 and the NLC as references.

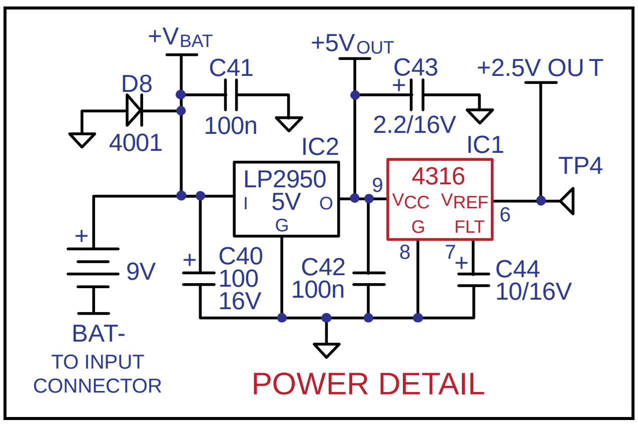

Figure 8. Power Distribution Circuit

The THAT4316 internal Vcc/2 voltage divider is bypassed by C44. The +2.5V V_{REF} output of the 4316 provides a reference for opamps E, F, G and H along with the 4316 VCA Ec+ pin. The 4316 V_{REF} output should not bypassed due to a maximum 100 pF load capacitance.

Calibration and Test Procedures

The only adjustment is the recommended trimmer, VR3, to compensate for variations in the 4316 RMS detector. The adjustment procedure is provided in the following steps.

1) Input 39 mV RMS, -26 dBu, to the input connector J1.

2) Check that the preamp output level is -20 dBu or 77.5 mV RMS. (There is 4.5V DC present at TP1.)

3) Measure the DC potential from TP4 to TP5. It should be within +/-13 mV.

4) Set the More control to maximum clockwise rotation.

5) Measure the DC potential from TP4 to TP3. Adjust VR3 for 0V +/- 1 mV.

6) Meter the AC level at TP2. It should be -20 dBu +/- 0.5 dBu. (There is +2.5V DC present at TP2.)

7) Rotate the More control from full clockwise to full counter-clockwise and back while noting the level shift at TP2. The level shift should be less than 1 dB.

Modifications and Experiments

The reader is encouraged to tweak this design to suit their requirements. Two areas ripe for experimentation are the NLC timing capacitor, C21, and diode pre-bias current set by R39.

If an NLC is not required for the intended application a conventional timing capacitor can be used from the THAT4316 C_T pin to ground. In this configuration the positive terminal of the cap connects to pin 4 and opamp C is eliminated.

When a variable gain output is not required R15 and the following circuitry can be connected directly to opamp D. In this configuration the overall input-to-output polarity will invert. An option to maintain correct polarity would be to eliminate VR2 and make the output stage B a fixed gain circuit.

Conclusion

The THAT4316 Analog Engine® provides a simple, low-cost and low power solution for the guitar pedal designer. This Design Note is just one example of a feed-forward “One Knob” compressor. Other compression topologies such as feedback and inverse compression benefit from the 4316's ease-of-use, low power and modest cost.

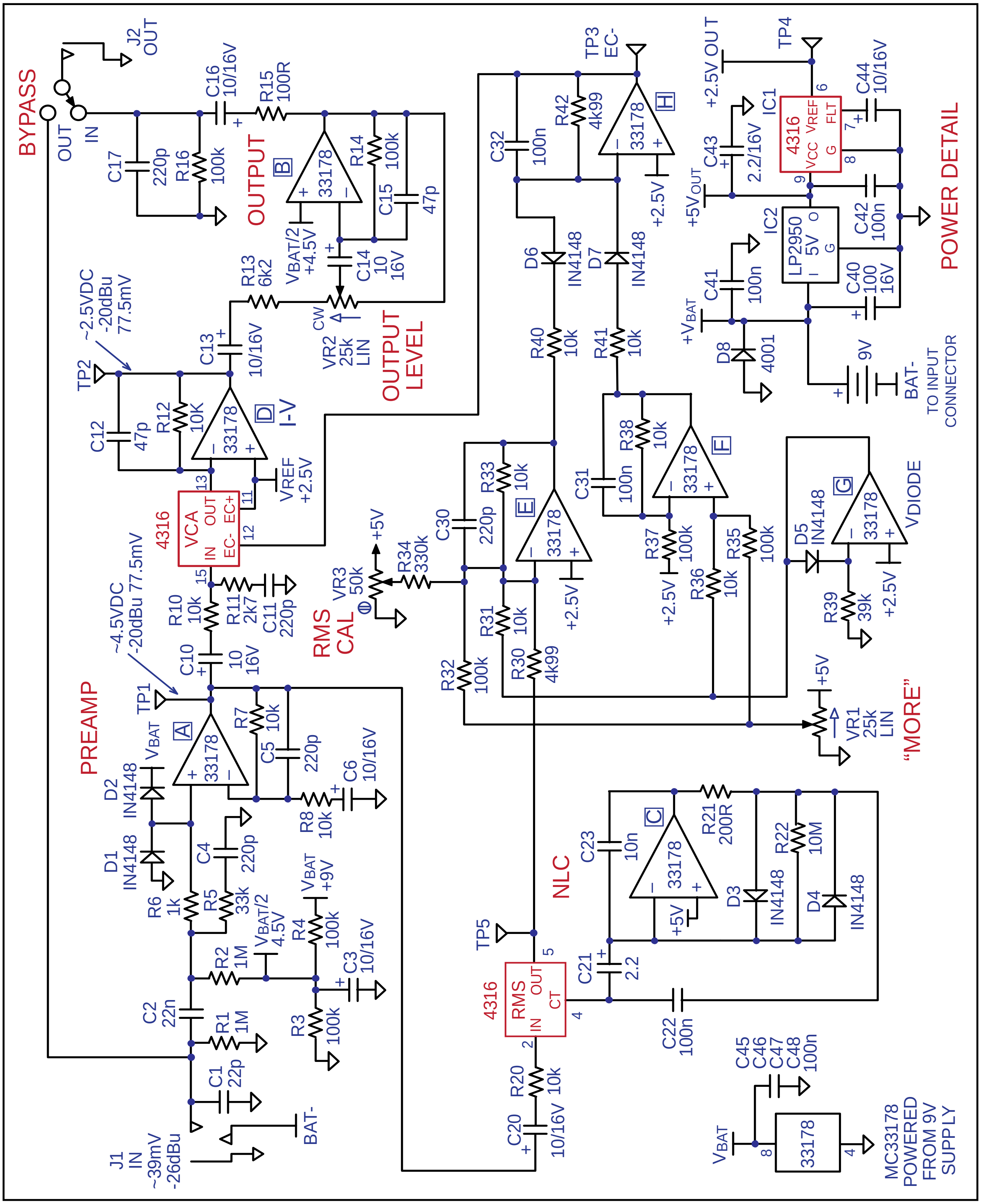

Figure 9. One Knob Squeezer Schematic