The "One Knob Squeezer"

The circuits within this application note feature THAT4301 Analog Engine® to provide the essential elements of voltage-controlled amplifier (VCA) and rms-level detector (RMS). Since writing this note, THAT has introduced several new models of Analog Engines, as well as new VCAs. With minor modifications, these newer ICs are generally applicable to the designs shown herein, and may offer advantages in performance, cost, power consumption, etc., depending on the design requirements. As well, a standalone RMS is available to complement our standalone VCAs. We encourage readers to consider the following alternatives in addition to the 4301:

- Low supply voltage and power consumption: 4320
- Low cost, supply voltage, and power consumption: 4315
- Low cost and power consumption: 4305
- High-performance (VCA only): 2180-series, 2181-series
- Dual (VCA only): 2162
- RMS (standalone): 2252

For more information about making these substitutions, please contact THAT Corporation's technical support group at apps_support@thatcorp.com.

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Electronic compressors are widely used throughout the audio industry for audio leveling, limiting, as an "effect", and for dynamic range preservation. The typical compressor seen in the pro audio industry can be an intimidating device to many end users however, with their assorted knobs and switches to control parameters such as gain, threshold, compression ratio, attack and release, stereo linking, and the like. With this many controls, it is difficult for even an experienced user to get the performance they desire, especially since these controls often interact with each other. These interactions can be distracting and confusing, making it difficult to discern the true effect of a given adjustment.

An alternative to this high level of complexity is a circuit we call the "One Knob Squeezer", the topic of this Design Note. The circuit allows for the continuous adjustment of gain, threshold and compression ratio with a single potentiometer, forming the basis for compressor designs which are more intuitively accessible to a wider range of users.

Conventional compressor side-chains

Developing an intuitive understanding this new circuit's advantages is easiest when compared with more conventional compressor designs. In this paper we contrast the "One Knob Squeezer" design with a generic compressor to illustrate the former's advantages.

Compressors can be of the feedforward or the feedback variety. While each topology has its merits, this application uses the feedforward topology, in part because there is no interaction between the compression ratio and the rms-level detector's timing characteristics.

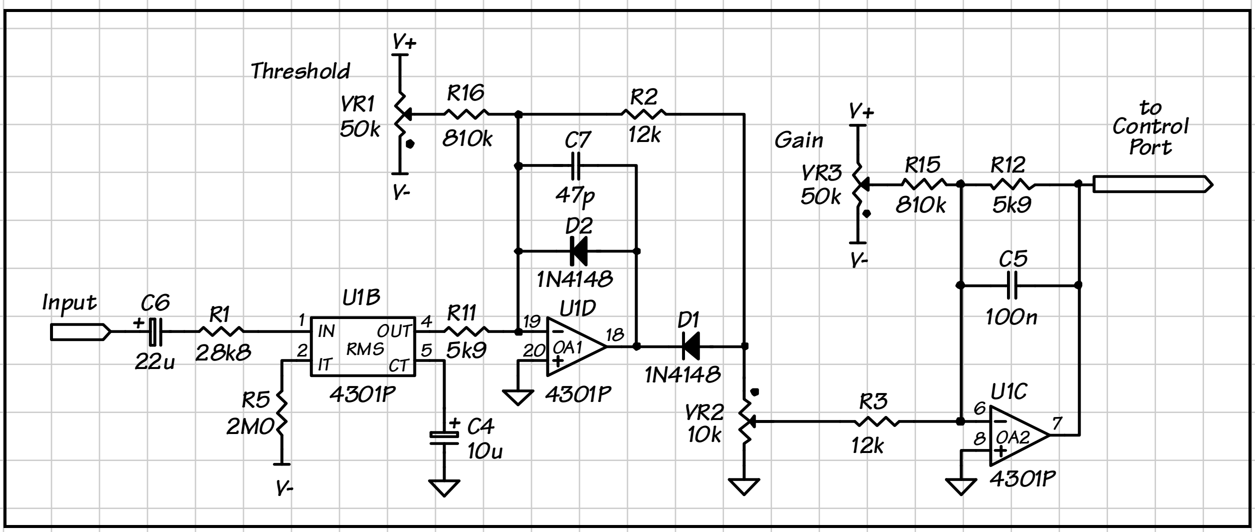

Figure 1. Basic comp/limiter sidechain with independent gain and threshold

A compressor may or may not include one or more threshold levels. Compressors without thresholds are typically used in noise reduction systems and in some gain leveling applications. While there have been a few compressors with multiple thresholds, these devices, as one might expect, are difficult to tune, and all but the most experienced users are left to rely on the previous user's settings or whatever factory presets are provided.

Most compressors have a single threshold, above which compression takes place, and below which the input is passed without modification (except for, in some cases, constant gain). The above threshold compressor is a first order approximation of gain riding in the sense that a recording engineer could be expected to reduce gain at higher levels to avoid clipping, but would be unlikely to raise gain in quieter passages which might exaggerate the noise floor. Still, while Still, while a single threshold makes setup easier, having a single compression ratio can be constraining, especially if that compression ratio is ∞:1.

Figure 1 shows the sidechain of just such a limiting compressor. This sidechain has both a threshold and a compression ratio adjustment, the two primary controls for an above-threshold compressor. Additionally, there is an adjustment for makeup gain. Figure 2 shows how the output varies as the threshold adjustment is swept from one end to the other in approximately 10 dB steps.

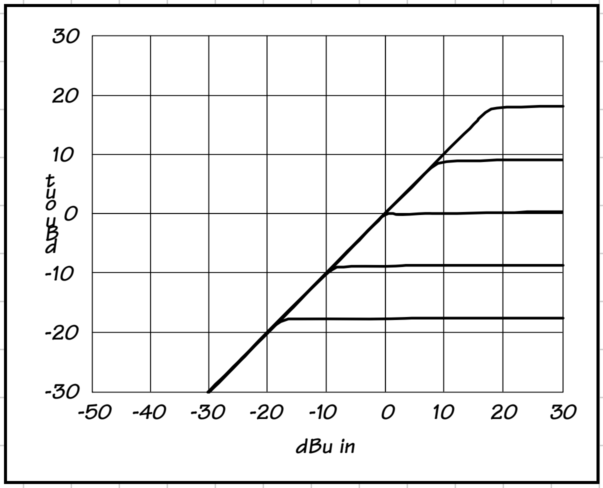

Figure 2. Typical hard knee threshold characteristic

The most obvious effect is that, as the threshold is lowered, the output level for signals above threshold is lowered as well. This interaction between threshold and output level necessitates the addition of a makeup gain adjustment. The effect of varying the makeup gain (with a fixed threshold) in 10 dB steps can be seen in Figure 3.

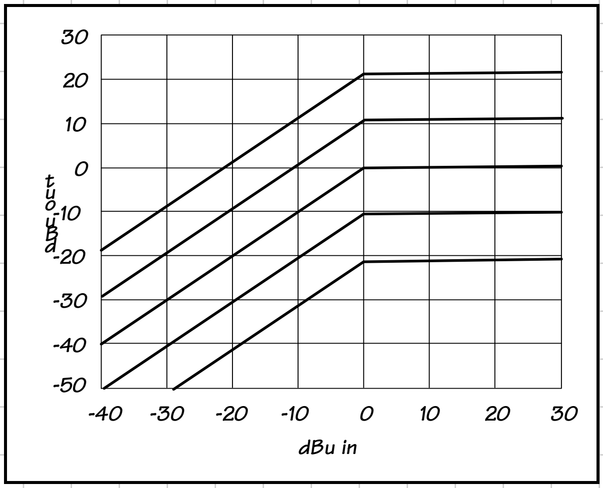

Figure 3. Typical makeup gain characteristic

In order to hear the effect of changing the threshold, the compressor must be adjusted while the signal is above threshold. To avoid having a change in threshold alter the overall output level, the user of a generic compressor must compensate by simultaneously adjusting the makeup gain control.

In addition to the gain/threshold interaction, there is also an interaction between compression ratio and output level. The effect of changing the compression ratio can be seen in Figure 4. Notice that the output level shift with change in compression ratio is proportional to the amount that the signal is above threshold.

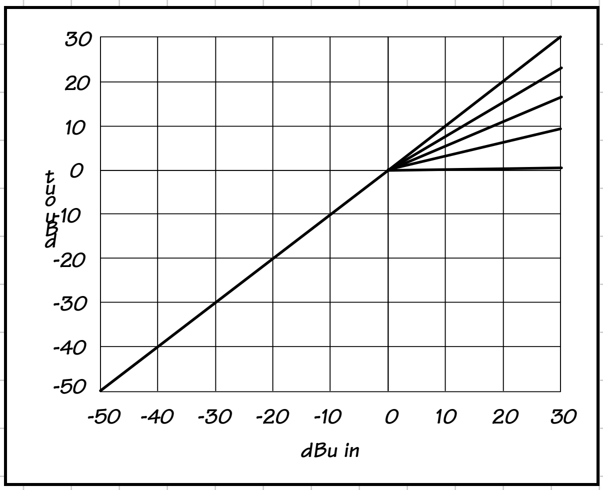

Figure 4. The effect of changing compression

Figure 5 shows a slight variation of the sidechain circuitry shown in Figure 1 to help deal with changes in output level. This circuit combines the gain and threshold control, and applies a gain change when the threshold is adjusted . The effect of this change can be seen in Figure 6.

Referring again to Figure 2 and the circuit of Figure 1, we see that reducing the threshold by 10 dB in a generic compressor results in a reduction in output level of 10 dB. For lack of a better term, we'll refer to this as the gain/threshold interaction ratio. With the modification of Figure 5, the degree of interaction

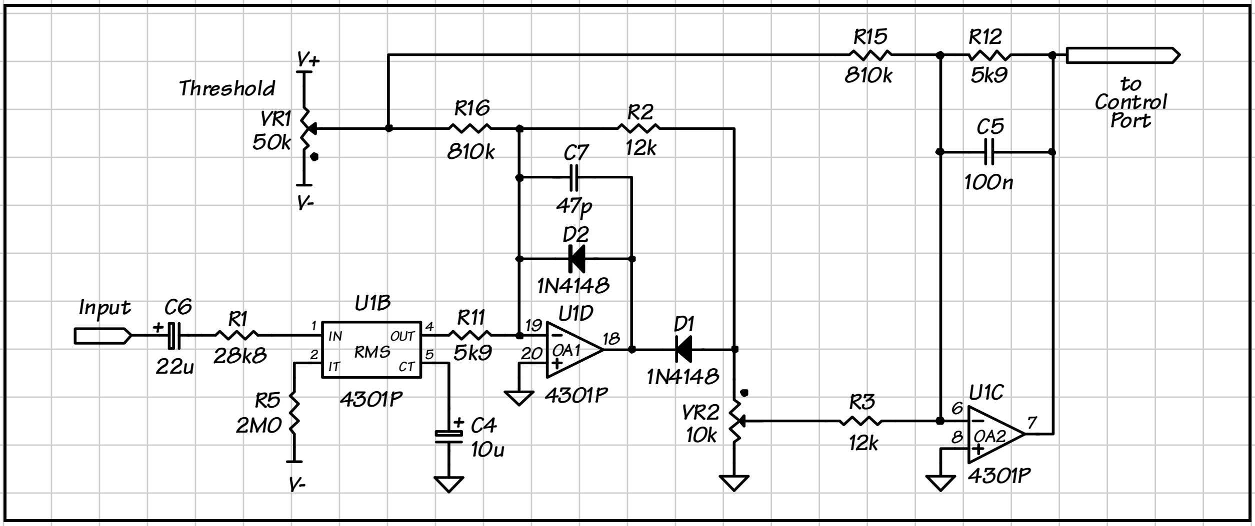

Figure 5. Comp/limiter sidechain with complementary gain and threshold

is actually reduced by a factor equal to the compression ratio. Thus, as is shown in Figure 6, a compression ratio of ∞:1 results in an output level variation of 1/∞, or zero.

For lower compression ratios, however, the situation is improved over that of the generic compressor, but it is not completely solved by the circuit of Figure 5. For example, a compression ratio of 4:1 results in a gain/threshold interaction ratio of 1/4 or 25%. With a compression ratio of 2:1, the gain/threshold interaction ratio is 1/2 or 50%, and so a 10 dB change in threshold results in a 5 dB change in output level. So, in order to ensure a constant output level at lower compression ratios, another makeup gain adjustment must be added, and at compression ratios other than ∞:1, the operator must still adjust both threshold and gain simultaneously.

The "soft knee" compressor

Above and beyond level interaction, the compressors discussed so far have very sharp thresholds where the compression ratio shifts abruptly from 1:1 to as much as ∞:1. This sudden transition can be audible and distracting whereas, in most uses, the end result of compression should be inconspicuous to the listener.

Lower compression ratios will generally result in a less conspicuous sonic signature, but can be inadequate to provide overload protection. High compression ratios provide adequate protection, but can sound unnatural. While overly compressed material is, under most circumstances, preferable to clipped or heavily distorted material, it can still be sonically undesirable. This property limits the use of higher compression ratios over a large portion of the input signal's dynamic range.

Multiple, adjustable thresholds would address this issue, since one could program different compression ratios over different parts of the initial dynamic range, and gradually squeeze the signal harder and harder as the overall level increased, but without the abrupt

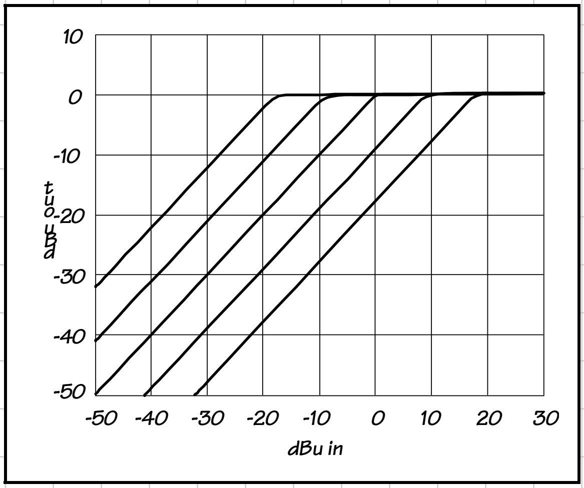

Figure 6. Control characteristic with complementary gain and threshold

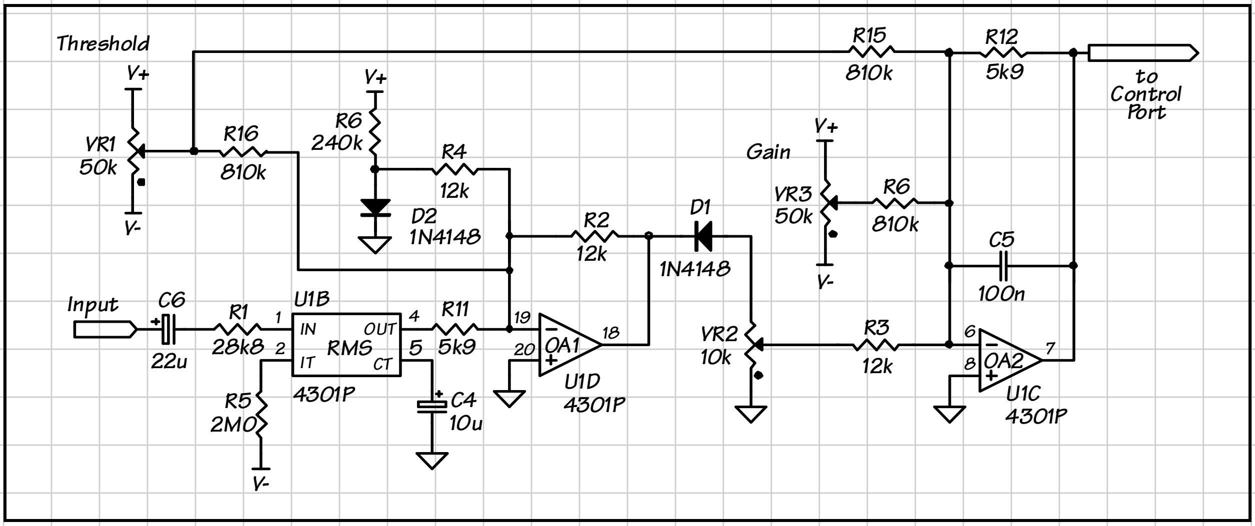

Figure 7. Soft knee comp/limiter with complementary gain and threshold

change in compression associated with a single threshold. However, this approach is not generally used due to the cost and complexity of the design. A practical alternative is the "soft knee" threshold shown in Figure 7.

The hard knee "operational rectifier" used in the preceding circuits acts, to a degree, like an ideal diode with no forward drop, and this behavior is essentially limited only by the non-ideal characteristics of the op-amp used to implement the circuit. In a soft knee approach, feedback is no longer used to idealize the threshold diode's behavior, and a second diode is used to generate a temperature-compensated offset to cancel the threshold diode's forward drop at a single forward current.

It can be shown that the compression ratio for a feedforward compressor is

$$C.R. = \frac{dB_{In}}{dB_{Out}} = \frac{1}{1-\beta} \quad \text{(Equation 1)}$$

where β is the net gain through the sidechain. We can see by inspection that a net sidechain gain of one results in a compression ratio of ∞:1, and that a net effective sidechain gain of one-half results in a compression ratio of two.

Neglecting parasitic resistance, the small-signal impedance of a diode at room temperature at any given current is

$$Z_d = \frac{V_T}{I_d} = \frac{26mV}{I_d} \quad \text{(Equation 2)}$$

This impedance can be used to make a first-order approximation of the compression ratio resulting from a given diode current. Here, one can see by inspection that the impedance equation is a hyperbolic function, and that as the diode current increases, the resulting impedance gets quite small which, when factored into the gain of the side-chain, results in an ultimate compression ratio which asymptotically approaches ∞:1. Likewise, when the diode current is very small or nonexistent, the diode becomes an effective open circuit, and the compression ratio approaches 1:1.

As an example, let's arbitrarily assume that the current through D1 is 3 μA. The diode's small-signal impedance becomes

$$Z_d = \frac{26mV}{3\mu A} = 8.7k\Omega$$

and the resulting side-chain gain will be

$$A_{S.C.} = \left(\frac{12k\Omega}{5.9k\Omega}\right)\left(\frac{5.9k\Omega}{12k\Omega+8.7k\Omega}\right) = 0.58$$

We can calculate the compression ratio to be

$$C.R. = \frac{1}{1-\beta} = \frac{1}{1-0.58} = 2.4$$

or 2.4:1.

Next, assume that the current through D1 is 20 µA. Then

$$Z_d = \frac{26mV}{20\mu A} = 1.3k\Omega$$

and the side-chain gain is

$$A_{S.C.} = \left(\frac{12k\Omega}{5.9k\Omega}\right)\left(\frac{5.9k\Omega}{12k\Omega+1.3k\Omega}\right) = 0.9$$

giving a compression ratio of

$$C.R. = \frac{1}{1-\beta} = \frac{1}{1-0.9} = 10$$

or 10:1.

It should be noted that these calculations are, at best, a first order approximation of the behavior of the soft-knee threshold. Nevertheless, one could calculate compression ratios at other diode currents to verify that the compression ratio increases smoothly as the diode current increases, eventually approaching ∞:1.

The actual solution must take into account both small and large signal effect of the diodes, as well as parasitic resistances, though the effects of these second-order terms result in only minor changes to the simplified calculation. Figure 8 shows the result of a SPICE simulation of a soft knee compressor (with the side chain shown in Figure 7). The desirable characteristic is evident, as the signal is initially compressed only slightly, but becomes more heavily compressed as the overall signal level increases. This is, in some sense, the equivalent of having an infinite number of thresholds and compression ratios which initially compress inconspicuously, but ultimately provide the protection of a limiter.

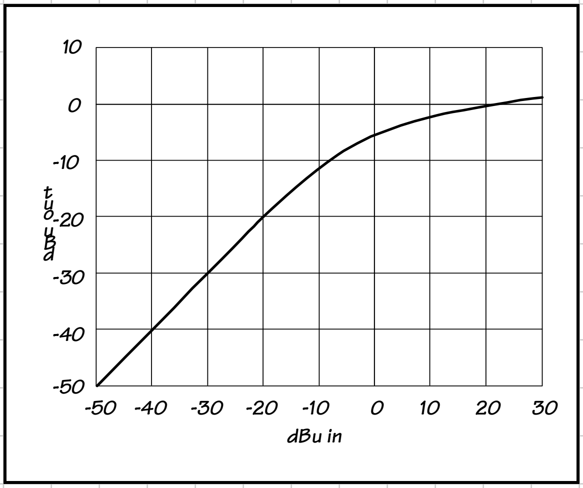

Figure 8. Soft knee threshold characteristic

Still, this circuit has a threshold, gain and compression ratio adjustment, and though it might by sonically superior to the circuit in Figures 1 and 4, it still suffers from the same interactions and consequent difficulties in user adjustment.

The "One Knob Squeezer"

There were two primary goals in designing the "One Knob Squeezer" circuit. The first was, obviously, that it sound good in those applications where compressors are usually employed.

The second was that it provide an interface simple enough for even a novice user to tune. A third (implicit) goal was that the circuit be inexpensive and practical.

The first goal was achieved by careful listening and tweaking of the circuit. The third was by achieved by using a single-chip dynamics processor, the THAT 4301 Analog Engine®, and being diligent about minimizing the parts count.

Tuning simplicity was achieved by an innovative design wherein threshold, compression ratio, and makeup gain were implemented with a single adjustment by taking advantage of the soft-knee threshold's signal-dependent compression ratio characteristic. As was discussed previously, any compression ratio from 1:1 to near ∞:1 is readily achievable with the soft-knee threshold circuit. The compression ratio that will result at any given input level is dependent on the threshold setting, and as such, the compression ratio adjustment can be omitted. To account for the changing output signal level, a variation of the complementary gain and threshold sidechain was designed. After auditioning a number of variations, the best approach was found to be a make-up gain adjustment that complied with the soft-knee curve.

The resulting transfer characteristic is shown in Figure 9. This series of curves shows input versus output while the "More" potentiometer is swept from fully CCW to fully CW. One can see that the output level remains constant around the -10 dBu level, the intended nominal listening level. As the "More" potentiometer is swept towards fully CW (which lowers the threshold while simultaneously increasing the makeup gain), the compression ratio increases and the curves pivot about the -10 dBu point. As this happens, a larger portion of the input signal's dynamic range is more heavily compressed.

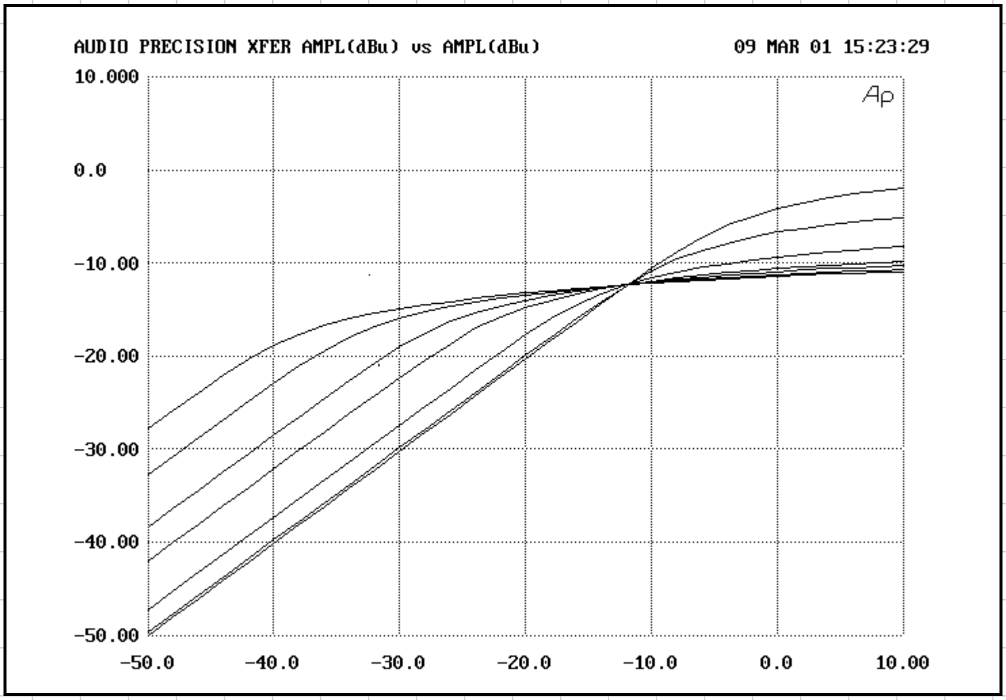

Figure 9. Transfer characteristic of the “One Knob Squeezer”

During normal operation, the user should adjust the gain of the signal chain ahead of the compressor so that the average signal level is at the desired nominal listening level (in this case, -10 dBu). Once this level is set, the user can easily add compression with a single adjustment, backing off when pumping or sibilants become noticeable or the signal sounds overly compressed, all without the distraction or confusion caused by changes in output level.

As a troubleshooting and design tool, Figure 10 shows the output of the control port buffer (U1C). The portion of the curves which are horizontal correspond to regions where the signal is not compressed.

Figure 11 shows the final version of the "One Knob Squeezer". The VCA portion of the circuit is identical to the recommended applications circuit in the data sheet, except that C6 has been increased to 22 µF. The rms-level detector is configured with 7.5 µA of timing current and a 10 µF timing capacitor, which results in a 34 mS time constant and, with a 28.8 kΩ input resistor, a -10 dBu zero dB reference level.

Some circuit "tricks" were used to minimize the parts count in the sidechain. Unlike earlier versions, the soft-knee threshold is implemented with a pair of matched NPN transistors. Q1 forms the threshold. The forward drop of its base-emitter junction is canceled by Q2 which is biased by R14. R14 effectively acts as a current source, biasing Q2 at approximately 9 µA. The threshold is adjusted by summing in the "More" signal with the rms-level detector output at inverting input of U1D. This offsets the detector's output on the "soft knee" curve.

A comparable circuit forms the "soft-knee" portion of the make-up gain circuit. A pair of PNP transistors, Q3 and Q4, and the resistor R13, are configured in a manner similar to the

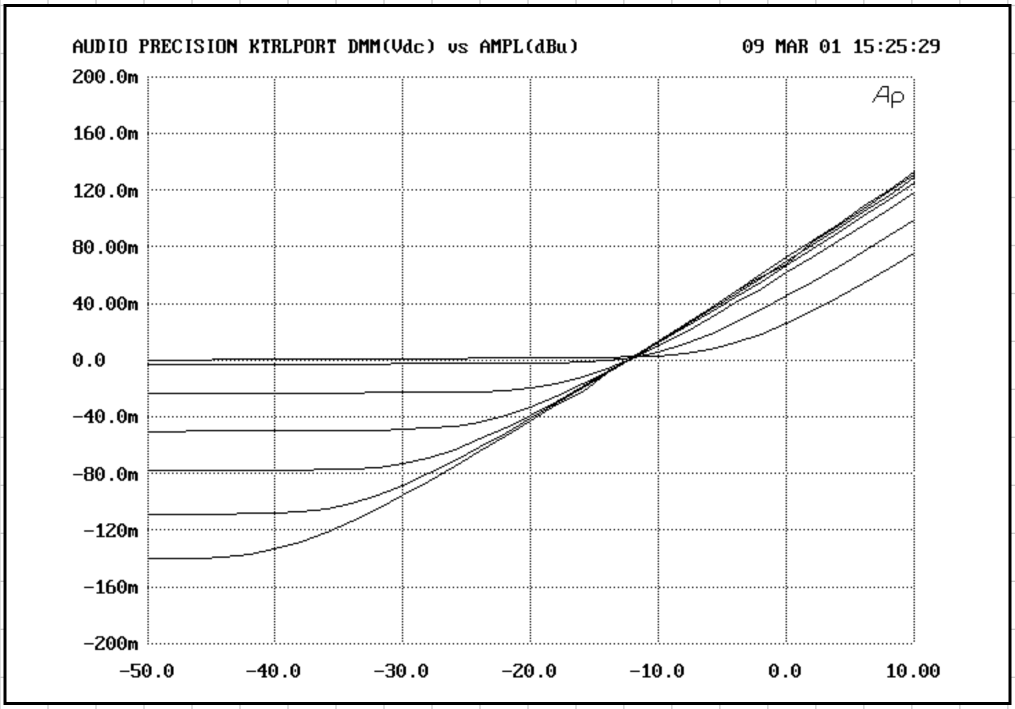

Figure 10. Output of the control port buffer

threshold circuit to provide "shaping" for the gain component of the "More" control, resulting in an appropriately attenuated version of the "More" control.

A conventional make-up gain adjustment is provided for situations where -10 dBu is not an appropriate pivot point. This make-up gain adjustment is summed with the "soft-knee" portion of the make-up gain and the output of the "soft-knee" threshold into the inverting input of U1C, which then drives the control port. While this constitutes a second control on the "One Knob Squeezer", it's an adjustment that only needs to be made once when the equipment is initially configured, and is left untouched thereafter. All tuning is still performed with the "More" knob.

Closing thoughts

The "One Knob Squeezer" can perform admirably in a variety of conventional compressor applications, and especially where the end product will be adjusted quickly or by relatively inexperienced users. Good examples are guitar and bass amplifiers, where a plethora of compressor controls would be out of place, but where a single-knob compressor control would be entirely welcome.

For certain specific applications, modifications can be made to the circuit of Figure 11. All compressors exhibit some LF (low frequency) distortion resulting from unfiltered ripple on the control port. A fixed value for the timing capacitor (C4) is a compromise between LF distortion and fast response. A "Non-Linear Capacitor" circuit, described in THAT Corporation's Design Note DN03 (formerly Application Note AN103), eliminates the need for this tradeoff. The Non-Linear Capacitor responds quickly to rapidly changing levels, but heavily filters static or slowly changing signals in the control path. This enhancement is perfect for a bass amplifier with a built-in compressor.

Stereo applications (obviously) require two channels. Unfortunately, two independently compressed channels can result in the stereo image "wandering" as the compressors react to the differing information in their own signal path. Stereo linking, which is described in Design Note DN116, addresses this problem. When two channels need to be linked, the ungrounded side of their respective timing capacitors are shorted together resulting in what is often referred to as "true power summing", and both VCA control ports should be driven from the resulting single side-chain signal.

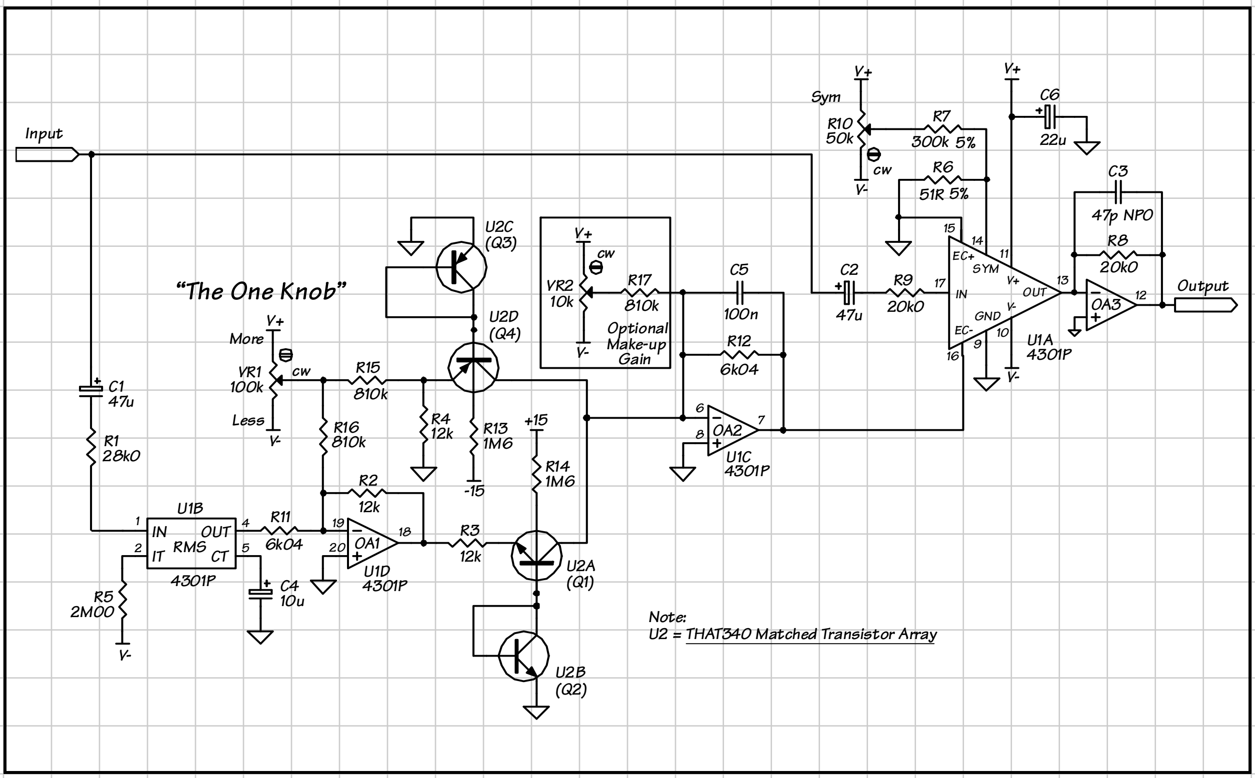

Figure 11. The “One Knob Squeezer”