Dealing with the PTAT Coefficient

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), or the THAT2180 (VCA) and 2252 (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. We encourage readers to consider the following alternatives in addition to the parts shown in the note:

- Analog Engine (VCA, RMS, opamps) with low supply voltage and low power: 4320
- Analog Engine (VCA, RMS) with low cost, low supply voltage, and low power: 4315
- Analog Engine (VCA, RMS) with low cost and low power: 4305
- High-performance Trimmable VCA: 2181-series
- Dual VCA: 2162

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

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The nature and origin of the PTAT coefficient in THAT Corporation's VCAs and RMS detectors was previously discussed in Design Note 128. This coefficient is a span coefficient, the effect of which can calculated as

$$Span\ error_{dB} = Gain_{dB}\left[\frac{T^{\circ}K - T_{Room}{}^{\circ}K}{T_{Room}{}^{\circ}K}\right]$$

By inspection we note that when the gain is zero, the span error is zero, and that the error is a linear function of gain.

VCAs are typically used at gains between 20 dB and -100 dB, though in reality, the most useful portion of the range is ±20 dB, and the last 50 dB on the negative side are varying degrees of mute. The span error at ±20 dB of gain and a ΔT of 45°C (70°C - 25 °C) is

$$Span\ error_{dB} = 20\ dB\left[\frac{-45\ {}^{\circ}C}{298\ {}^{\circ}K}\right] = -3\ dB$$

If this amount of error is acceptable, then there is usually no need to consider further correction. While the worst case error could be as high as 15 dB at a gain of -100 dB, this is typically not an issue, since the audible difference between -85 dB and -100 dB is minimal. Additionally, there are a number of other circumstances where compensation is not necessary.

Consider the companding noise reduction encoder in Figure 1. This circuit is basically a feedback compressor with a 2:1 compression ratio, but with the addition of a low pass Sallen-Key filter and pre-emphasis for both the signal and the detector. Note that the output of the detector is connected directly to the control port of the VCA. This connection results in the cancellation of the VCA and RMS detector's respective temperature coefficients.

This fact may not be immediately obvious, since the polarities of the coefficients are the same. Notice however, that the detector's temperature coefficient refers to its output, but the VCA's coefficient refers to its control port. Consequently, as the detector become more sensitive with rising temperature, the VCA's control port becomes correspondingly less sensitive, and the temperature coefficients cancel.

This cancellation in nearly perfect with the THAT4301 and THAT4311, since their detectors and VCAs are on the same die, and are essentially at the same temperature. Furthermore, second order effects that we haven't discussed also cancel, though these are typically quite small anyway. With the THAT215X/218X VCAs and the THAT2252 RMS detector, the situation can be more problematic, but by placing the THAT2252 right next to the VCA which it is controlling, temperature variations between the parts can be minimized. For best results, the two SIP packages (ideal for this sort of co-location) should be so close that they can actually touch.

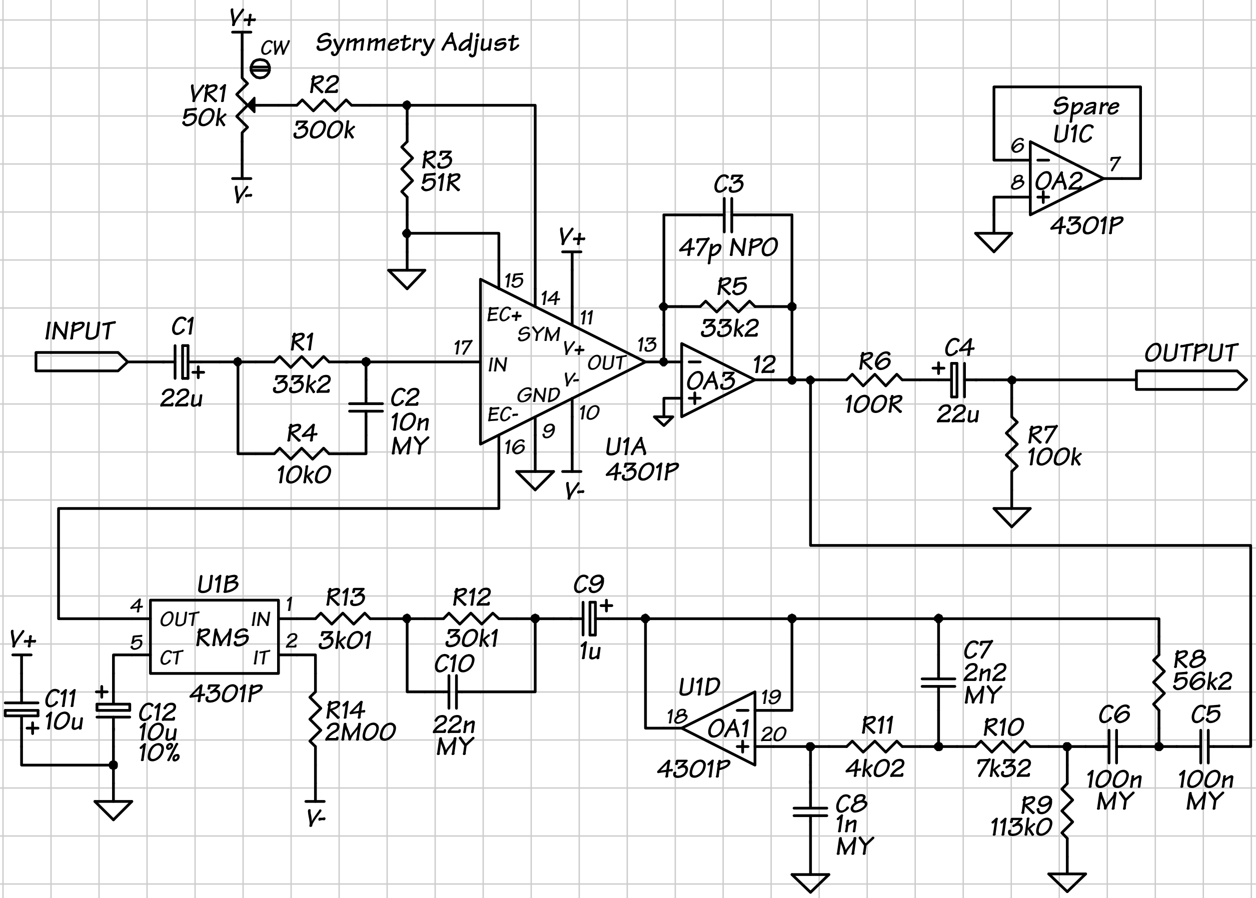

Figure 1. 2:1 companding noise reduction encoder

For feedback compressors, connecting the output of the RMS detector directly to the VCA inverting control port results in a compression ratio of 2:1, and for the feed forward topology, the compression ratio will be infinity:1. Fortunately, the aforementioned temperature coefficient cancellation occurs even when the control signal is amplified or attenuated, so other compression ratios are available as well.

Figure 2 shows a THAT4301P in a typical hard-knee feed forward compressor with variable compression ratio and adjustments for both gain and threshold. Since the gain and threshold adjustment offsets are not PTAT (in fact, they're temperature independent), they will result in temperature dependant behavior even thought the compression ratio will not. To address this problem, R13 and R17 have a temperature coefficient of +3300 ppm/ °C, which is derived from

$$TC = \frac{1\,^{\circ}K}{300\,^{\circ}K} = 0.003333\ldots \approx +3300\frac{ppm}{^{\circ}C}$$

R13 compensates for the PTAT coefficient of the detector, and R17 'un-compensates' the signal by re-introducing the PTAT behavior.

Both R13 and R17 should be placed as close to the THAT4301 (or THAT4311) as is practical to ensure the best possible compensation. When this same circuit is implemented with a discrete VCA and RMS detector (i.e. A THAT2252 and a THAT215X or THAT218X), R13 should be placed in close proximity to the detector, and R17 should be placed adjacent to the VCA in question.

Remember that while the temperature coefficients of the detector and the VCA are large, these coefficients are truly proportional to absolute temperature, with no substantial tolerance. The coefficients of R13 and R16 are not produced by such a mechanism, but rather by mixing various resistive materials to achieve the appropriate coefficient. Consequently, temperature coefficients of these devices, while nominally +3300 ppm/ °C, will still have a tolerance , and as such be unable to achieve complete cancellation of the PTAT coefficient in most instances. Nevertheless, the improvement will be sufficient to make the effects of temperature changes insignificant.

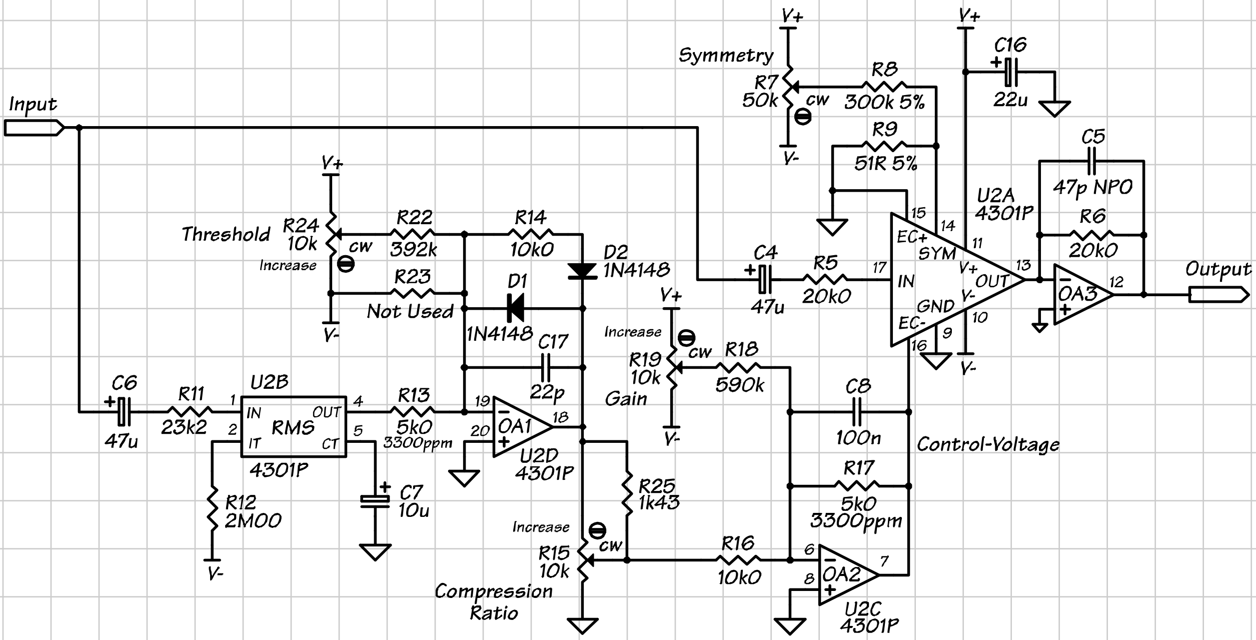

Figure 2. Typical Compressor/Limiter with threshold and gain adjustments

The circuit in Figure 3 circumvents this issue by making the threshold adjustment ahead of the RMS detector, where the signal is not temperature sensitive. The input network of the RMS detector provides for ±20 dBu of threshold adjustment.

Consider that for +20 dBu,

$$R_{IN} = \frac{0.775\left[10^{\left(\frac{Threshold_{in-dbu}}{20}\right)}\right]}{1.13 \times I_T} = \frac{0.775\left[10^{\left(\frac{20}{20}\right)}\right]}{1.13 \times 7.5\,\mu A} = 914\ k\Omega$$

And for -20 dBu

$$R_{IN} = \frac{0.775\left[10^{\left(\frac{-20}{20}\right)}\right]}{1.13 \times 7.5\,\mu A} = 9.14\ k\Omega$$

909 kΩ is the closest standard value for R22. 9.14 kΩ is the desired value for the parallel combination of R22 andR11. Thus,

$$R11 = \frac{1}{\left[\frac{1}{9.14\ k\Omega}\right] - \left[\frac{1}{909\ k\Omega}\right]} \approx 9.2\ k\Omega$$

Note that R11 shouldn't be any lower than this, since lower values of input resistors will result in bandwidth degradation at lower levels. If lower thresholds are desired, a variable gain amplifier ahead of the detector should be used.

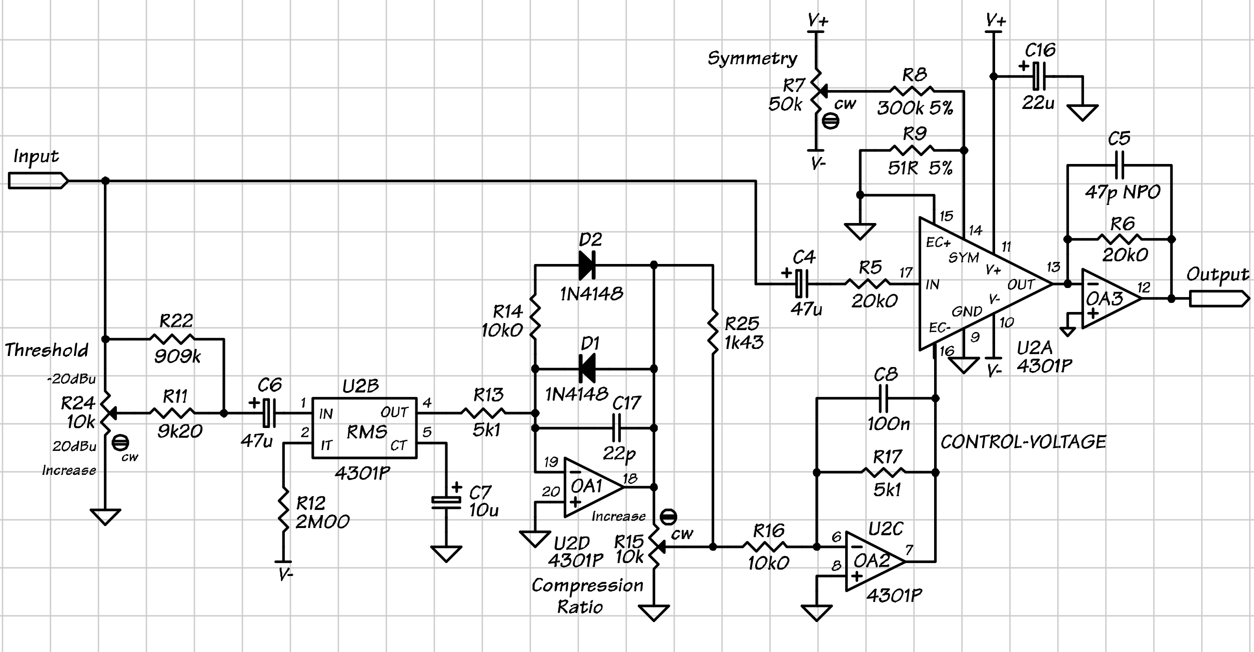

Figure 3. Typical Compressor/Limiter with threshold adjustments ahead of RMS detector

The circuit in Figure 4 shows the appropriate method of compensating a VCA in a purely gain control application. R11 is kept small to minimize its noise contribution, but this low value would require a very large capacitor for filtering. Consequently, a 'T' network is provided for filtering unwanted noise in the signal path. The corner frequency for this filter is calculated

$$f_C = \frac{1}{2 \times \pi \times 4.125\ k\Omega \times 2.2\,\mu F} \approx 18\,Hz$$

Where 4.125 kΩ is the Thevenin impedance seen at C3. The sensitivity at the input of the amplifier is

$$\Delta \frac{mV}{dB} = 6.1 \frac{mV}{dB}\left[\frac{R4 + R9}{R11}\right] = 6.1 \frac{mV}{dB}\left[\frac{8.25\ k\Omega + 8.25\ k\Omega}{1\ k\Omega}\right] \approx 100 \frac{mV}{dB}$$

The +3300 ppm/°C temperature coefficient of R11 corrects for the PTAT coefficient of the -Ec control port.

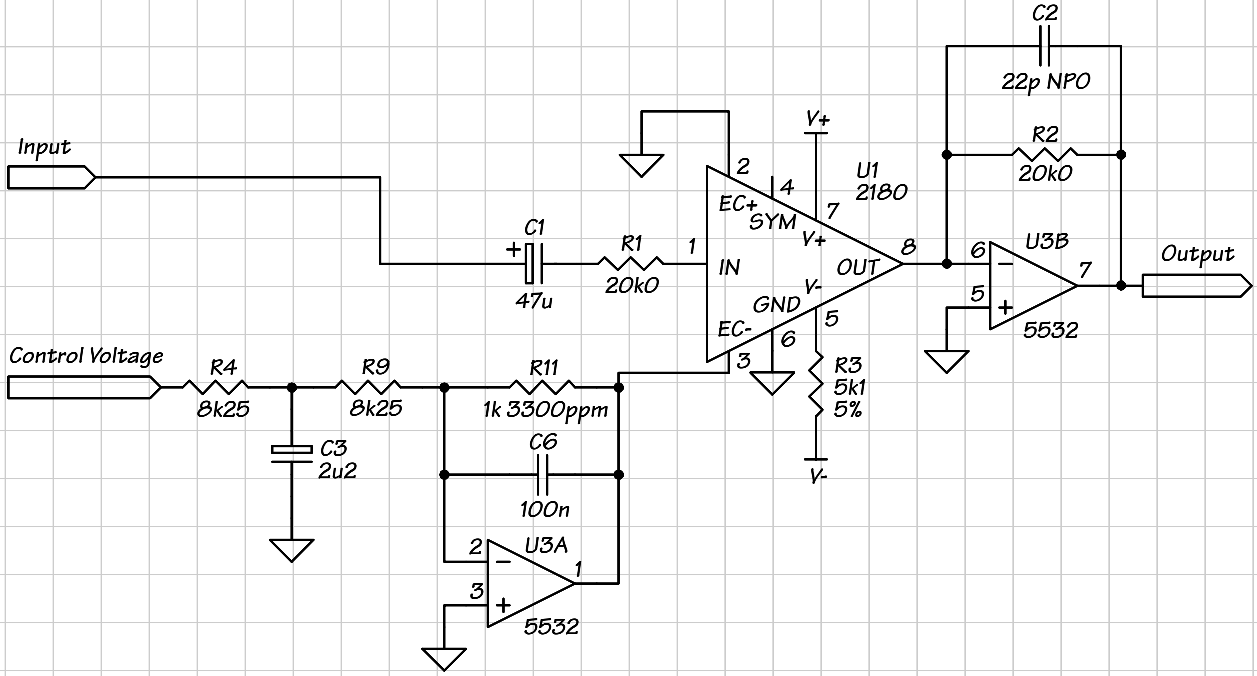

Figure 4. VCA temperature compensation in a gain control application

Figure 5 shows a THAT2252 RMS converter configured for a standalone metering application. R2 is a +3300 ppm/°C resistor to correct for the detector's span coefficient, and R3 is 33.2 kΩ to scale the output to 100 mV/dB.

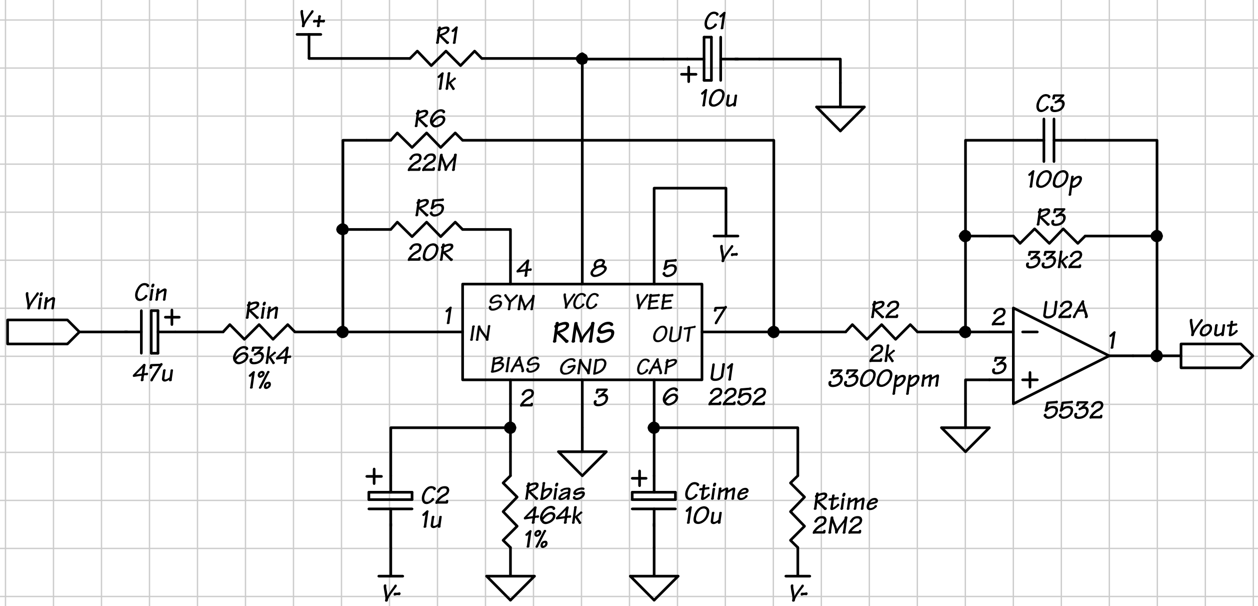

Figure 5. Compensating a THAT2252 RMS converter in a metering application