Basic Compressor/Limiter Design with the THAT4305

Abstract

THAT Corporation's Analog Engines are ideal basic building blocks for compressor/limiter designs. This design brief describes in detail the circuitry for two basic compressor/limiter designs using the THAT4305 Analog Engine. The first design is an above-threshold, hard-knee compressor with variable ratio, threshold and gain controls. The second design adds a soft-knee threshold. Suggestions for alignment are presented, as are ideas for modifying the basic circuits to allow common variations.

Basic Compressor/Limiter Design

This design brief describes how to use THAT Corporation's 4305 Analog Engine to make basic above-threshold compressor/limiters. Throughout the text, it is assumed that the reader has become familiar with the basic application of these devices. For additional information on the operation of the devices themselves, please refer to the 4305 data sheet. A THAT 4305 makes an ideal RMS detector and VCA controller pair for audio compressor and limiter designs. The RMS detector provides a dc output in logarithmic (decibel-scaled) format, while a VCA accepts gain control commands in exponential format (also decibel-scaled). The combination of a RMS detector and a VCA makes it possible to construct a variety of compressors and/or limiters with unprecedented ease, freeing the design engineer to concentrate on the functional requirements of a design, rather than on the methods to achieve this functionality.

Above-Threshold Compressor

Figure 1 shows a basic above-threshold compressor utilizing a 4305 Analog Engine. This design offers independent control over threshold, compression ratio, and after compression gain. Time constants are handled "automatically" by the RMS detector. The design exploits the highly predictable behavior of the 4305 to make possible a simple, effective and versatile feedforward approach to gain control. (For a mathematical analysis of this class of circuit, see DN-01A, The Mathematics of Log-Based Dynamic Processors, also available from THAT Corporation.)

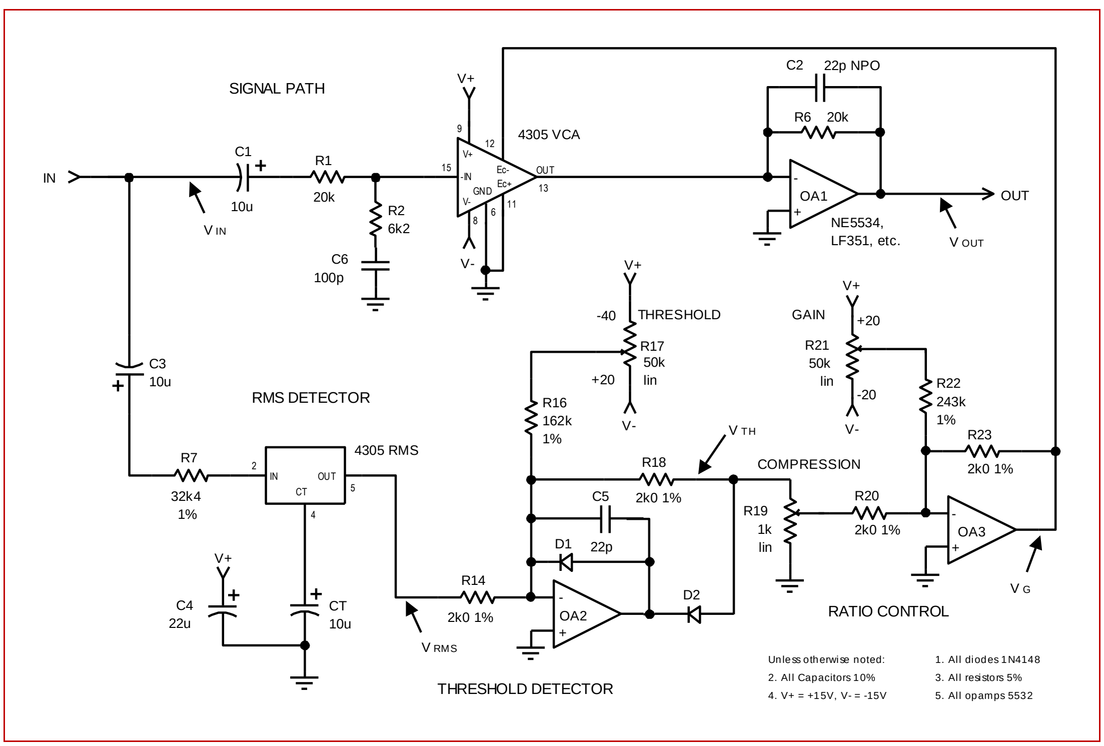

Figure 1. Basic Above-Threshold Compressor/Limiter.

Signal Path

The audio signal flows only through the 4305 VCA and OA1, making the signal path short enough to locate it entirely around the input and output jacks on the PC board. Input signals are coupled to the VCA through C1 and R1. Since the input of the VCA is a virtual ground, R1 determines the strength of the input (current) to the VCA. The 20 kΩ resistor shown is optimum for input voltages of up to about 10 V_{RMS}, or +22.22 dBu; C1 (along with R1) sets the low-frequency limit in the signal path ($fc = 1/(2\pi \cdot R1 \cdot C1)$). As shown, the -3 dB corner is at about 0.8 Hz. The VCA produces an output current signal in pin 13 which is a replica of the input signal, scaled (in decibels) by the voltage at pin 12. OA1 converts this current back to a voltage based on its feedback resistor, R6. For R1 = R6, as shown, $V_{IN} = V_{OUT}$ whenever pin 12 (the control port) is at 0 V (this is unity, or 0 dB gain). For every 6.2 mV increase in the voltage at pin 12, the gain decreases by 1 dB. For every 6.2 mV decrease in voltage, the gain increases by 1 dB. Therefore, the output signal level depends only on the input signal and the control voltage applied to pin 12.

RMS-Level Detector

The input signal is also applied to the 4305 RMS detector through C3 and R7 (like the VCA, the RMS's input is a virtual ground). In this circuit, the RMS detector is configured to provide 0 V at its output (pin 5) when approximately 243 mV rms (-10 dBu) is present at the circuit input. As the input signal varies, the RMS detector's output voltage will vary. For each 1 dB of increase in input level, its output increases by 6.2 mV. Every 1 dB decrease in input level causes a 6.2 mV decrease in dc output.

Adjusting the Threshold

The output of the RMS detector is connected to OA2, which is configured as an inverting, half-wave operational rectifier. Neglecting the effect of R16 and R17, when V_{RMS} is negative, the output of OA2 will be positive, and D2 blocks this voltage from reaching V_{TH}. Therefore, $V_{TH} = 0$ for $V_{RMS} < 0$. However, when V_{RMS} is positive, the output of OA2 goes negative, and V_{TH} follows V_{RMS} with a gain of –1. Therefore, $V_{TH} = -V_{RMS}$ for $V_{RMS} > 0$ V.

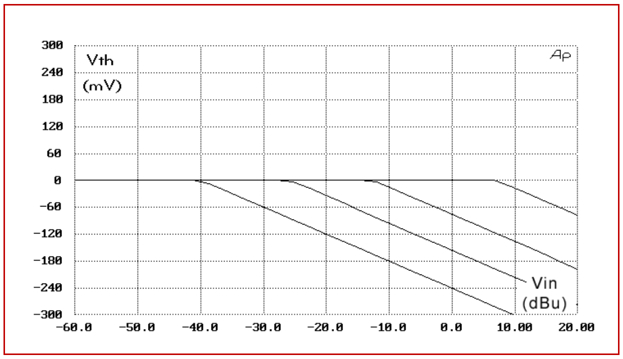

Figure 2. V_{TH} vs. VIN for various THRESHOLD settings.

Neglecting the effects of R16 and R17, OA2 and its associated circuitry only passes information when the input signal is above the input level which causes $V_{RMS} = 0$ V (the threshold). No information passes for signals below this threshold. The transition from below to above threshold is sharp, because the operational rectifier used as the threshold detector linearizes the diode's exponential V-I characteristic.

R17 and R16 provide a means of adjusting the threshold. For supply rails of ±15 V, R17 adjusts the threshold over ±186 mV (from (V+)*R18/R16 to (V-)*R18/R16) equivalent to ±30 dB at 6.2 mV/dB. With the wiper of R17 towards V+, V_{TH} will respond for any V_{RMS} > -186 mV, or V_{IN} > -40 dBu. With the wiper of R16 towards V-, V_{TH} will respond for V_{RMS} > +186 mV, or V_{IN} > 20 dBu. This adjusts the threshold over the range +20 dBu to -40 dBu.

Note that a linear-taper potentiometer should be used for R17, the THRESHOLD control. This is because the signal at the RMS detector output represents the log of the input signal level (it has already been converted to decibels.) A linear change in threshold voltage corresponds to a linear change in decibel threshold.

V_{TH} therefore represents the decibel level of the input signal above THRESHOLD. See Figure 2 for a plot of V_{TH} versus V_{IN}, with various settings of the THRESHOLD control.

Adjusting Compression

R19, the COMPRESSION control, allows the user to scale V_{TH} before it is passed on to the rest of the circuitry. Neglecting the action of R21 and R22, when the wiper of R19 is at its ground end, no signal is passed on to OA3. When the wiper is at the opposite end (the maximum), the output of OA3 (V_G) exactly mirrors V_{TH}. For settings in between, V_G will be a mirror image of some fraction of V_{TH}, with the fraction determined by the setting of the COMPRESSION control.

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When COMPRESSION is at maximum, $V_G = V_{TH}$, so V_G in turn represents V_{IN} above threshold at 6.2 mV/dB. But, V_G is applied to pin 12 of the 4305 VCA, which controls gain at the rate of -6.2 mV/dB. For every 1 dB increase in V_{IN} (above threshold) V_G increases by 6.2 mV, and the gain of the VCA decreases by 1 dB. Therefore, at maximum COMPRESSION, the signal gain decreases in exact proportion to signal level increases above threshold, preventing any increase in output level above the threshold.

For intermediate settings of the COMPRESSION control, the decrease in signal gain is proportional to, but less than, the increase in signal level above threshold. For example, at the electronic halfway point for R19, signal gain will decrease by 0.5 dB for each 1 dB increase in input signal above threshold. This will result in an increase in output signal of 0.5 dB for each 1 dB increase in input signal.

The Compression Ratio is a measure of the increase in output signal for increases in input signal above threshold. It is defined as

$$RATIO = \frac{\Delta V_{IN}}{\Delta V_{OUT}},$$

where ΔV_{IN} is the decibel change in input signal and ΔV_{OUT} is the decibel change in output signal. The compression ratio is ∞:1 when the COMPRESSION control is at its maximum, and 1:1 at its minimum. For settings in between, the ratio is determined by the setting of R19, taking into account the loading effect of R20. If the electrical setting of the COMPRESSION control is expressed as a ratio R relative to full scale (i.e., maximum is 1.0, 50% of full scale is 0.5, etc.), then the compression ratio is determined by the setting of the COMPRESSION control as follows: RATIO = 1/(1-R). In the circuit shown, 2:1 compression will occur at slightly more than the halfway point in the pot's rotation, due to the loading of R20. It is not uncommon in this sort of design to add a resistor between the top of R19 and its wiper, in order to set 4:1 compression at the 50% rotation point. (Approximately 180 Ω would be right.)

Figure 3 plots V_G versus V_{IN}, for several settings of the COMPRESSION control, at a fixed THRESHOLD setting.

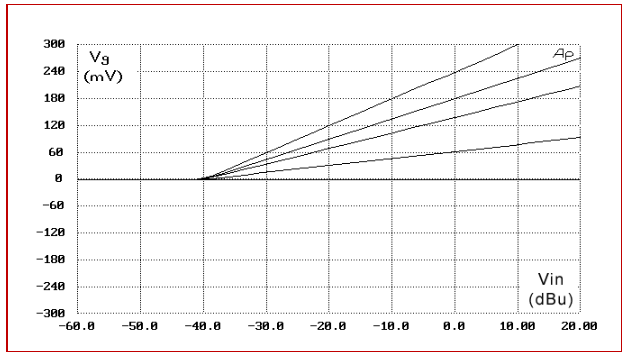

Figure 3. V_G vs. V_{IN} for various COMPRESSION settings.

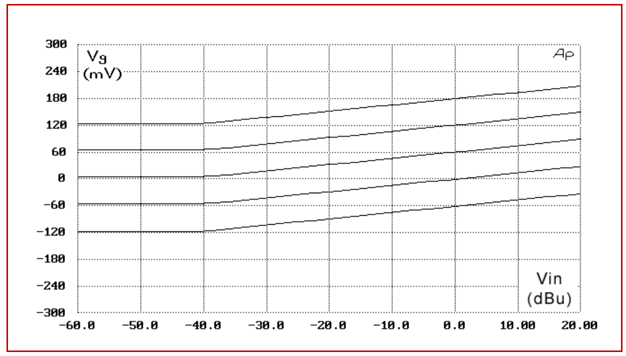

Figure. 4. V_G vs. V_{IN} for various GAIN settings.

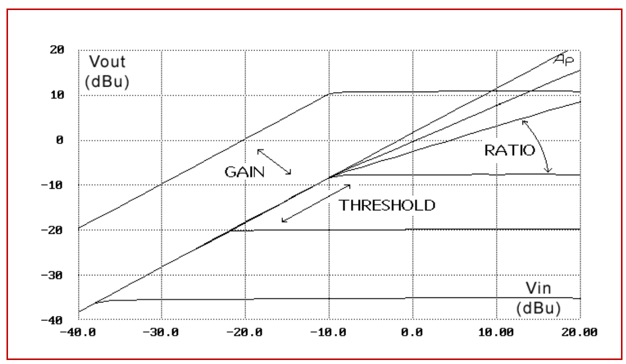

Figure. 5. V_{IN} vs. V_{OUT} for various Control Settings.

Adjusting Gain

The action of R21 and R22, neglected in the foregoing analysis, is to add a dc offset to the gain control voltage, V_G. This causes a static gain or loss in the signal path, at the familiar constant of 6.2 mV/dB. As shown, with ±15 V supply rails, varying R21 (the GAIN control) will cause V_G to vary over ±124 mV. This corresponds to approximately ±20 dB of gain change. This variation is useful in making up for level lost during compression. Figure 4 plots V_G vs. V_{IN} for various settings of the GAIN control, at constant COMPRESSION and THRESHOLD settings.

Resulting Compression Characteristic

The circuit of Figure 1 produces a family of input vs. output characteristic curves as shown in Figure 5. Note that the onset of compression (the bend in the curves) is sharp, deriving from the sharp rectification characteristic of the operational rectifier used in the threshold detector. Also note the similarity of the previous curves showing control voltages versus V_{IN} to the plots of V_{OUT} vs. V_{IN}. This follows from the fact that the RMS detector produces a decibel representation of the input signal, and that the VCA responds directly to decibel gain commands.

Trim Adjustments

The THAT4305 does not require any trim adjustments.

Time Constants

The time constants of the compressor shown in Figure 1 are entirely determined by the RMS detector and choice of its timing component, C_T. As shown, the integration time of the RMS detector is set to approximately 32 ms, appropriate for most audio applications. For certain applications, however, it may be desirable to vary this. Simply changing the value of C_T will scale the integration time proportionately, and is conceptually the easiest way to alter timing (see the 4305 data sheet for details).

More elaborate variations in time constants are also possible. For more detail about the time constants in RMS-based compressor limiters, see Audio Engineering Society Preprint number 4054, Attack and Release Time Constants in RMS-Based Compressors and Limiters, by Fred Floru.

Higher (or Lower) Input Levels

1.8 mA is the maximum recommended signal current (I_{IN} + I_{OUT}) for the 4305 VCA when it is operated from +/-15V power supplies. (I_{IN} is the input signal current, I_{OUT} is the output signal current.) The I_{OUT} which corresponds to a given I_{IN} will be determined by the control settings, but the maximum I_{OUT} is likely to be several dB lower than the peak I_{IN} due to the compressor action. A reasonable assumption is that the peak I_{OUT} is 6 dB less than the peak I_{IN}. In that event, for I_{IN} + I_{OUT} = 1.8 mA, I_{IN} = 1.2 mA and I_{OUT} = 600 µA.

With the values shown for R1 and R6, 1.2 mA (peak) of input current will flow when the input signal reaches 17 V_{RMS} (+26.83 dBu). To accommodate higher input voltages, R1 should be scaled larger. Where the maximum input signal will never approach +26.83dBu, R1 (and R6) may be reduced proportionately, obtaining a commensurate improvement in signal-to-noise ratio.

Soft-Threshold Compressor

The preceding basic above-threshold compressor design may be easily altered to suit different applications. One common variation is to provide a "soft knee" in the compression characteristic (see Figure 9) for a look at this characteristic. The circuit of Figure 6 will accomplish this.

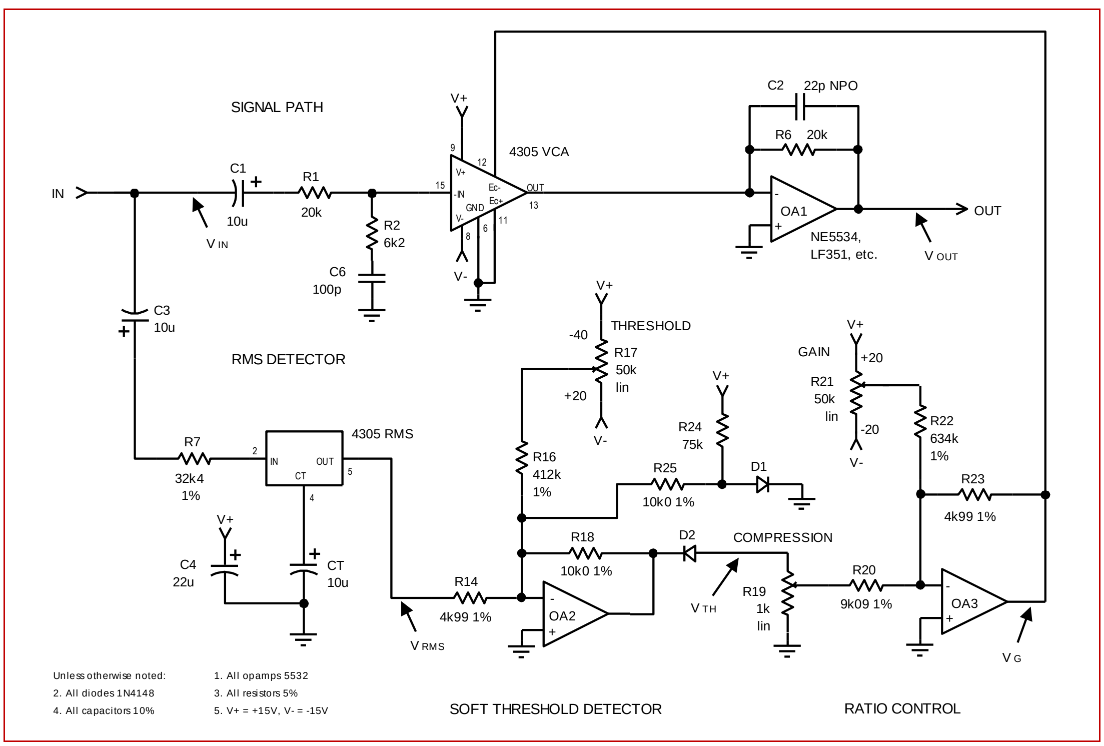

Figure. 6. Basic Soft-Threshold Compressor/Limiter

In Figure 6, the operational rectifier used as the threshold detector in Figure 1 has been replaced with an open-loop diode (D2). A silicon diode such as the 1N4148 used in Figure 6 has an exponential V-I characteristic, requiring several tenths of a volt to switch from non-conducting to conducting. In the circuit shown, the effective resistance of D2 will vary with the voltage at the output of OA2, from virtually infinite for negative voltages to tens of ohms at voltages approaching 700 mV. The variation produces a "sloppy" half-wave rectification of the RMS detector's output signal.

The range of voltages over which the D2 provides useful variation in impedance is from about 300 mV to 600 mV, or about 300 mV in total. A 300 mV variation at the RMS detector's output represents approximately 50 dB variation in signal level — too much to be directly useful for the threshold region. Therefore, additional gain (OA2, R14, R18, etc.) has been provided to present D2 with a larger voltage range, thereby sharpening the resulting threshold characteristic. The gain from V_{RMS} to V_{TH} reaches a maximum of approximately 1.8. (At 20 dB compression, D2 has an impedance of 100 Ω.) R16 has been changed to produce the same threshold range as in the original circuit.

Figure 7 plots V_{TH} vs. V_{IN} for the circuit of Figure 6 (with variations in THRESHOLD setting). Notice the gradual transition from 0 V output (no signal passing through) to positive signal output (passing V_{RMS} onwards). A sharper transition may be achieved by increasing the closed loop gain of OA2 while simultaneously reducing the closed-loop gain of OA3 by the same ratio.

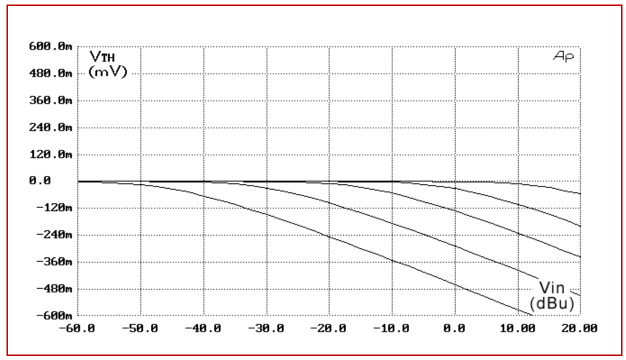

Figure. 7. V_{TH} vs. V_{IN} for the Soft-Knee Circuit.

R24, D1 and R25 are included to provide temperature compensation for the forward voltage drop of D2. Assuming +/-15V power supply rails, R24 sets up a current of approximately 130 µA through D1, giving D1 an impedance of approximately 200 Ω. R25 adds D1's forward drop through the summing junction of OA2 such that it appears in the output of OA2 at a gain of -1. The forward voltage drop of D1 varies with temperature at approximately 2 mV/°C. The forward voltage drop of D2 will vary at the same rate. The compensation thus adds enough drift to OA2's output voltage to compensate for the drift of D2.

For optimum compensation, D1 and D2 should be matched and co-located so they will track in temperature. Note that this scheme will not compensate for all the drift of the circuit. The shape of the "knee" drifts slightly because a diode depends on absolute temperature for its transimpedance. The circuit shown minimizes this effect by matching the currents through D1 and D2 at the point of 10 dB compression (for R19 at its maximum setting).

The final difference between the circuits of Figure 1 and Figure 6 is in the resistor values around OA3. R20 was scaled upwards to reduce loading on R19, R23 was changed to produce a gain of 0.55 (approximately 1/1.8). This compensates for the control path gain introduced by OA2 and its associated components, and for the loss caused by D2. (The compensation for D2 is approximate, since the diode's impedance varies with current.) And, R22 was scaled to produce a ±20 dB gain command at V_G. The gain from V_{RMS} to V_G is approximately 1.0 for signals far above threshold (those which turn on D2), with R19 at its maximum rotation.

The THRESHOLD, COMPRESSION, and GAIN controls operate just as they did in Figure 1. THRESHOLD adds in a varying offset to raise or lower the apparent input signal level (from the point of view of the threshold detector); COMPRESSION allows attenuation of the signal above threshold voltage, and GAIN allows addition of a varying offset to the static gain of the 4305 VCA.

The result of these changes is to produce a family of "soft-knee" characteristic curves, as shown in Figure 8 and Figure 9. Note the similarity in shape between the plots of control voltage versus input voltage and the plot of output voltage versus input voltage. The THAT4305 Analog Engine allows the designer to execute a desired compression characteristic by designing a dc-processing circuit which has that transfer characteristic. This makes achieving unusual characteristics particularly easy with these parts.

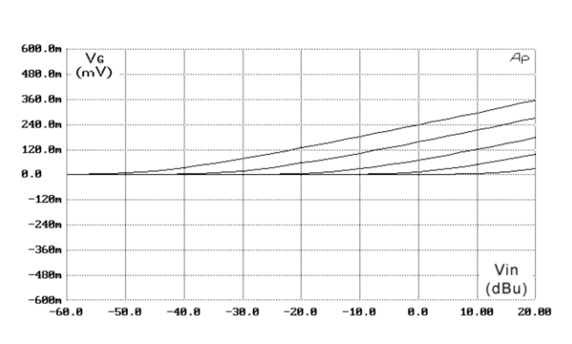

Figure. 8. V_G vs. V_{IN} for the Soft-Knee Circuit.

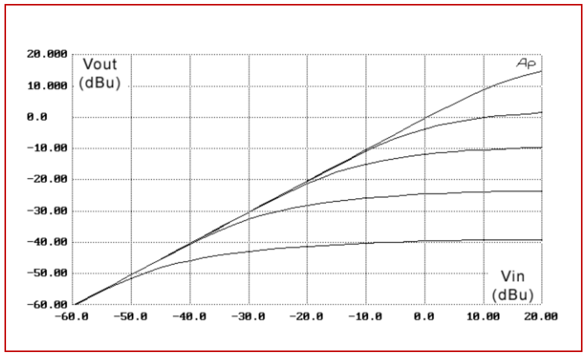

Figure. 9. V_{OUT} vs. V_{IN} for the Soft-Knee Circuit.

Closing Thoughts

THAT Corporation welcomes comments, questions and suggestions regarding this application note and its subject matter. Our engineering staff has extensive experience in designing commercial compressor/limiters based on the VCAs and RMS-level detectors. We are pleased to offer assistance in optimizing circuitry for your application. Please feel free to contact us with your thoughts and questions.