Replacing the SSM2120 Level Detector

Introduction

In the course of providing applications support for our VCAs, we've noticed that a significant number of designers have used our VCAs in conjunction with the dual level-detectors available in the SSM 2120 (having disabled the SSM 2120's VCAs). Since the 2120 has been discontinued, users need an alternative to this device.

The detectors employed in the SSM 2120 function in a manner somewhat similar to THAT Corporation's RMS detectors. Like the THAT 2252, an SSM 2120 detector input is held at a virtual ground by a feedback servo (but offset from the IC's ground pin by two volts), and the subsequent stage rectifies a replica of the feedback current which is then shunted through a logging transistor whose emitter is connected to the IC's ground. Another transistor acts as both a buffer and a log filter diode (See the THAT 2252 datasheet for a more in-depth discussion of log filtering). Additionally, since the log-rectified signal is only a single diode drop above ground after logging, the log filter diode also acts to "buck out" this logging diode's offset and make the signal properly referenced to ground. Since the log filter diode operates at a fixed current and the logging transistor operates at a signal dependent current, the output has a temperature coefficient that is proportional to absolute temperature (as a result of the V_T term in the diode equation), just like the THAT 2252. A significant difference between the SSM 2120 and the THAT 2252 is that the SSM 2120 has an open emitter output buffer. This feature allows the output to act as a threshold diode when the circuit is configured as a gate (below-threshold downward expander) but, on the other hand, complicates the implementation of an above-threshold compressor.

The remainder of this Design Note describes circuitry for using the THAT 2252 in place of the SSM2120 in two common applications — a downward expander and a hard-knee compressor/limiter.

The downward expander and noise gate

Figure 1 shows the SSM 2120 configured as a downward expander, a device commonly known as a "gate". The circuit shown is in many ways similar to the application circuit shown in the SSM 2120 datasheet, but has been modified to have an op-amp based control port buffer which is more appropriate for driving the control port of one of THAT Corporation's VCAs.

The value of R2 is 1.5 MΩ which, with ±15 V supplies, programs the timing current (I_{Ref} in the SSM 2120 datasheet) to the recommended 10 µA. We have chosen C1, the timing capacitor, to be 2 µF, a value which results in a release (decrementation) rate of over 1665 dB/s at the timing capacitor.

The SSM 2120, like THAT Corporation's RMS detectors, has what we refer to as a "zero dB reference current", defined as the particular input current which results in zero volts at the output of the detector. In the SSM 2120, this current is equal to the timing current. We can translate this to voltage by the appropriate choice of resistor. We have chosen 245 mV, or -10 dBu, as our zero dB reference voltage. Thus,

$$R_{In} = \frac{0.245}{10\mu A} \cong 24.3k\Omega$$

As previously mentioned, the open emitter output of the SSM 2120 acts as a threshold diode when the IC is configured as a downward expander. Con_{Out} begins to sink current when the voltage on the filter capacitor (which is the voltage on the positive input of the output buffer) drops below that on the inverting input of this buffer. By adding a DC offset to this point, one can adjust the threshold of the circuit. As shown, the circuit shown provides 30 dB of adjustment range.

Let R_{eq} equal the parallel combination of R6 + R4 and R7. Then using the voltage divider rule,

$$V_{Thresh} = 15V \times \frac{R_{eq}}{R_{eq} + R3}$$

and

$$V_{Thresh} = 30\ dB \times 3\frac{mV}{dB}$$

Substituting yields

$$90mV = 15V \times \frac{R_{eq}}{R_{eq} + R3}$$

and after rearranging,

$$R3 = R_{eq} \times \frac{15-0.09}{0.09} \cong 160k\Omega$$

Since the level detector's output is zero volts at -10 dBu, the threshold adjustment range is, therefore, -10 dBu to -40 dBu.

It can be shown (see Extra credit: The mathematics of expanders and compressors at the end of this document) that the expansion ratio of a feedforward expander is

$$E.R. = \frac{dB_{Out}}{dB_{In}} = 1 + \beta$$

where β is the sidechain gain. In our case, the SSM 2120 threshold amplifier has a gain of 40, and the control port buffer has a gain of one half. Additionally, there is an implicit gain of one half that results from the output sensitivity of the detector being 3 mV/dB, and the VCA control port sensitivity being 6 mV/dB. Thus, the net sidechain gain is 10 for a resulting expansion ratio of 11:1.

The sidechain gain also affects the effective release rate of the circuit. The initial rate of 1665 dB/s is multiplied by the sidechain gain for a total release rate of 16650 dB/s. Note that if the designer chooses to make the expansion ratio variable, the release rate becomes a function of the expansion ratio as well as of the timing current and the value of the timing capacitor.

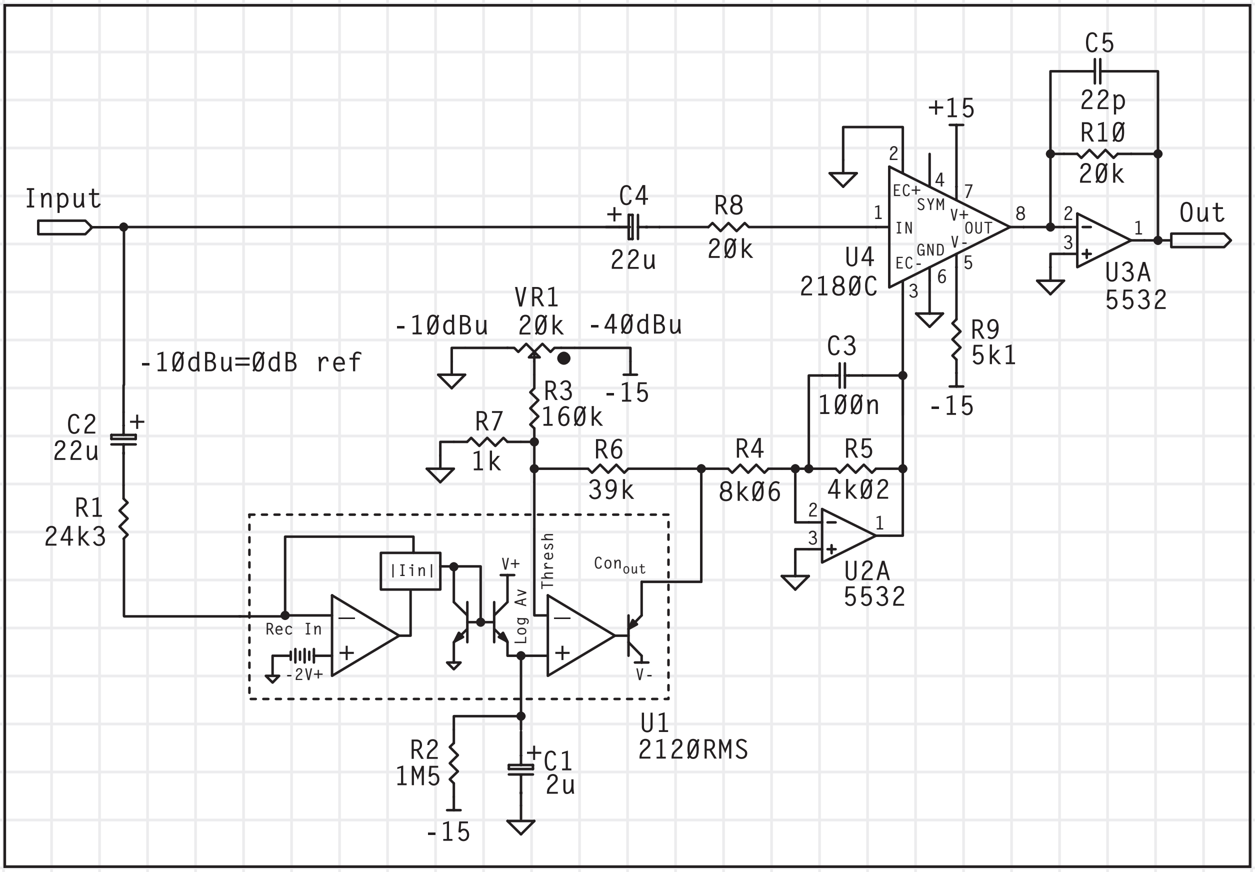

Figure 1: SSM 2120 detector configured for a downward expander

Downward expander using a THAT 2252

Figure 2 shows the THAT 2252 configured to mimic the performance of the previous circuit. The THAT 2252 is capable of both sourcing and sinking current, though its ability to sink current is limited to 12 times I_{Bias}.

In this implementation, the symmetry adjustment is disabled for simplicity, and we have set I_{Bias} to be 16 µA, which results in a maximum sink current of 192 µA. In this configuration, the THAT 2252 is still capable of driving a 2 kΩ load to -0.3 V, or -50 dB.

R11 programs I_{Bias} to 16 µA. We calculate this resistor value using:

$$R11 = \frac{|V_{CC} - 2.1|}{16\mu A} \cong 820k\Omega$$

We've set the timing current to 10 µA to match the SSM 2120:

$$R12 = \frac{-V_{EE} + 1.4}{10\mu A} = 1.6M\Omega$$

The zero dB reference current is then calculated:

Revision 7/20/01

$$I_{ZERO\ dB} = \frac{\sqrt{I_{Bias} \times I_{tim}}}{2.9} = 4.36\ \mu A$$

To make the zero dB reference voltage 245 mV$_{RMS}$ to match the earlier circuit,

$$R10 = \frac{0.245\ V_{RMS}}{4.36\ \mu A} \cong 56 k\Omega$$

In order to provide 30 dB of threshold adjustment, we calculate the current sensitivity at the input to the threshold amplifier (U2A):

$$Thresh_{Sens} = \frac{6\frac{mV}{dB}}{R_{in}} = \frac{6\frac{mV}{dB}}{10 k\Omega} = 0.6\frac{\mu A}{dB}$$

Thus the current needed for 30 dB of adjustment is

$$I_{30\ dB} = 30\ dB \times 0.6\frac{\mu A}{dB} = 18 \mu A$$

We have a maximum of 15 volts to generate this current, so

$$R14 = \frac{15 V}{18\ \mu A} \cong 820 k\Omega$$

Since the output of the level detector is referenced to -10 dBu, the adjustment range is -10 dBu to -40 dBu.

The net gain of the sidechain of this circuit is 10, and since the THAT 2252's output sensitivity matches that of the VCA, the resulting expansion ratio is, again, 11:1.

The release rate at C5 is

$$\frac{dV}{dt} = \frac{I_t}{C5} = 10\frac{V}{s}$$

When multiplied by the gain of the sidechain (which is 10), this becomes 100 V/s and if we divide by the control port sensitivity, the release rate is

$$Rel_{Rate} = \frac{100\frac{V}{s}}{6\frac{mV}{dB}} = 16667\frac{dB}{s}$$

which reasonably approximates the release rate of the SSM 2120 expander under the same conditions.

In either this or the SSM 2120 based designs, allowing variable expansion ratios results in correspondingly variable release rate.

The factor of two difference between the timing capacitor of the SSM 2120 detector and that of the THAT RMS detectors is due to the difference in their output sensitivities (3 mV/dB for the former, 6 mV/dB for the latter).

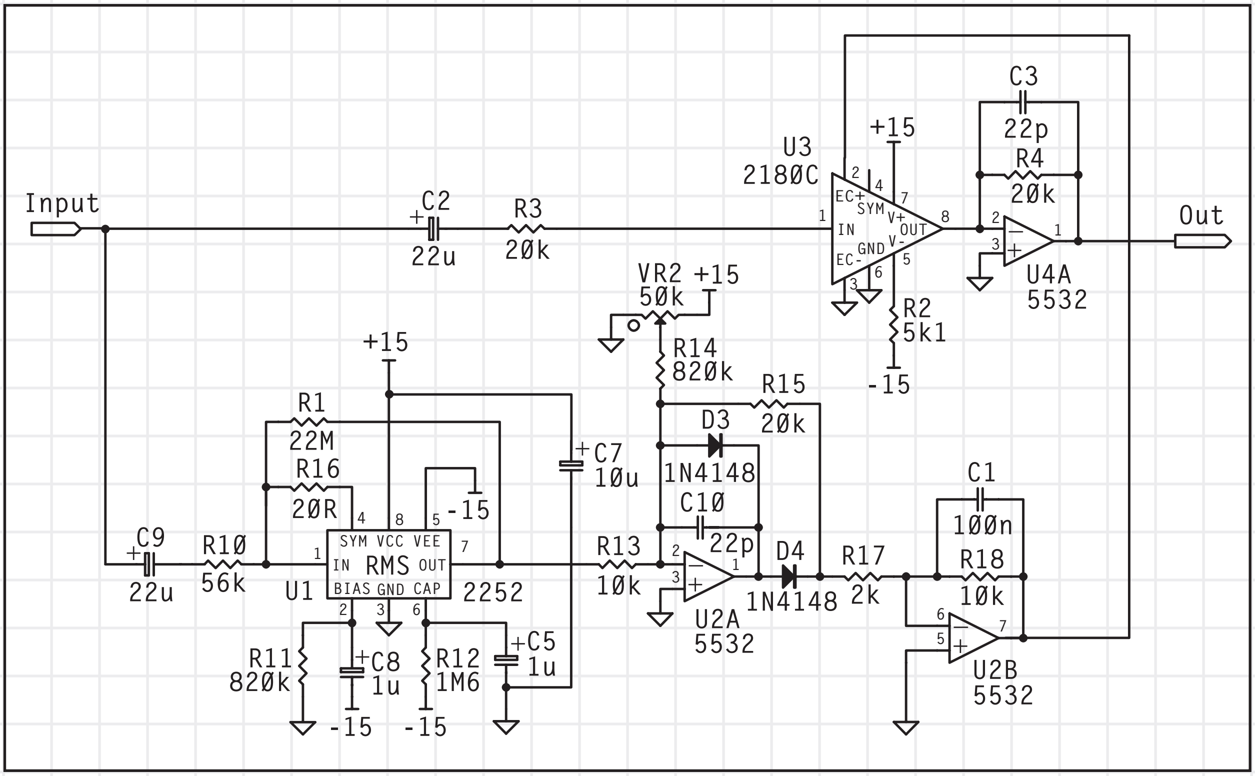

Figure 2: THAT 2252 detector configured as a downward expander

The hard-knee compressor / limiter

Compression is another popular application for the SSM 2120 and THAT Corporation's products. Figure 3 shows one implementation, adapted from the 2120 datasheet, of an infinite compressor, or "limiter". As was mentioned before, the SSM 2120's output topology is convenient for implementing gates, but problematic when designing compressors. The recommended circuit for a compressor / limiter threshold effectively implements a variation on the soft-knee thresholds that have been used for decades in pro audio, but utilizes so much gain that the threshold begins to approximate a hard-knee threshold. Though the soft-knee threshold is generally considered audibly advantageous, we've assumed that most users of the SSM 2120 follow the datasheet recommendations, and have configured the circuit to reflect this scenario.

As before, setting R2 to 1.5 MΩ sets the timing current to the recommended 10 μA. Setting C1 to 22 μF results in a release rate of 150 dB/s, which is a good compromise between response time and low-frequency THD.

The SSM 2120's 10 μA timing current results, again, in a 10 μA zero dB reference current, so setting R1 to 24.9 kΩ results in a -10 dBu zero dB reference voltage. R3 is set to 160 kΩ, as it was for the gate, to provide a 30 dB adjustment range, which swings from -10 dBu to 20 dBu. Note that the supply voltage was reversed on VR1 (relative to the expander) to achieve this.

Unlike the expander, the compression ratio of a feedforward compressor is calculated:

$$C.R. = \frac{dB_{In}}{dB_{Out}} = \frac{1}{1-\beta}$$

Where β is the gain through the sidechain. By inspection we can see that for a sidechain gain of one, there would be a compression ration of ∞ : 1, and for a sidechain gain of one half, the compression ratio would be 2:1.

Note that the 2120's detector has an output sensitivity of 3 mV/dB, whereas THAT Corporation's VCAs have a control port sensitivity of 6 mV/dB. The result is an implicit gain of one-half at the VCAs control port. Therefore, though Figure 3 shows an explicit sidechain gain of 2, the implicit gain of one-half at the VCAs control port results in a net gain of one, making this circuit an infinite compressor, or limiter. Further reducing the gain of the control port buffer (U1A) would result in lower compression ratios.

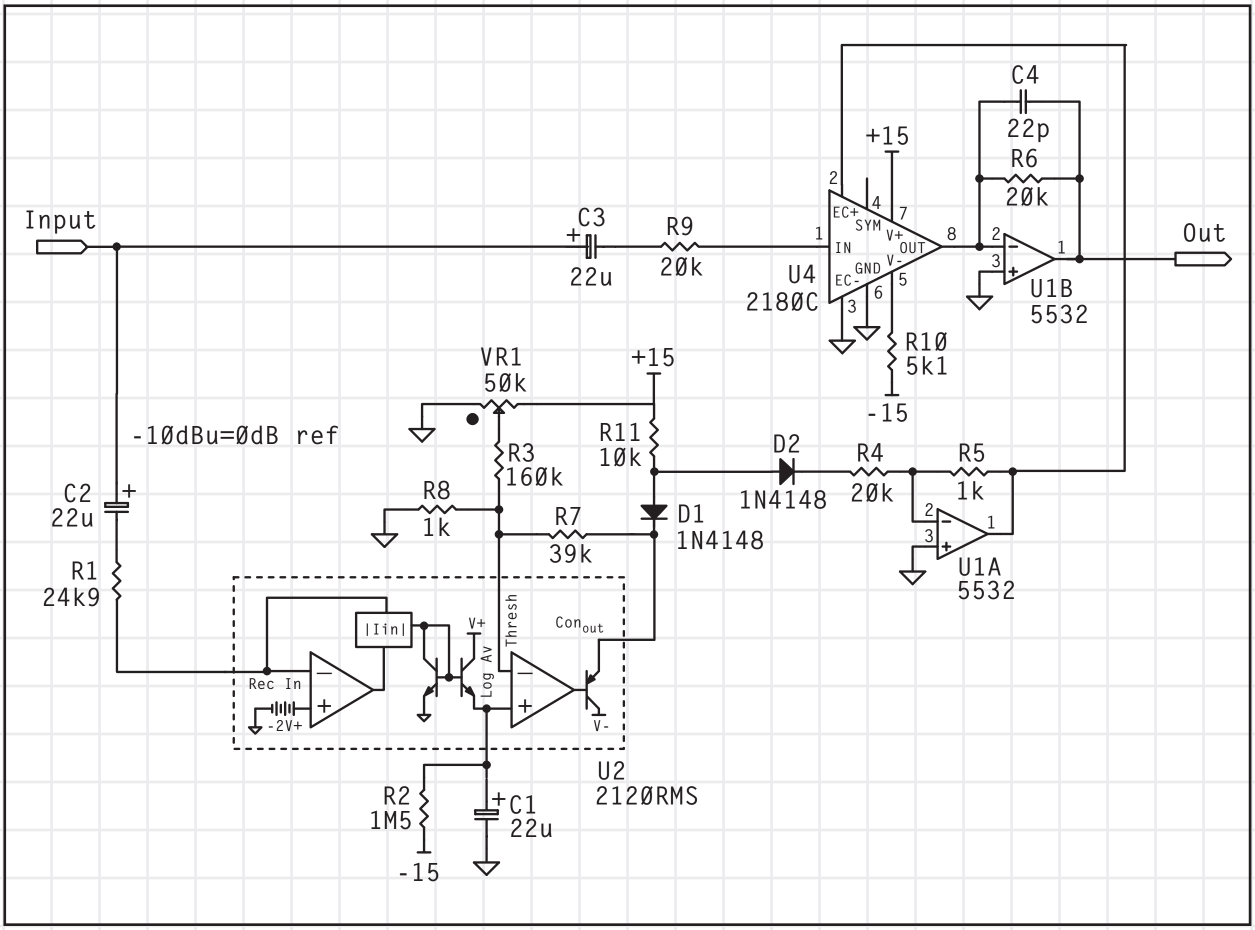

Figure 3: SSM 2120 detector configured as a hard-knee compressor

The hard-knee compressor / limiter using the THAT 2252

Figure 4 shows the sidechain of a hard-knee compressor / limiter based on the THAT 2252. The RMS detector in this circuit is configured nearly identically with the one in Figure 2, with the exception of the value of the timing capacitor. In this case, we're using a value of 10 µF, which *results in essentially the same 150 dB/s release rate we saw in the SSM 2120 version of the compressor / limiter. As noted before, the difference in capacitor values is a direct result of the factor of two difference in the two devices' output scaling constants.*

Since the timing current is still 10 μA, the zero dB reference current is unchanged, and setting R1 to 56 kΩ still results in a zero dB reference level of -10 dBu.

The threshold amplifier in this circuit is identical to the threshold circuit in Figure 2, except that the diode polarities and the supply polarity on VR1 have been reversed. Reversing the diodes results in gain changing above the threshold. The reversed voltage polarity on VR1 results in the threshold polarity varying from -10 dBu to 20 dBu.

The net sidechain gain, including the effect of the relative device sensitivities, is one, making this a limiter. See THAT Corporation's AN 100A, Basic Compressor / Limiter Design, for more insights into soft-knee thresholds and pot taper shaping when implementing variable compression.

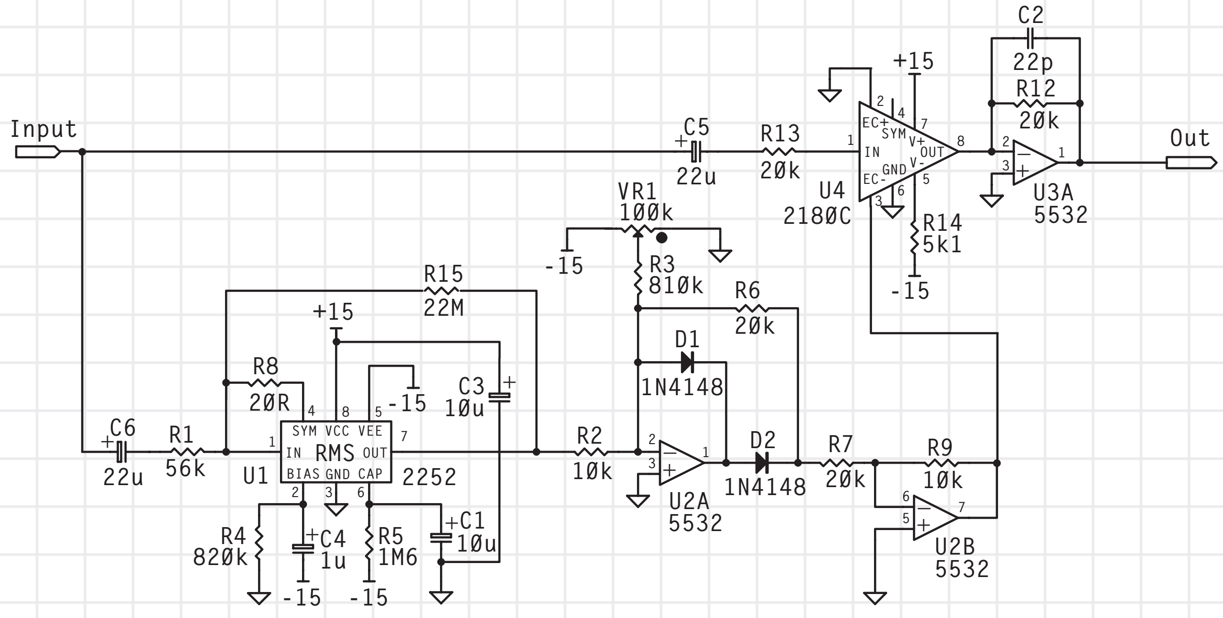

Figure 4: THAT 2252 detector configured as a hard-knee compressor

Revision 7/20/01

Extra credit: The mathematics of expanders and compressors

While the mathematics of compressors and expanders in the linear domain can be counterintuitive, evaluating these systems in the log domain is much more straightforward, and can provide valuable insights into their operation. Compressors and expanders can be configured as either feedforward or feedback systems. A generic feedforward system is shown in figure 5.

We can see that

$$dB_{Out} = dB_{In} + G_{dB}$$

and that

$$G_{dB} = dB_{In} \times \pm\beta$$

The sign of β depends on whether the system is a compressor or an expander. When the input is at zero dB, then the gain will be zero dB, which results in an output level of zero dB. If β is positive, then as the input signal goes above zero dB, the output will be greater than the input making the circuit behave as an expander.

Thus, for an expander,

$$dB_{Out} = dB_{In} + dB_{In} \times \beta$$

or

$$dB_{Out} = dB_{In}(1+\beta)$$

The expander ratio can then be calculated

$$E.R. = \frac{dB_{Out}}{dB_{In}} = 1+\beta$$

Likewise, if the circuit is a compressor,

$$dB_{Out} = dB_{In} - dB_{In} \times \beta$$

or

$$dB_{Out} = dB_{In}(1-\beta)$$

We can then derive the compression ratio

$$C.R. = \frac{dB_{In}}{dB_{Out}} = \frac{1}{1-\beta}$$

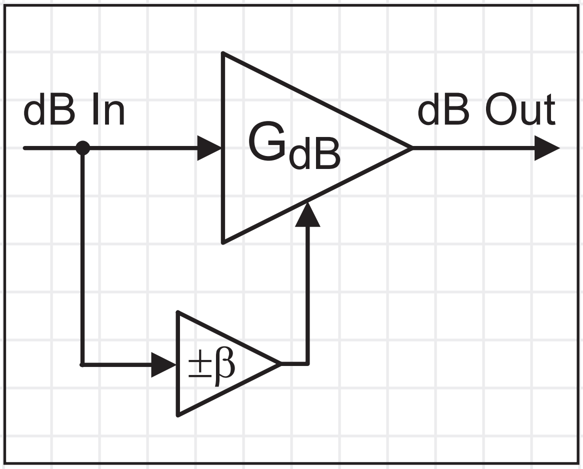

Figure 5: Generic feedforward compressor / expander topology

We can see by inspection that, for a feedforward expander, a sidechain gain of 1 results in an expansion ratio of 2 and a sidechain gain of 9 results in an expansion ratio of 10. For a feedforward compressor, a sidechain gain of minus one results in a compression ratio of infinity, and an effective sidechain gain of minus one-half results in a compression ratio of two.