APPLICATIONS
The following circuits will illustrate some of the wide variety of applications for the SA570.

BASIC EXPANDOR
Figure 1 shows how the circuit would be hooked up for use as an expander. Both the rectifier and ΔG cell inputs are tied to $V_{IN}$ so that the gain is proportional to the average value of $(V_{IN})$. Thus, when $V_{IN}$ falls 6dB, the gain drops 6dB and the output drops 12dB. The exact expression for the gain is

$$\text{Gain exp.} = \left( \frac{2 R_2}{R_1 R_2} \frac{V_{IN}}{I_b} \right)^2$$

$I_b = 140\mu A$

The maximum input that can be handled by the circuit in Figure 1 is a peak of 3V. The rectifier input current can be as large as

$$I = 3V/R_1 = 3V/10k = 300\mu A.$$  

The ΔG cell input current should be limited to

$$I = 2.8V/R_2 = 2.8V/20k = 140\mu A.$$  

If it is necessary to handle larger input voltages than $\pm 300\mu A$ peak current restriction.

DISTORTION TRIM
Distortion can be produced by voltage offsets in the ΔG cell. The distortion is mainly even harmonics, and drops with decreasing input signal (input signal meaning the current into the ΔG cell). The THD trim terminal provides a means for trimming out the offset voltages and thus trimming out the distortion. The circuit shown in Figure 3 is suitable, as would be any other capable of delivering $\pm 30\mu A$ into $100\Omega$ resistor tied to 1.8V.
LOW LEVEL MISTRACKING

The compandor will follow a 2-to-1 tracking ratio down to very low levels. The rectifier is responsible for errors in gain, and it is the rectifier input bias current of <100nA that produces errors at low levels. The magnitude signal level drops to a 1µA average, the bias current will produce a 10% or 1dB error in gain. This will occur at 42dB below the maximum input level.

It is possible to deviate from the 2-to-1 transfer characteristic at low levels as shown in the circuit of Figure 4. Either RA or RB, (but not both), is required. The voltage on C RECT is 2×V BE plus V IN avg. For low level inputs V IN avg is negligible, so we can assume 1.3V as the bias on C RECT. If RA is placed from C RECT to AND we will bleed off a current I=1.3V/RA. If the rectifier average input current is less than this value, there will be no gain control input to the ΔG cell so that its gain will be zero and the expander output will be zero. As the input level is raised, the input current will exceed 1.3V/RA and the expander output will become active. For large input signals, RA will have little effect. The result of this is that we will deviate from the 2-to-1 expansion, present at high levels, to an infinite expansion at low levels where the output shuts off completely. Figure 5 shows some examples of tracking curves which can be obtained.

Complementary curves would be obtained for a compressor, where at low level signals the result would be infinite compression. The bleed current through RA will be a function of temperature because of the two V BE drops, so the low level tracking will drift with temperature. If a negative supply is available, it would be desirable to tie RA to that, rather than ground, and to increase its value accordingly. The bleed current will then be less sensitive to the V BE temperature drift.

RA will supply an extra current to the rectifier equal to (V CC−1.3V)R B. In this case, the expander transfer characteristic will deviate towards 1-to-1 at low levels. At low levels the expander gain will stop dropping and the expansion will cease. In a compressor, this would lead to a lack of compression at low levels. Figure 6 shows some typical transfer curves. An RA value of approximately 2.5M would trim the low level tracking so as to match the Bell system N2 trunk compandor characteristic.
Applications for compandors NE570/571/SA571

The rectifier has an input bias current of between 50 and 100nA. This limits the dynamic range of the rectifier to about 60dB. It also limits the amount of attenuation of the ΔG cell. The rectifier dynamic range may be increased by about 20dB by the bias current trim network shown in Figure 7. Figure 8 shows the rectifier performance with and without bias current cancellation.

Attack and decay times of the compandor are determined by the rectifier filter time constant 10k×C RECT. Figure 9 shows how the gain will change when the input signal undergoes a 10, 20, or 30dB change in level.

The attack time is much faster than the decay, which is desirable in most applications. Figure 10 shows the compressor attack envelope for a +12dB step in input level. The initial output level of 1 unit instantaneously rises to 4 units, and then starts to fall towards its final value of 2 units. The CCITT recommendation on attack and decay times for telephone system compandors defines the attack time as when the envelope has fallen to a level of 3 units, corresponding to t=0.15 in the figure. The CCITT recommends an attack time of 3 ±2ms, which suggests an RC product of 20ms.

Figure 11 shows the compressor output envelope when the input level is suddenly reduced 12dB. The output, initially at a level of 4 units, drops 12dB to 1 unit and then rises to its final value of 2 units. The CCITT defines release time as when the output has risen to 1.5 units, and suggests a value of 13.5 ±9ms. This corresponds to t=0.675 in the figure, which again suggests a 20ms RC product. Since R 1=10k, the CCITT recommendations will be met if C RECT=2μF.

There is a trade-off between fast response and low distortion. If a small C RECT is used to get very fast attack and decay, some ripple...
will appear on the gain control line and produce distortion. As a rule, a 1µF $C_{RECT}$ will produce 0.2% distortion at 1kHz. The distortion is inversely proportional to both frequency and capacitance. Thus, for telephone applications where $C_{RECT}=2\mu F$, the ripple would cause 0.1% distortion at 1kHz and 0.33% at 800Hz. The low frequency distortion generated by a compressor would be cancelled (or undistorted) by an expander, providing that they have the same value of $C_{RECT}$.

**FAST ATTACK, SLOW RELEASE HARD LIMITER**

The SA570/571 can be easily used to make an excellent limiter. Figure 12 shows a typical circuit which requires one SA570/571, of an LM339 quad comparator, and a PNP transistor. For small signals, the $\Delta G$ cell is nearly off, and the circuit runs at unity gain as set by $R_8$, $R_7$. When the output signal tries to exceed a $+1$ or $-1$V peak, a comparator threshold is exceeded. The PNP is turned on and rapidly charges $C_4$ which activates the $\Delta G$ cell. Negative feedback through the $\Delta G$ cell reduces the gain and the output signal level. The attack time is set by the RC product of $R_{18}$ and $C_4$, and the release time is determined by $C_4$ and the internal rectifier resistor, which is 10k. The circuit shown attacks in less than 1ms and has a release time constant of 100ms. $R_9$ trickles about 0.7µA through the rectifier to prevent $C_4$ from becoming completely discharged. The gain cell is activated when the voltage on Pin 1 or 16 exceeds two diode drops. If $C_4$ were allowed to become completely discharged, there would be a slight delay before it recharged to $>1.2V$ and activated limiting action.

A stereo limiter can be built out of 1 SA570/571, 1 LM339 and two PNP transistors. The resistor networks $R_{12}$, $R_{13}$ and $R_{14}$, $R_{15}$, which set the limiting thresholds, could be common between channels. To gang the stereo channels together (limiting in one channel will produce a corresponding gain change in the second channel to maintain the balance of the stereo image), then Pins 1 and 16 should be jumpered together. The outputs of all 4 comparators may then be tied together, and only one PNP transistor and one capacitor $C_4$ need be used. The release time will then be the product $5k \times C_4$ since two channels are being supplied current from $C_4$.

**USE OF EXTERNAL OP AMP**

The operational amplifiers in the SA570/571 are not adequate for some applications. The slew rate, bandwidth, noise, and output drive capability can limit performance in many systems. For best performance, an external op amp can be used. The external op amp may be powered by bipolar supplies for a larger output swing.

Figure 13 shows how an external op amp may be connected. The non-inverting input must be biased at about 1.8V. This is easily accomplished by tying it to either Pin 8 or 9, the THD trim pins, since these pins sit at 1.8V. An optional RC decoupling network is shown which will filter out the noise from the SA570/571 reference (typically about 10µV in 20kHz BW). The inverting input of the external op amp is tied to the inverting input of the internal op amp. The output of the external op amp is then used, with the internal op amp output left to float. If the external op amp is used single supply ($+V_{CC}$ and ground), it must have an input common-mode range down to less than 1.8V.
N2 COMPANDOR

There are four primary considerations involved in the application of the SA570/571 in an N2 compandor. These are matching of input and output levels, accurate 600Ω input and output impedances, conformance to the Bell system low level tracking curve, and proper attack and release times.

Figure 14 shows the implementation of an N2 compressor. The input level of 0.245V RMS is stepped up to 1.41V RMS by the 600Ω:20kΩ matching transformer. The 20k input resistor properly terminates the transformer. An internal 20kΩ resistor (R3) is provided, but for accurate impedance termination an external resistor should be used. The output impedance is provided by the 4kΩ output resistor and the 4kΩ:600Ω output transformer.

The 0.275V RMS output level requires a 1.4V op amp output level. This can be provided by increasing the value of R2 with an external resistor, which can be selected to fine trim the gain. A rearrangement of the compressor gain equation (6) allows us to determine the value for R2.

\[
R_2 = \frac{\text{Gain}^2 \times 2 \times R_3 \times V_{IN \ text{avg}}}{R_1 \times I_B}
\]

\[
= \frac{1^2 \times 2 \times 20k \times 1.27}{10k \times 140\mu A}
\]

\[
= 36.3k
\]

The external resistance required will thus be 36.3k–20k=16.3k.

The Bell-compatible low level tracking characteristic is provided by the low level trim resistor from C RECT to VCC. As shown in Figure 6, this will skew the system to a 1:1 transfer characteristic at low levels. The 2µF rectifier capacitor provides attack and release times of 3ms and 13.5ms, respectively, as shown in Figures 10 and 11. The R-C-R network around the op amp provides DC feedback to bias the output at DC.

An N2 expander is shown in Figure 15. The input level of 3.27V RMS is stepped down to 1.33V by the 600Ω:100Ω transformer, which is terminated with a 100Ω resistor for accurate impedance matching. The output impedance is accurately set by the 150Ω output resistor.
and the 150Ω:600Ω output transformer. With this configuration, the 3.46V transformer output requires a 3.46V op amp output. To obtain this output level, it is necessary to increase the value of R3 with an external trim resistor. The new value of R3 can be found with the expander gain equation

\[
R_3 = \frac{R_1 R_2 I_B}{2 V_{IN}} \quad \text{Gain}
\]

\[
= \frac{10k \times 20k \times 140\mu A \times 2.6}{2 \times 1.20}
\]

= 30.3k

An external addition to R3 of 10k is required, and this value can be selected to accurately set the high level gain.

A low level trim resistor from CRECT to VCC of about 3M provides matching of the Bell low-level tracking curve, and the 2μF value of CRECT provides the proper attack and release times. A 16k resistor from the summing node to ground biases the output to 7VDC.

**VOLTAGE-CONTROLLED ATTENUATOR**

The variable gain cell in the SA570/571 may be used as the heart of a high quality voltage-controlled amplifier (VCA). Figure 16 shows a typical circuit which uses an external op amp for better performance, and an exponential converter to get a control characteristic of –6dB/V. Trim networks are shown to null out distortion and DC shift, and to fine trim gain to 0dB with 0V of control voltage.

Op amp A2 and transistors Q1 and Q2 form the exponential converter generating an exponential gain control current, which is fed into the rectifier. A reference current of 150μA, (15V and R20=100k), is attenuated a factor of two (6dB) for every volt increase in the control voltage. Capacitor C6 slows down gain changes to a 20ms time constant (C2×R1) so that an abrupt change in the control voltage will produce a smooth sounding gain change. R18 assures that for large control voltages the circuit will go to full attenuation. The rectifier bias current would normally limit the gain reduction to about 70dB. R18 draws excess current out of the rectifier. After approximately 50dB of attenuation at a –6dB/V slope, the slope steepens and attenuation becomes much more rapid until the circuit totally shuts off at about 9V of control voltage. A1 should be a low noise high slew rate op amp. R13 and R14 establish a DC output voltage variation of only a few millivolts. The clipping of the Bell low-level tracking curve, and the 2μF value of CRECT provides the proper attack and release times. A 16k resistor from the summing node to ground biases the output to 7VDC.

With a 0V control voltage, R18 should be adjusted for 0dB gain. At 1V(–6dB gain) R9 should be adjusted for minimum distortion with a large (+10dBm) input signal. The output DC bias (A1 output) should be measured at full attenuation (+10V control voltage) and then R8 is adjusted to give the same value at 0dB gain. Properly adjusted, the circuit will give typically less than 0.1% distortion at any gain with a DC output voltage variation of only a few millivolts. The clipping level (140μA into Pin 3, 14) is ±10V peak. A signal-to-noise ratio of 90dB can be obtained.

If several VCAs must track each other, a common exponential converter can be used. Transistors can simply be added in parallel with Q2 to control the other channels. The transistors should be maintained at the same temperature for best tracking.

**AUTOMATIC LEVEL CONTROL**

The SA570 can be used to make a very high performance ALC as shown in Figure 17. This circuit hook-up is very similar to the basic compressor shown in Figure 2 except that the rectifier input is tied to the input rather than the output. This makes gain inversely proportional to input level so that a 20dB drop in input level will produce a 20dB increase in gain. The output will remain fixed at a constant level. As shown, the circuit will maintain an output level of ±1dB for an input range of +14 to –43dB at 1kHz. Additional external components will allow the output level to be adjusted. Some relevant design equations are:

\[
\text{Output level} = \frac{R_1 R_2 I_B}{2 R_3} \left(\frac{V_{IN}}{V_{IN} \text{ (avg)}}\right)
\]

\[
\text{Gain} = \frac{R_1 R_2 I_B}{2 R_3 V_{IN} \text{ (avg)}}
\]

\[
V_{IN} \text{ (avg)} = \pi \frac{\text{freq}}{2} = 1.11 \text{ (for sine wave)}
\]

If ALC action at very low input levels is not desired, the addition of resistor RX will limit the maximum gain of the circuit.

\[
\text{Gain max} = \frac{R_1 + RX}{2 R_3} \times \frac{1.8V}{R_2 I_B}
\]

The time constant of the circuit is determined by the rectifier capacitor, CRECT, and an internal 10k resistor. τ=10k CRECT

Response time can be made faster at the expense of distortion. Distortion can be approximated by the equation:

\[
\text{THD} = \left(\frac{1\mu F}{C_{RECT}}\right) \left(\frac{1\text{kHz}}{\text{freq}}\right) \times 0.2\%
\]

**VARIABLE SLOPE COMPRESSOR-EXPANDOR**

Compression and expansion ratios other than 2:1 can be achieved by the circuit shown in Figure 18. Rotation of the dual potentiometer causes the circuit hook-up to change from a basic compressor to a basic expander. In the center of rotation, the circuit is 1:1, has neither compression nor expansion. The (input) output transfer characteristic is thus continuously variable from 2:1 compression, through 1:1 up to 2:1 expansion. If a fixed compression or expansion ratio is desired, proper selection of fixed resistors can be used instead of the potentiometer. The optional threshold resistor will make the compression or expansion ratio deviate towards 1:1 at low levels. A wide variety of input output characteristics can be created with this circuit, some of which are shown in Figure 18.

**HI-FI COMPANDOR**

The SA570 can be used to construct a high performance compandor suitable for use with music. This type of system can be used for noise reduction in tape recorders, transmission systems, bucket brigade delay lines, and digital audio systems. The circuits to be described contain features which improve performance, but are not required for all applications.

A major problem with the simple SA570 compressor (Figure 2) is the limited op amp gain at high frequencies.
For weak input signals, the compressor circuit operates at high gain and the 570 op amp simply runs out of loop gain. Another problem with the 570 op amp is its limited slew rate of about 0.6V/µs. This is a limitation of the expander, since the expander is more likely to produce large output signals than a compressor.

Figure 20 is a circuit for a high fidelity compressor which uses an external op amp and has a high gain and wide bandwidth. An input compensation network is required for stability.

Another feature of the circuit in Figure 20 is that the rectifier capacitor (C9) is not grounded, but is tied to the output of an op amp circuit. This circuit, built around an LM324, speeds up the compressor attack time at low signal levels. The response times of the simple expander and compressor (Figures 1 and 2) become longer at low signal levels. The time constant is not simply $10kC_{RECT}$, but is really:

$$\left(10k + 2 \left(\frac{0.026V}{I_{RECT}}\right)\right)C_{RECT}$$

When the rectifier input level drops from 0dBm to –30dBm, the time constant increases from $10.7kC_{RECT}$ to $32.6kC_{RECT}$. In systems where there is unity gain between the compressor and expander, this will cause no overall error. Gain or loss between the compressor and expander will be a mistracking of low signal dynamics. The circuit with the LM324 will greatly reduce this problem for systems which cannot guarantee the unity gain.
Figure 17. Automatic Level Control

Figure 18. Variable Slope Compressor-Expander
When a compressor is operating at high gain, (small input signal), and is suddenly hit with a signal, it will overload until it can reduce its gain. Overloaded, the output will attempt to swing rail to rail. This compressor is limited to approximately a 7V-P-P output swing by the brute force clamp diodes \( D_3 \) and \( D_4 \). The diodes cannot be placed in the feedback loop because their capacitance would limit high frequency gain. The purpose of limiting the output swing is to avoid overloading any succeeding circuit such as a tape recorder input.

The time it takes for the compressor to recover from overload is determined by the rectifier capacitor \( C_9 \). A smaller capacitor will allow faster response to transients, but will produce more low frequency third harmonic distortion due to gain modulation. A value of 1\( \mu \)F seems to be a good compromise value and yields good subjective results. Of course, the expander should have exactly the same value rectifier capacitor for proper transient response. Systems which have good low frequency amplitude and phase response can use compandors with smaller rectifier capacitors, since the third harmonic distortion which is generated by the compressor will be undistorted by the expander.

Simple compandor systems are subject to a problem known as breathing. As the system is changing gain, the change in the background noise level can sometimes be heard.

The compressor in Figure 20 contains a high frequency pre-emphasis circuit (\( C_2, R_5 \) and \( C_8, R_{14} \)), which helps solve this problem. Matching de-emphasis on the expander is required. More complex designs could make the pre-emphasis variable and further reduce breathing.

The expander to complement the compressor is shown in Figure 21. Here an external op amp is used for high slew rate. Both the compressor and expander have unity gain levels of 0dB. Trim networks are shown for distortion (THD) and DC shift. The distortion trim should be done first, with an input of 0dB at 10kHz. The DC shift should be adjusted for minimum envelope bounce with tone bursts. When applied to consumer tape recorders, the subjective performance of this system is excellent.

![Figure 20. Hi-Fi Compressor With Pre-emphasis](SR00739)
Figure 21. Hi-Fi Expandor With De-emphasis