

# Compador cookbook

AN176

Compadors are versatile, low cost, dual-channel gain control devices for audio frequencies. They are used in tape decks, cordless telephones, and wireless microphones performing noise reduction. Electronic organs, modems and mobile telephone equipment use compadors for signal level control.

So what is companding? Why do it at all? What happens when we do it? Compador is the contraction of the two words compressor and expander. There is one basic reason to compress a signal before sending it through a telephone line or recording it on a cassette tape: to process that signal (music, speech, data) so that all parts of it are above the inherent noise floor of the transmission medium and yet not running into the max. dynamic range limits, causing clipping and distortion. The diagrams below demonstrate the idea; they are not totally correct because in the real world of electronics the 3kHz tone is riding on the 1kHz tone. They are shown separated for better explanation.

Figure 1 is the signal from the source. Figure 2 shows the noise always in the transmission medium. Figure 3 shows the max limits of the transmission medium and what happens when a signal larger than those limits is sent through it. Figure 4 is the result of compressing the signal (note that the larger signal would not be clipped when transmitted).

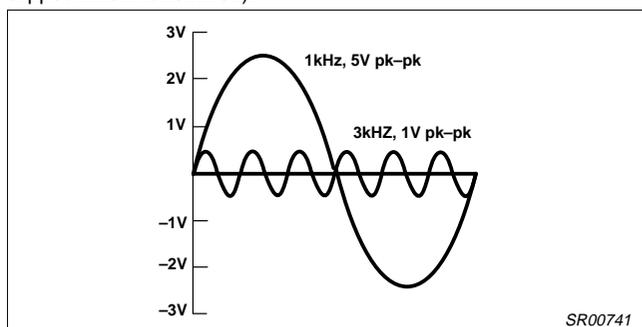


Figure 1. Original Signal Input



Figure 2. Wide-Band Noise Floor of Transmission Line

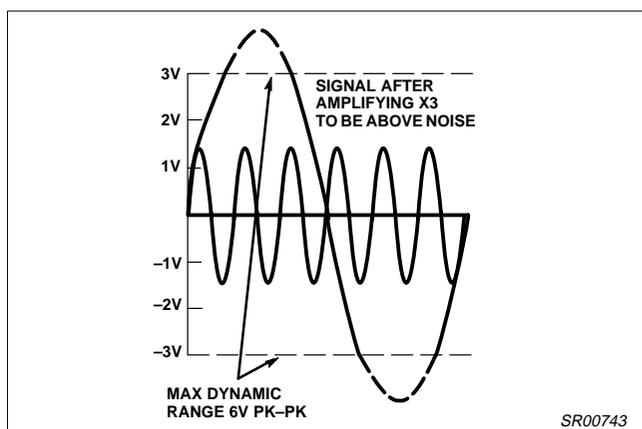


Figure 3.

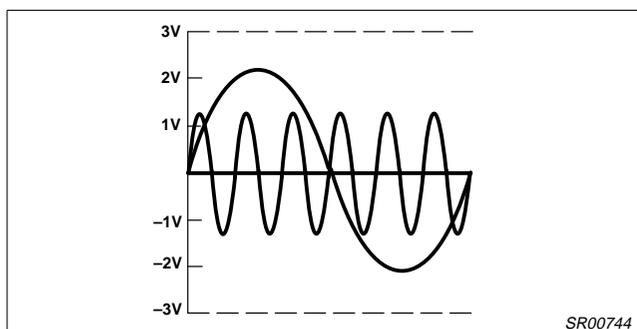


Figure 4. Signal After Compression

The received/playback signal is processed (expanded) in exactly the same — only inverted — ratio as the input signal was compressed. The end result is a clean, undistorted signal with a high signal-to-noise ratio.

This document has been designed to give the reader a basic working knowledge of the Signetics Compador family. The analyses of three primary applications will be accompanied by “recipes” describing how to select external components (for both proper operation and function modification). Schematic and artwork for an application board are also provided. For comprehensive technical information consult the Compador Product Guide or the Linear Data Manual.

The basic blocks in a compador are the current-controlled variable gain cell ( $\Delta G$ ), voltage-to-current converter (rectifier), and operational amplifier. Each Signetics compador package has two identical, independent channels with the following block diagrams (notice that the 570/71 is different from the 572).

The operational amplifier is the main signal path and output drive.

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## BLOCK DIAGRAMS

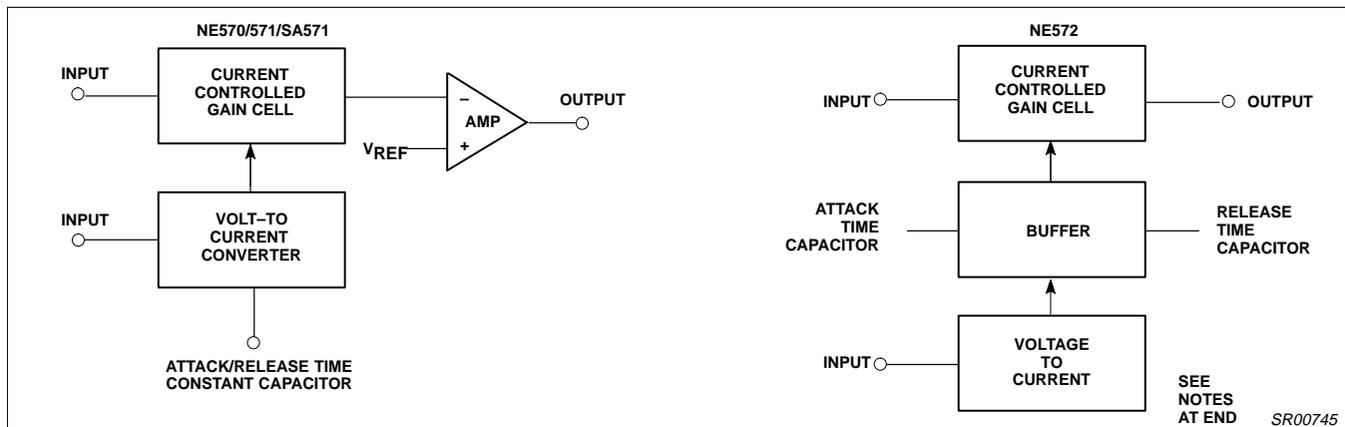


Figure 5. Block Diagrams

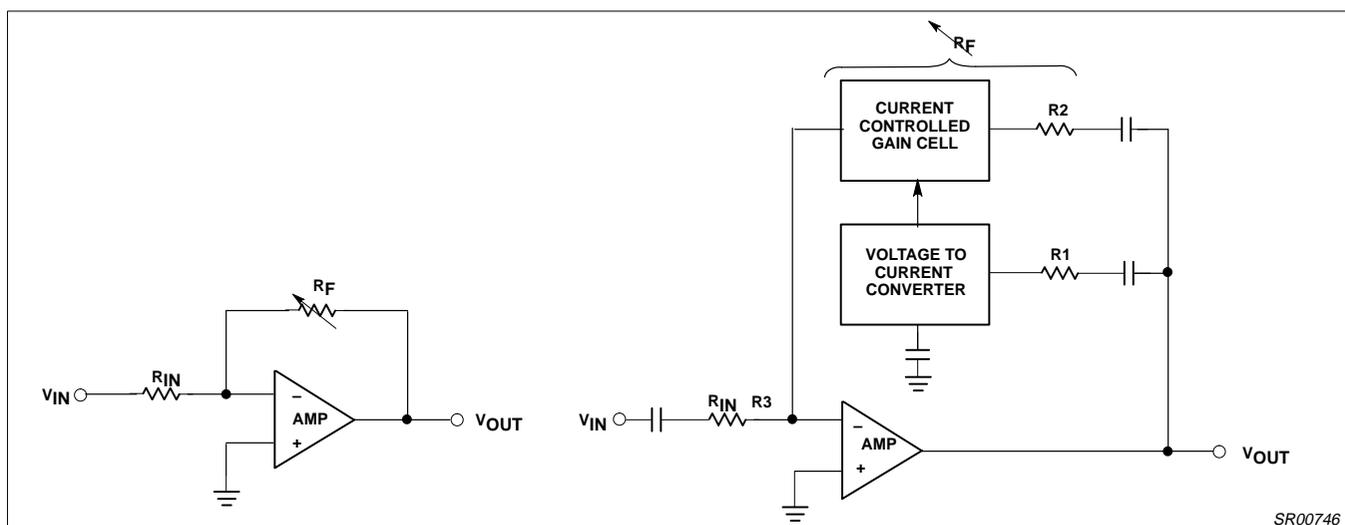


Figure 6. Basic Compressor

The full-wave averaging rectifier measures the AC amplitude of a signal and develops a control current for the variable gain cell.

The variable gain cell uses the rectifier control current to provide variable gain control for the operational amplifier gain block.

The compandor can function as a Compressor, Expander, and Automatic Level Controller or as a complete compressor/expander system as described in the following:

- 1) The COMPRESSOR function processes uncontrolled input signals into controlled output signals. The purpose of this is to avoid distortion caused by a narrow dynamic range medium, such as telephone lines, RF and satellite transmissions, and magnetic tape. The Compressor can also limit the level of a signal.
- 2) The EXPANDOR function allows a user to increase the dynamic range of an incoming compressed signal such as radio broadcasts.
- 3) The compressor/expander system allows a user to retain dynamic range and reduce the effects of noise introduced by the transmission medium.
- 4) The AUTOMATIC LEVEL CONTROL (ALC) function (like the familiar automatic gain control) adjusts its gain proportionally with the input amplitude. This ALC circuit therefore transforms a widely

varying input signal into a fixed amplitude output signal without clipping and distortion.

## HOW TO DESIGN COMPANDOR CIRCUITS

The rest of the cookbook will provide you with basic compressor, expander, and automatic level control application information. A NE570/571 has been used in all of the circuits. If high-fidelity audio or separately programmable attack and decay time are needed, the NE572 with a low noise op amp should be used.

The compressor (see Figure 6) utilizes all basic building blocks of the compandor. In this configuration, the variable gain cell is placed in the feedback loop of the standard inverting amplifier circuit. The gain equation is  $A_V = -R_F/R_{IN}$ . As shown above, the variable gain cell acts as a variable feedback resistor ( $R_F$ ) (See Figure 6).

As the input signal increases above the crossover level of 0dB, the variable resistor decreases in value. This causes the gain to decrease, thus limiting the output amplitude.

Below the crossover level of 0dB, an increase in input signal causes the variable resistor to increase in value, thereby causing the output signal's amplitude to increase.

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In the compressor configuration, the rectifier is connected to the output.

The complete equation for the compressor gain is:

$$\text{Gain comp.} = \left[ \frac{R_1 R_2 I_B}{2 R_3 V_{IN}(\text{avg})} \right]^2$$

where:

$$\begin{aligned} R_1 &= 10\text{k} \\ R_2 &= 20\text{k} \\ R_3 &= 20\text{k} \\ I_B &= 140\mu\text{A} \end{aligned}$$

$$V_{IN}(\text{avg}) = 0.9(V_{IN}(\text{RMS}))$$

**COMPRESSOR RECIPE**

1) DC bias the output half way between the supply and ground to get maximum headroom. The circuit in Figure 7 is designed around a system supply of 6V, thus the output DC level should be 3V.

$$V_{OUT\ DC} = (1 + (2R_{DC}/R_4)) V_{REF}$$

where:

$$\begin{aligned} R_4 &= 30\text{k} \\ V_{REF} &= 1.8\text{V} \\ R_{DC} &\text{ is external} \end{aligned}$$

manipulating the equation, the result is. . .

$$R_{DC} = \left( \left( \frac{V_{OUT}}{V_{REF}} \right) - 1 \right) \frac{R_4}{2}$$

Note that the  $C_{(DC)}$  should be large enough to totally short out any AC in this feedback loop.

2) Analyze the OUTPUT signal's anticipated amplitude.

a) if larger than 2.8V peak,  $R_2$  needs to be increased. (see INGREDIENTS section)

b) if larger than 3.0V peak,  $R_1$  will also need to be increased.

By limiting the peak input currents we avoid signal distortion.

3) The input and output coupling caps need to be large enough not to attenuate any desired frequencies ( $X_C = 1/(6.28xf)$ ).

4) The  $C_{RECT}$  should be  $1\mu\text{F}$  to  $2\mu\text{F}$  for initial setup. This directly affects Attack and Release times.

5) An input buffer may be necessary if the source's output impedance needs matching.

6) Pre-emphasis may be used to reduce noise/pumping, breathing, etc., if present. See the NE570/571 data sheet for specific details.

7) Distortion (THD) trim pins are available if the already low distortion needs to be further reduced. Refer to data sheet for trimming network. Note that if not used, the THD trim pins should have  $200\text{pF}$  caps to ground.

8) At very low input signal levels, the rectifier's errors become significant and can be reduced with the Low Level Mistracking network. (This technique prevents infinite compression at low input levels.)

The EXPANDOR utilizes all the basic building blocks of the compressor (see Figure 8). In this configuration the variable gain cell is placed in the inverting input lead of the operational amplifier and acts as a variable input resistance,  $R_{IN}$ . The basic gain equation for operational amplifiers in the standard inverting feedback loop is  $A_V = -R_F/R_{IN}$ .

As the input amplitude increases above the crossover level of 0dBm, this variable resistor decreases in value, causing the gain to

increase, thus forcing the output amplitude to increase (refer to Figure 11).

Below the crossover level, an increase in input amplitude causes the variable resistor to increase in value, thus forcing the output amplitude to decrease.

The complete equation for the expander gain is:

$$\text{Gain expander} = (2R_3 V_{IN}(\text{avg})) / R_1 R_2 I_B$$

where:

$$\begin{aligned} R_1 &= 10\text{k} \\ R_2 &= 20\text{k} \\ R_3 &= 20\text{k} \\ I_B &= 140\mu\text{A} \end{aligned}$$

$$V_{IN}(\text{avg}) = 0.9(V_{IN}(\text{RMS}))$$

In the expander configuration the rectifier is connected to the input.

**EXPANDOR RECIPE**

1) DC bias the output halfway between the supply and ground to get maximum headroom. The circuit in Figure 9 is designed around a system supply of 6V so the output DC level should be 3V.

$$V_{OUT\ DC} = (1 + R_3/R_4) V_{REF}$$

where:

$$\begin{aligned} R_3 &= 20\text{k} \\ R_4 &= 30\text{k} \\ V_{REF} &= 1.8\text{V} \end{aligned}$$

Note that when using a supply voltage higher than 6V the DC output level should be adjusted. To increase the DC output level, it is recommended that  $R_4$  be decreased by adding parallel resistance to it. (Changing  $R_3$  would also affect the expander's AC gain and thus cause a mismatch in a compressing system.)

2) Analyze the input signal's anticipated amplitude:

a) if larger than 2.8V peak,  $R_2$  needs to be increased. (see INGREDIENTS section)

b) if larger than 3.0V peak,  $R_1$  will also need to be increased. (see INGREDIENTS)

By limiting the peak input currents we avoid signal distortion.

3) The input and output decoupling caps need to be large enough not to attenuate any desired frequencies.

4) The  $C_{RECT}$  should be  $1\mu\text{F}$  to  $2\mu\text{F}$  for initial setup.

5) An input buffer may be necessary if the source's output impedance needs matching.

6) De-emphasis would be necessary if the complementary compressor circuit had been pre-emphasized (as in a tape deck application). See the Hi-Fi Expander application in the Linear Data Manual.

7) Distortion (THD) trim pins are available if the already low distortion needs to be further reduced. See Linear Data Manual for trimming network. Note that if not used, the THD trim pins should have  $200\text{pF}$  caps to ground.

8) At very low input signal levels, the rectifier's errors become significant and can be reduced with the Low Level Mistracking network (see Linear Data Manual). (This technique prevents infinite expansion at low input levels.)

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In the ALC configuration, (Figure 10), the variable gain cell is placed in the feedback loop of the operational amplifier (as in the Compressor) and the rectifier is connected to the input.

As the input amplitude increases above the crossover point, the overall system gain decreases proportionally, holding the output amplitude constant.

As the input amplitude decreases below the crossover point, the overall system gain increases proportionally, holding the output amplitude at the same constant level.

The complete gain equation for the ALC is:

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

$$\text{Output Level} = \frac{R_1 R_2 I_B}{2 R_3} \left( \frac{V_{IN}}{V_{IN} (\text{avg})} \right)$$

where  $\frac{V_{IN}}{V_{IN} (\text{avg})} = \frac{\pi}{2\sqrt{2}} = 1.11$  (for sine wave)

Note that for very low input levels, ALC may not be desired and to limit the maximum gain, resistor  $R_X$  has been added. The modified gain equation is:

$$\text{Gain max.} = \frac{(R_1 + R_X) \cdot R_2 \cdot I_B}{2 R_3}$$

$$R_X \equiv ((\text{desired max gain}) \times 26k) - 10k$$

## INGREDIENTS

[Application guidelines for internal and external components (and input/output constraints) needed to tailor (cook) each of the three trees (applications) to your taste.]

$R_1$  (10k $\Omega$ ) limits input current to the rectifier. This current should not exceed an AC peak value of  $\pm 300\mu\text{A}$ . An external resistor may be placed in series with  $R_1$  if the input voltage to the rectifier will exceed  $\pm 3.0\text{V}$  peak (i.e.,  $10k \times 300\mu\text{A} = 3.0\text{V}$ ).

$R_2$  (20k $\Omega$ ) limits input current to the variable gain cell. This current should not exceed an AC peak value of  $\pm 140\mu\text{A}$ . Again, an external

resistor has to be placed in series with  $R_2$  if the input voltage to the variable gain cell exceeds  $\pm 2.8\text{V}$  (i.e.,  $20k \times 140\mu\text{A}$ ).

$R_3$  (20k $\Omega$ ) acts in conjunction with  $R_4$  as the feedback resistor ( $R_F$ ) (expandor configuration) in the equation. ( $R_3$ 's value can be either reduced or increased externally.) However, it is recommended that  $R_4$  be the one to change when adjusting the output DC level.

$R_4$  (30k $\Omega$ ) acts as the input resistor ( $R_{IN}$ ) in the standard non-inverting op amp circuit. (Its value can only be reduced.)

$$V_{OUT DC} = (1 + (R_3/R_4))V_{REF}$$

(for the Expandor)

$$V_{OUT DC} = (1 + (2R_{DC}/R_4))V_{REF}$$

(for the Compressor, ALC)

[The purpose of these DC biasing equations is to allow the designer to set the output halfway between the supply rails for largest headroom (usually some positive voltage and ground).]

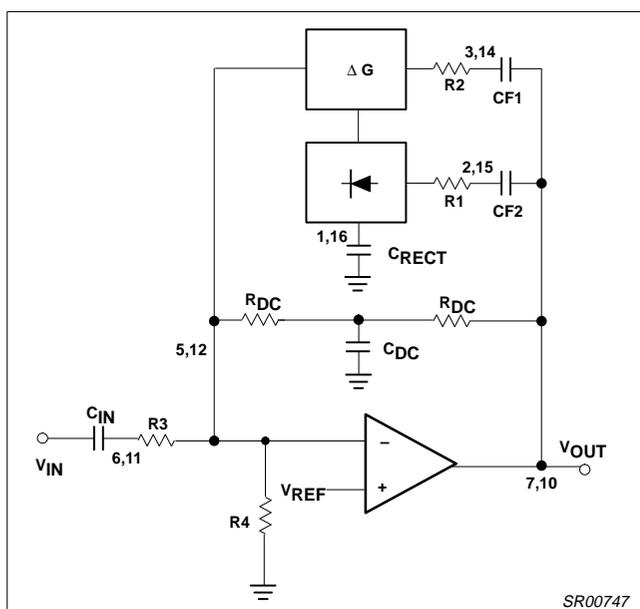


Figure 7. Basic Compressor

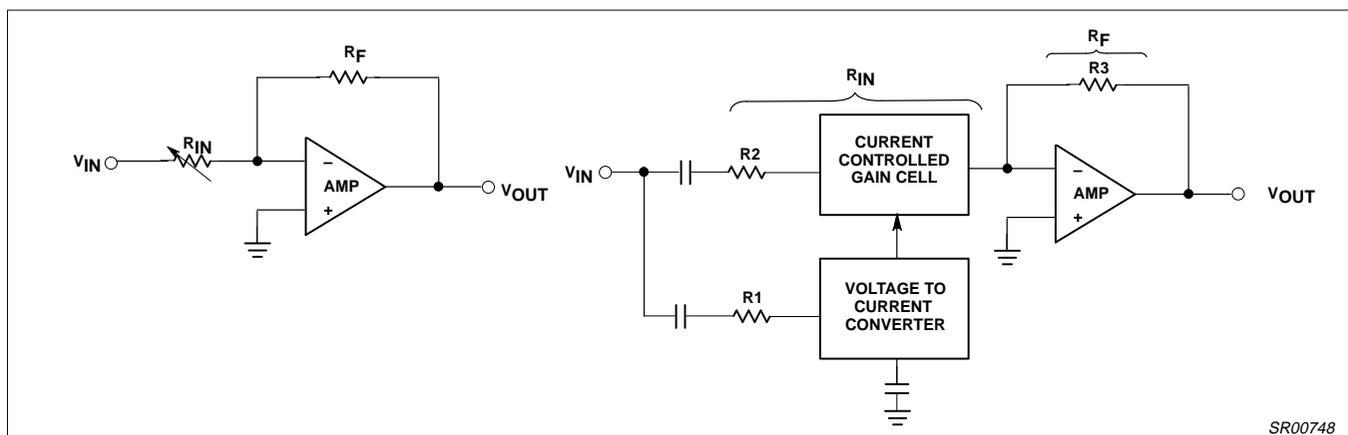
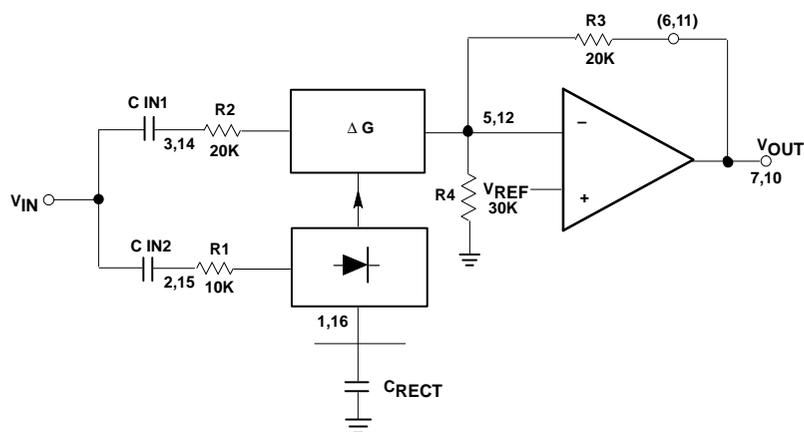


Figure 8. Basic Expandor

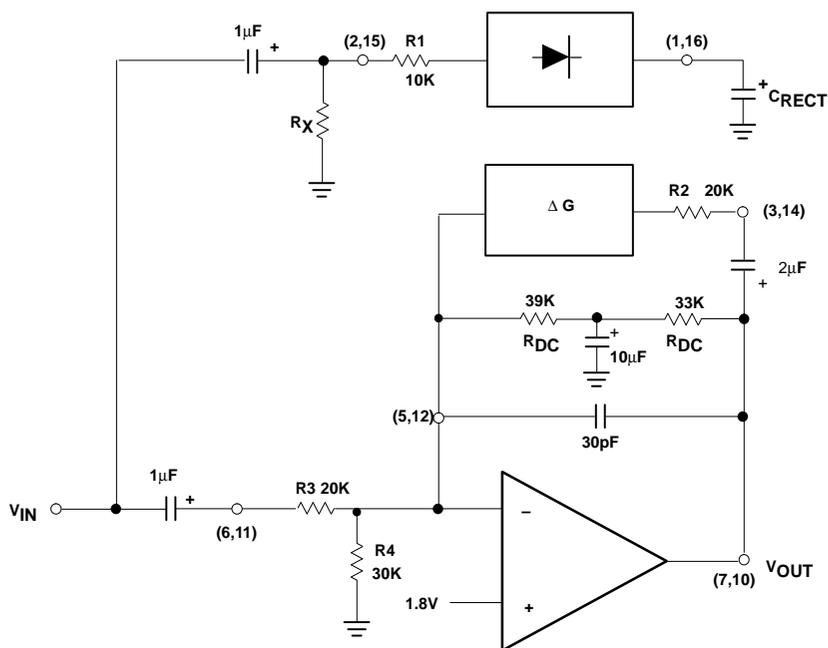
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SR00749

Figure 9. Basic Expander



SR00750

Figure 10. Automatic Level Control

$C_{DC}$  acts as an AC shunt to ground to totally remove the DC biasing resistors from the AC gain equation.

$C_F$  caps are AC signal coupling caps.

$C_{RECT}$  acts as the rectifier's filter cap and directly affects the response time of the circuit. There is a trade-off, though, between fast attack and decay times and distortion.

The time constant is:  $10k \times C_{RECT}$

The total harmonic distortion (THD) is approximated by:

$$THD \cong (1\mu F / C_{RECT})(1kHz / freq.) \times 0.2\%$$

**NOTES:**

The NE572 differs from the 570/571 in that:

1. There is no internal op amp.
2. The attack and release times are programmed separately.

## SYSTEM LEVELS OF A COMPLETE COMPANDING SYSTEM

Figure 11 demonstrates the compressing and expanding functions:

Point A represents a wide dynamic range signal with a maximum amplitude of +16dB and minimum amplitude of -80dB.

Point B represents the compressor output showing a 2:1 reduction in dynamic range (-40dB is increased to -20dB, for example). Point B can also be seen as the dynamic range of a transmission medium. Transmission noise is present at the -60dB level from Point B to Point C.

Point C represents the input signal to the expander.

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Point D represents the output of the expander. The signal transformation from Point C to D represents a 1:2 expansion.

Expansion and one channel of Compression (which can be switched to Automatic Level Control).

## APPLICATION BOARD

Shown below is the schematic (Figure 12) for Signetics' NE570/571 evaluation/demo board. This board provides one channel of

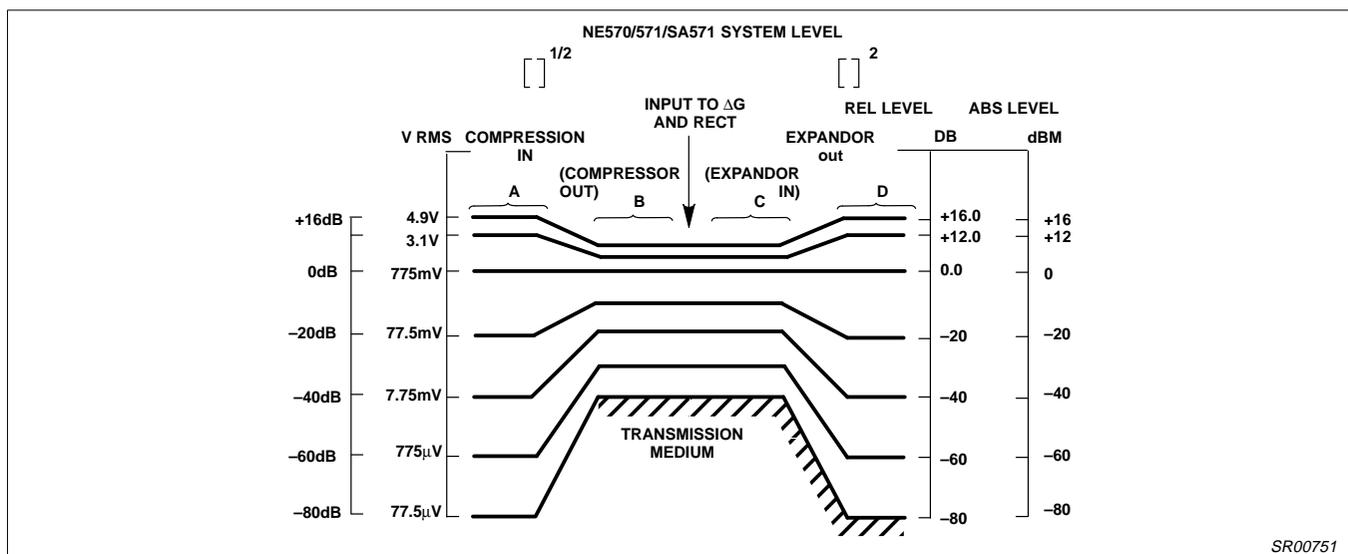


Figure 11. System Levels of a Complete Companding System

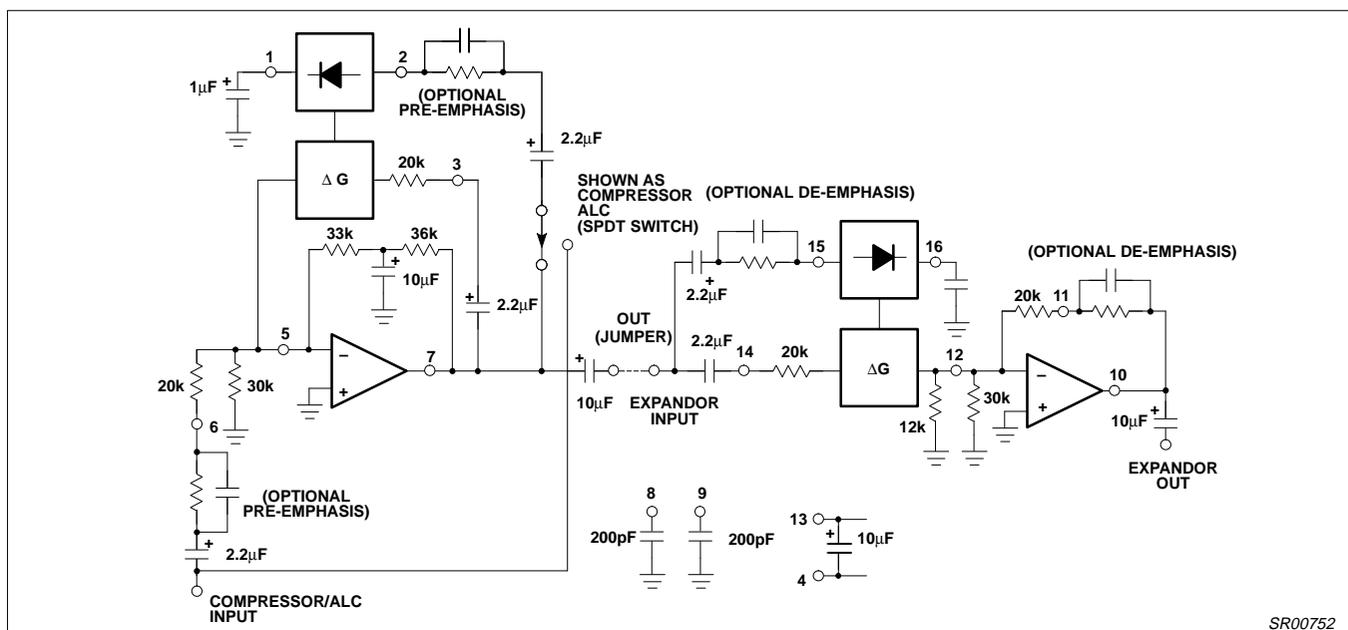


Figure 12.